

# Rules and Regulations for the Classification of Ships

Part 5  
Main and Auxiliary Machinery  
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# General Requirements for the Design and Construction of Machinery

## Part 5, Chapter 1

Section 1

### Section

- 1 **General**
- 2 **Plans and particulars**
- 3 **Operating conditions**
- 4 **Machinery room arrangements**
- 5 **Trials**
- 6 **Quality Assurance Scheme for Machinery**
- 7 **Spare gear for machinery installations**

### ■ Scope

The Chapters in this Part cover the construction and installation of main propulsion and auxiliary machinery systems, together with their associated equipment, boilers, pressure vessels, pumping and piping arrangements and steering gear fitted in classed ships.

### ■ Section 1 General

#### 1.1 Machinery to be constructed under survey

1.1.1 In ships built under Special Survey, all important units of equipment are to be surveyed at the manufacturer's works. The workmanship is to be to the Surveyor's satisfaction and the Surveyor is to be satisfied that the components are suitable for the intended purpose and duty. Examples of such units are:

- Main propulsion engines including their associated gearing, flexible couplings, scavenge blowers and superchargers.
- Boilers supplying steam for propulsion or for services essential for the safety or the operation of the ship at sea, including superheaters, economisers, desuperheaters, steam heated steam generators and steam receivers. All other boilers having working pressures exceeding 3,4 bar (3,5 kgf/cm<sup>2</sup>), and having heating surfaces greater than 4,65 m<sup>2</sup>.
- Auxiliary engines which are the source of power for services essential for safety or for the operation of the ship at sea.
- Steering machinery.
- Athwartship thrust units, their prime movers and control mechanisms.
- All pumps necessary for the operation of main propulsion and essential machinery, e.g. boiler feed, cooling water circulating, condensate extraction, oil fuel and lubricating oil pumps.

- All heat exchangers necessary for the operation of main propulsion and essential machinery, e.g. air, water and lubricating oil coolers, oil fuel and feed water heaters, de-aerators and condensers, evaporators and distiller units.
- Air compressors, air receivers and other pressure vessels necessary for the operation of main propulsion and essential machinery. Any other unfired pressure vessels for which plans are required to be submitted as detailed in Ch 11, 1.6.
- All pumps essential for safety of the ship, e.g., fire, bilge and ballast pumps.
- Valves and other components intended for installation in pressure piping systems having working pressures exceeding 7 bar.
- Alarm and control equipment as detailed in Pt 6, Ch 1.
- Electrical equipment and electrical propelling machinery as detailed in Pt 6, Ch 2.

#### 1.2 Survey for classification

1.2.1 The Surveyors are to examine and test the materials and workmanship from the commencement of work until the final test of the machinery under full power working conditions. Any defects, etc., are to be indicated as early as possible. On completion, the Surveyors will submit a report and if this is found to be satisfactory by the Committee a certificate will be granted and an appropriate notation will be assigned in accordance with Pt 1, Ch 2.

#### 1.3 Alternative system of inspection

1.3.1 Where items of machinery are manufactured as individual or series produced units the Committee will be prepared to give consideration to the adoption of a survey procedure based on quality assurance concepts utilising regular and systematic audits of the approved manufacturing and quality control processes and procedures as an alternative to the direct survey of individual items.

1.3.2 In order to obtain approval, the requirements of Section 6 are to be complied with.

#### 1.4 Departures from the Rules

1.4.1 Where it is proposed to depart from the requirements of the Rules, the Committee will be prepared to give consideration to the circumstances of any special case.

1.4.2 Any novelty in the construction of the machinery, boilers or pressure vessels is to be reported to the Committee.

# General Requirements for the Design and Construction of Machinery

## Part 5, Chapter 1

Sections 2 & 3

### Section 2 Plans and particulars

#### 2.1 Plans

2.1.1 Before the work is commenced, plans in triplicate of all machinery items, as detailed in the Chapters giving the requirements for individual systems, are to be submitted for consideration. The particulars of the machinery, including power ratings, grade(s) of fuel and design calculations, where applicable, necessary to verify the design, are also to be submitted. Any subsequent modifications are subject to approval before being put into operation. It will not be necessary for plans and particulars to be submitted for each ship, provided the basis plans for the engine size and type have previously been approved as meeting the requirements of these Rules. Any alterations to basis design materials or manufacturing procedure are to be re-submitted for consideration.

#### 2.2 Materials

2.2.1 The materials used in the construction are to be manufactured and tested in accordance with the requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials). Materials for which provision is not made therein may be accepted, provided that they comply with an approved specification and such tests as may be considered necessary.

2.2.2 Materials used in the construction of machinery and its installation are not to contain asbestos.

#### 2.3 Welding

2.3.1 Welding consumables, plant and equipment are to be in accordance with the requirements specified in Ch 13,1.8 of the Rules for Materials.

2.3.2 Welding procedures and welder qualifications are to be tested and qualified in accordance with the requirements specified in Chapter 12 of the Rules for Materials.

2.3.3 Production weld tests are to be carried out where specified in the subsequent Chapters of these Rules.

2.3.4 All finished welds are to be subjected to non-destructive examination in accordance with the requirements specified in Ch 13,2.12 of the Rules for Materials and or the requirements specified in the subsequent Chapters of these Rules.

### Section 3 Operating conditions

#### 3.1 Availability for operation

3.1.1 The design and arrangement are to be such that the machinery can be started and controlled on board ship, without external aid, so that the operating conditions can be maintained under all circumstances.

3.1.2 Machinery is to be capable of operating at defined power ratings with a range of fuel grades specified by the engine, boiler or machinery manufacturer and agreed by the Owner/Operator.

3.1.3 Machinery is to be capable of operating satisfactorily in accordance with the manufacturer's stated operating conditions within an operational profile specified for the ship by the Owner/Operator and agreed by the manufacturer/system designer.

#### 3.2 Fuel

3.2.1 The flash point (closed cup test) of oil fuel for use in ships classed for unrestricted service is, in general, to be not less than 60°C.

3.2.2 For emergency generator engines, fuel having a flash point of not less than 43°C may be used.

3.2.3 Fuels with flash points lower than 60°C, but not less than 43°C unless specially approved, may be used in ships intended for service restricted to geographical limits where it can be ensured that the temperature of the machinery and boiler spaces will always be 10°C below the flash point of the fuel. In such cases, safety precautions and the arrangements for storage and pumping will be specially considered.

3.2.4 The use of fuel having a lower flash point than specified in 3.2.1 to 3.2.3 as applicable may be permitted provided that such fuel is not stored in any machinery space and the arrangements for the complete installation are specially approved.

3.2.5 For engines operating on 'boil-off' vapours from the cargo, see Lloyd's Register's (hereinafter referred to as 'LR') *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk*.

#### 3.3 Power ratings

3.3.1 In the Chapters where the dimensions of any particular component are determined from shaft power,  $P$ , in kW ( $H$ , in shp), and revolutions per minute,  $R$ , the values to be used are to be derived from the following:

- For main propelling machinery, the maximum shaft power and corresponding revolutions per minute giving the maximum torque for which the machinery is to be classed.
- For auxiliary machinery, the maximum continuous shaft power and corresponding revolutions per minute which will be used in service.

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## Part 5, Chapter 1

Section 3

### 3.4 Definitions

3.4.1 Main propulsion engines and turbines are defined as those which drive main propelling machinery directly or indirectly through mechanical shafting and which may also drive electrical generators to provide power for auxiliary services. Auxiliary engines and turbines are defined as those coupled to electrical generators which provide power for auxiliary services, for electrical main propulsion motors or a combination of both.

3.4.2 Units and formulae included in the Rules are shown in SI units followed by metric units in brackets, where appropriate.

3.4.3 Where the metric version of shaft power, i.e. (shp), appears in the Rules, 1 shp is equivalent to 75 kgf m/s or 0,735 kW.

3.4.4 Pressure gauges may be calibrated in bar, where:  
 $1 \text{ bar} = 0,1 \text{ N/mm}^2 = 1,02 \text{ kgf/cm}^2$ .

### 3.5 Ambient reference conditions

3.5.1 The rating for classification purposes of main and essential auxiliary machinery intended for installation in sea-going ships to be classed for unrestricted (geographical) service is to be based on a total barometric pressure of 1000 mb, an engine room ambient temperature or suction air temperature of 45°C, a relative humidity of 60 per cent and sea-water temperature or, where applicable, the temperature of the charge air coolant at the inlet of 32°C. The equipment manufacturer is not expected to provide simulated ambient reference conditions at a test bed.

3.5.2 In the case of a ship to be classed for restricted service, the rating is to be suitable for the temperature conditions associated with the geographical limits of the restricted service, see Pt 1, Ch 2.

### 3.6 Ambient operating conditions

3.6.1 Main and essential auxiliary machinery and equipment is to be capable of operating satisfactorily under the conditions shown in Table 1.3.1.

3.6.2 Where it is intended to allow for operation in ambient temperatures outside those shown in Table 1.3.1, the permissible temperatures and associated periods of time are to be specified and details are to be submitted for consideration. Propelling and essential auxiliary machinery, see Pt 1, Ch 2,2.8.1, is to retain a continuous level of functional capability under these conditions and any level of degraded performance is to be defined. Operation under these circumstances is not to be the cause of damage to equipment in the system and is additionally to be acceptable to the National Authority of the country in which the ship is to be registered.

**Table 1.3.1 Ambient operating conditions**

Air		
Installations, Components	Location, arrangement	Temperature range (°C)
Machinery and electrical installations	In enclosed spaces	0 to +45, see Note 1
	On machinery component, boilers. In spaces subject to higher and lower temperatures	According to specific local conditions, see Note 2
	On the open deck	–25 to +45, see Note 1
Water		
Coolant		Temperature (°C)
Sea-water or charge air coolant inlet to charge air cooler		–2 to +32, see Notes 1 and 3
<b>NOTES</b> 1. For ships intended to be classed for restricted service, a deviation from the temperatures stated may be considered. 2. Details of local environmental conditions are stated in Annex B of IEC 60092: <i>Electrical installations in ships – Part 101: Definitions and general requirements</i> . 3. Charge air cooling arrangements utilising re-circulated cooling to maintain temperatures in a different range are accepted where the machinery and equipment operation is not degraded with a primary supply of cooling in the temperature range stated in this Table.		

### 3.7 Inclination of ship

3.7.1 Main and essential auxiliary machinery is to operate satisfactorily under the conditions as shown in Table 1.3.2.

3.7.2 Any proposal to deviate from the angles given in Table 1.3.2 will be specially considered taking into account the type, size and service conditions of the ship.

3.7.3 The dynamic angles of inclination in Table 1.3.2 may be exceeded in certain circumstances dependent upon ship type and operation. The Shipbuilder is, therefore, to ensure that the machinery is capable of operating under these angles of inclination.

### 3.8 Power conditions for generator sets

3.8.1 Auxiliary engines coupled to electrical generators are to be capable under service conditions of developing continuously the power to drive the generators at full rated output (kW) and in the case of oil engines and gas turbines, of developing for a short period (15 minutes) an overload power of not less than 10 per cent, see Pt 6, Ch 2,8.2. In the case of oil engines, they are to be tested at works trials at an overload power of 10 per cent for a period of 30 minutes, see Table 2.11.1 in Pt 5, Ch 2.

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**Table 1.3.2 Inclination of ship**

Installations, components	Angle of inclination, degrees, see Note 1			
	Athwartships		Fore-and-aft	
	Static	Dynamic	Static	Dynamic
Main and auxiliary machinery essential to the propulsion and safety of the ship	15	22,5	5 see Note 2	7,5
Emergency machinery and equipment fitted in accordance with Statutory Requirements	22,5 see Note 3	22,5	10	10
<p><b>NOTES</b></p> <p>1. Athwartships and fore-and-aft inclinations may occur simultaneously.</p> <p>2. Where the length of the ship exceeds 100 m, the fore-and-aft static angle of inclination may be taken as:</p> $\frac{500}{L} \text{ degrees}$ <p>where <math>L</math> = length of ship, in metres.</p> <p>3. In ships for the carriage of liquefied gas and of liquid chemicals the emergency machinery and equipment fitted in accordance with Statutory Requirements is also to remain operable with the ship flooded to a final athwartships inclination to a maximum angle of 30°.</p>				

3.8.2 Engine builders are to satisfy the Surveyors by tests on individual engines that the above requirements, as applicable, can be complied with, due account being taken of the difference between the temperatures under test conditions and those referred to in 3.5. Alternatively, where it is not practicable to test the engine/generator set as a unit, type tests (e.g., against a brake) representing a particular size and range of engines may be accepted. With oil engines and gas turbines any fuel stop fitted is to be set to permit the short period overload power of not less than 10 per cent above full rated output (kW) being developed.

### 3.9 Astern power

3.9.1 Sufficient astern power is to be provided to maintain control of the ship in all normal circumstances.

3.9.2 Astern turbines are to be capable of maintaining in free route astern 70 per cent of the ahead revolutions, corresponding to the maximum propulsion shaft power for which the machinery is to be classed, for a period of at least 30 minutes without undue heating of the ahead turbines and condensers.

### 3.10 Machinery interlocks

3.10.1 Interlocks are to be provided to prevent any operation of engines or turbines under conditions that could hazard the machinery and personnel. These are to include 'turning gear engaged', 'low lubricating oil pressure', where oil pressure is essential for the prevention of damage during start up, 'shaft brake engaged' and where machinery is not available due to maintenance or repairs. The interlock system is to be arranged to be 'fail safe'.

3.10.2 Where machinery is provided with manual turning gear, warning devices or notices may be provided as an alternative to interlocks as required by 3.10.1.

## Section 4 Machinery room arrangements

### 4.1 Accessibility

4.1.1 Accessibility, for attendance and maintenance purposes, is to be provided for machinery plants.

### 4.2 Machinery fastenings

4.2.1 Bedplates, thrust seatings and other fastenings are to be of robust construction, and the machinery is to be securely fixed to the ship's structure to the satisfaction of the Surveyor.

### 4.3 Resilient mountings

4.3.1 The dynamic angles of inclination in Table 1.3.2 may be exceeded in certain circumstances dependent upon ship type and operation. The Shipbuilder is, therefore, to ensure that the vibration levels of flexible pipe connections, shaft couplings and mounts remain within the limits specified by the component manufacturer for the conditions of maximum dynamic inclinations to be expected during service, start-stop operation and the natural frequencies of the system. Due account is to be taken of any creep that may be inherent in the mount.

4.3.2 Anti-collision chocks are to be fitted together with positive means to ensure that manufacturers' limits are not exceeded. Suitable means are to be provided to accommodate the propeller thrust.

4.3.3 A plan showing the arrangement of the machinery together with documentary evidence of the foregoing is to be submitted.

### 4.4 Ventilation

4.4.1 All spaces including engine and cargo pump spaces, where flammable or toxic gases or vapours may accumulate, are to be provided with adequate ventilation under all conditions.



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4.4.2 Machinery spaces of category A shall be adequately ventilated so as to ensure that when machinery or boilers therein are operating at full power in all weather conditions, including heavy weather, a sufficient supply of air is maintained to the spaces for the safety and comfort of personnel and the operation of the machinery. Any other machinery space shall be adequately ventilated, as appropriate for the purpose of that machinery space.

### 4.5 Fire protection

4.5.1 All surfaces of machinery where the surface temperature may exceed 220°C and where impingement of flammable liquids may occur are to be effectively shielded to prevent ignition. Where insulation covering these surfaces is oil-absorbing or may permit penetration of oil, the insulation is to be encased in steel or equivalent.

### 4.6 Means of escape

4.6.1 For means of escape from machinery spaces, see SOLAS 1974 as amended Regulation II-2/13.4.1 or 13.4.2 or Pt 6, Ch 4,3.4, as applicable.

### 4.7 Communications

4.7.1 Two independent means of communication are to be provided between the bridge and engine room control station from which the engines are normally controlled, see also Pt 6, Ch 1,2.

4.7.2 One of these means is to visually indicate the order and response, both at the engine room control station and on the bridge.

4.7.3 At least one means of communication is to be provided between the bridge and any other control position(s) from which the propulsion machinery may be controlled.

### 4.8 Category A machinery spaces

4.8.1 'Machinery spaces of Category A' are those spaces and trunks to such spaces which contain:

- (a) internal combustion machinery used for main propulsion; or
- (b) internal combustion machinery used for purposes other than main propulsion where such machinery has in the aggregate a total power output of not less than 375 kW; or
- (c) any oil-fired boiler or oil fuel unit.

## Section 5 Trials

### 5.1 Inspection

5.1.1 Tests of components and trials of machinery, as detailed in the Chapters giving the requirements for individual systems, are to be carried out to the satisfaction of the Surveyors.

### 5.2 Sea trials

5.2.1 For all types of installation, the sea trials are to be of sufficient duration, and carried out under normal manoeuvring conditions, to prove the machinery under power. The trials are also to demonstrate that any vibration which may occur within the operating speed range is acceptable.

5.2.2 The trials are to include demonstrations of the following:

- (a) The adequacy of the starting arrangements to provide the required number of starts of the main engines.
- (b) The ability of the machinery to reverse the direction of thrust of the propeller in sufficient time, under normal manoeuvring conditions, and so bring the ship to rest from maximum service speed. Results of the trials are to be recorded.
- (c) In turbine installations, the ability to permit astern running at 70 per cent of the full power ahead revolutions without adverse effects. This astern trial need only be of 15 minutes' duration, but may be extended to 30 minutes at the Surveyor's discretion.

5.2.3 Where controllable pitch propellers are fitted, the free route astern trial is to be carried out with the propeller blades set in the full pitch astern position. Where emergency manual pitch setting facilities are provided, their operation is to be demonstrated to the satisfaction of the Surveyors.

5.2.4 In geared installations, prior to full power sea trials, the gear teeth are to be suitably coated to demonstrate the contact markings, and on conclusion of the sea trials all gears are to be opened up sufficiently to permit the Surveyors to make an inspection of the teeth. The marking is to indicate freedom from hard bearing, particularly towards the ends of the teeth, including both ends of each helix where applicable. The contact is to be not less than that required by Ch 5,4.2 or Ch 5,5.2, as applicable.

5.2.5 The following information is to be available on board for the use of the master and designated personnel:

- The results of trials to determine stopping times, ship headings and distance;
- For ships having multiple propellers, the results of trials to determine the ability to navigate and manoeuvre with one or more propellers inoperative.
- For ships having a single propulsor driven by multiple engines or electric motors, the results of trials to determine the ability to navigate and manoeuvre with the largest engine or electric motor inoperative.

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5.2.6 Where the ship is provided with supplementary means for manoeuvring or stopping, the effectiveness of such means are to be demonstrated and recorded as referred to in 5.2.5.

5.2.7 The stopping distance achieved when ship is initially proceeding ahead with a speed of at least 90 per cent of the ship's speed corresponding to 85 per cent of the maximum rated propulsion power should not exceed 15 ship lengths after the astern order has been given. However, if the displacement of the ship makes this criterion impracticable then in no case should the stopping distance exceed 20 ship lengths.

5.2.8 All trials are to be to the Surveyor's satisfaction.

## Section 6 Quality Assurance Scheme for Machinery

### 6.1 General

6.1.1 This certification scheme is applicable to both individual and series produced items manufactured under closely controlled conditions and will be restricted to works where the employment of quality control procedures is well established. LR will have to be satisfied that the practices employed will ensure that the quality of finished products is to standards which would be demanded when using traditional survey techniques.

6.1.2 The Committee will consider proposed designs for compliance with LR's Rules or other appropriate requirements and the extent to which the manufacturing processes and control procedure ensure conformity of the product to the design. A comprehensive survey will be made by the Surveyors of the actual operation of the quality control programme and of the adequacy and competence of the staff to implement it.

6.1.3 The procedures and practices of manufacturers which have been granted approval will be kept under review.

6.1.4 Approval by another organisation will not be accepted as sufficient evidence that a manufacturer's arrangements comply with LR's requirements.

### 6.2 Requirements for approval

6.2.1 **Facilities.** The manufacturer is required to have adequate equipment and facilities for those operations appropriate to the level of design, development and manufacture being undertaken.

6.2.2 **Experience.** The manufacturer is to demonstrate that the firm has experience consistent with technology and complexity of the product type for which approval is sought and that the firm's products have been of a consistently high standard.

6.2.3 **Quality policy.** The manufacturer is to define management policies and objectives or quality and ensure that these policies and objectives are implemented and maintained throughout all phases of the work.

6.2.4 **Quality system documentation.** The manufacturer is to establish and maintain a documented quality system capable of ensuring that material or services conform to the specified requirements, including the requirements of this Section.

6.2.5 **Management representative.** The manufacturer is to appoint a management representative preferably independent of other functions, who is to have defined authority and responsibilities for the implementation and maintenance of the quality system.

6.2.6 **Responsibility and authority.** The responsibilities and authorities of senior personnel within the quality system are to be clearly documented.

6.2.7 **Internal audit.** The manufacturer is to conduct internal audits to ensure continued adherence to the system. An audit programme is to be established with audit frequencies scheduled on the basis of the status and importance of the activity and adjusted on the basis of previous results.

6.2.8 **Management review.** The quality system established in accordance with the requirements of this Section is to be systematically reviewed at appropriate intervals by the manufacturer to ensure its continued effectiveness. Records of such management reviews are to be maintained and be made available to the Surveyors.

6.2.9 **Contract review.** The manufacturer is to establish and implement procedures for conducting a contract review prior to and after acceptance to ensure that:

- (a) the requirements of the contract are adequately defined and documented;
- (b) any requirements differing from those specified in the original enquiry/tender are resolved; and
- (c) the manufacturer has the capability to meet and verify compliance to the specified requirements.

6.2.10 **Work instruction.** The manufacturer is to establish and maintain clear and complete written work instructions that prescribe the communication of specified requirements and the performance of work in design, development and manufacture which would be adversely affected by lack of such instructions.

6.2.11 **Documentation and change control.** The manufacturer is to establish and maintain control of all documentation that relates to the requirements of this scheme. This control is to ensure that:

- (a) documents are reviewed and approved for adequacy by authorised personnel prior to use, are uniquely identified and include indication of approval and revision status;
- (b) all changes to documentation are in writing and are processed in a manner that will ensure their availability at the appropriate location and preclude the use of non-applicable documents;
- (c) provision is made for the prompt removal of obsolete documentation from all points of issue or use; and



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- (d) documents are to be re-issued after a practical number of changes have been issued.

**6.2.12 Records.** The manufacturer is to develop and maintain a system for collection, use and storage of quality records. The period of retention of such records is to be established in writing and is to be subject to agreement by the Committee.

**6.2.13 Design.** The manufacturer is to establish and maintain a design control system appropriate to the level of design being undertaken. Documented design procedures are to be established which:

- identify the design practices of the manufacturer's organisation including departmental instructions to ensure the orderly and controlled preparation of design and subsequent verification;
- make provision for the identification, documentation and appropriate approval of all design change and modifications;
- prescribe methods for resolving incomplete, ambiguous or conflicting requirements; and
- identify design inputs such as sources of data, preferred standard parts or materials and design information and provide procedures for their selection and review by the manufacturer for adequacy.

**6.2.14 Purchasing.** The manufacturer is to ensure that purchased material and services conform to specified requirements.

**6.2.15 Selection and approval of sub-contractors and suppliers.** The manufacturer is to establish and maintain records of acceptable suppliers and sub-contractors. The selection of such sources, and the type and extent of control exercised, are to be appropriate to the type of product or service and the suppliers' or sub-contractors' previously demonstrated capability and performance. Documented procedures for approval of new suppliers are to be established and records of vendor assessments (where carried out) are to be maintained and made available to the Surveyors upon request.

**6.2.16 Purchasing data.** Each purchasing document should contain a clear description of the material or service ordered including as applicable, the following:

- The type, class, grade, or other precise identification;
- The title or other positive identification and applicable issue of specifications, drawings, process requirements, inspection instructions and other relevant data.

**6.2.17 Verification of purchased material and services.** The manufacturer is to ensure that the Surveyors are afforded the right to verify at source or upon receipt that purchased material and services conform to specified requirements. Verification by the Surveyors shall not relieve the manufacturer of his responsibility to provide acceptable material nor is it to preclude subsequent rejection.

**6.2.18 Product identification.** The manufacturer is to establish and maintain a system for identification of the product to relevant drawings, specifications or other documents during all stages of production, delivery and installation.

**6.2.19 Manufacturing control.** The manufacturer is to ensure that those operations which directly affect quality are carried out under controlled conditions. These are to include the following:

- Written work instructions wherever the absence of such instructions could adversely affect compliance with specified requirements. These should define the method of monitoring and control of product characteristics.
- Established criteria for workmanship through written standards or representative samples.

**6.2.20 Special processes.** Those processes where effectiveness cannot be verified by subsequent inspection and test of the product are to be subjected to continuous monitoring in accordance with documented procedures in addition to the requirements specified in 6.2.19.

**6.2.21 Receiving inspection.** The manufacturer is to ensure that all incoming material is not to be used or processed until it has been inspected or otherwise verified as conforming to specified requirements. In establishing the amount and nature of receiving inspection, consideration is to be given to the control exercised by the supplier and documented evidence of quality conformance supplied.

**6.2.22 In-process inspection.** The manufacturer is to:

- perform inspection during manufacture on all characteristics that cannot be inspected at a later stage;
- inspect test and identify products in accordance with specified requirements;
- establish product conformance to specified requirements by use of process monitoring and control methods where appropriate;
- hold products until the required inspections and tests are completed and verified; and
- clearly identify non-conforming products to prevent unauthorised use, shipment, or mixing with conforming material.

**6.2.23 Final inspection.** The manufacturer is to perform all inspections and tests on the finished product necessary to complete the evidence of conformance to the specified requirements. The procedures for final inspection and test are to ensure that:

- all activities defined in the specification, quality plan or other documented procedure have been completed;
- all inspections and tests that should have been conducted at earlier stages have been completed and that the data is acceptable; and
- no product is to be dispatched until all the activities defined in the specifications, quality plan or other documented procedure have been completed, unless products have been released with the permission of the Surveyors.

**6.2.24 Inspection equipment.** The manufacturer is to be responsible for providing, controlling, calibrating and maintaining the inspection, measuring and test equipment necessary to demonstrate the conformance of material and services to the specified requirements or used as part of the manufacturing control system required by 6.2.19 and 6.2.20.

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**6.2.25 Inspection and test status.** The manufacturer is to establish and maintain a system for the identification of inspection status of all material, components and assemblies by suitable means which distinguish between conforming, non-conforming and uninspected items. The relevant inspection and test procedures and records are to identify the authority responsible for the release of conforming products.

**6.2.26 Control of non-conforming material.**

- (a) The manufacturer is to establish and maintain procedures to ensure that material that does not conform to the specified requirements is controlled to prevent inadvertent use, mixing or shipment. Repair, rework or concessions on non-conforming material and reinspection is to be in accordance with documented procedures.
- (b) Records clearly identifying the material, the nature and extent of non-conformance and the disposition are to be maintained.

**6.2.27 Sampling procedures.** Where sampling techniques are used by the manufacturer to verify the acceptability of groups of products, the procedures adopted are to be in accordance with the specified requirements or are to be subject to agreement by the Surveyors.

**6.2.28 Corrective action.** The manufacturer is to establish and maintain documented procedures for the review of non-conformances and their disposition. These should provide for:

- (a) monitoring of process and work operations and analysis of records to detect and eliminate potential causes of non-conforming material;
- (b) continuing analysis of concessions granted and material scrapped or reworked to determine causes and the corrective action required;
- (c) an analysis of customer complaints;
- (d) the initiation of appropriate action with suppliers or sub-contractors with regard to receipt of non-conforming material; and
- (e) an assurance that corrective actions are effective.

**6.2.29 Purchaser supplied material.** The manufacturer is to establish and maintain documented procedures for the control of purchaser supplied material.

**6.2.30 Handling, storage, and delivery.**

- (a) The manufacturer is to establish and maintain a system for the identification preservation, segregation and handling of all material from the time of receipt through the entire production process. The system is to include methods of handling that prevent abuse, misuse, damage or deterioration.
- (b) Secure storage areas or rooms are to be provided to isolate and protect material pending use. To detect deterioration, at an early stage, the condition of material is to be periodically assessed.
- (c) The manufacturer is to arrange for the protection of the quality of his product during transit. The manufacturer is to ensure, in so far as it is practicable, the safe arrival and ready identification of the product at destination.

**6.2.31 Training.** The manufacturer is to follow a policy for recruitment and training which provides an adequate labour force with such skills as are required for each type of work operation. Appropriate records are to be maintained to demonstrate that all personnel performing process control, special processes inspection and test or quality system maintenance activities have appropriate experience or training.

### 6.3 Arrangements for acceptance and certification of purchased material

**6.3.1** The manufacturer is to establish and maintain procedures and controls to ensure compliance with LR's requirements for certification of materials and components at the supplier's plant. The manufacturer's system for control of such purchased material may be based on one of the following alternatives subject to the approval of LR:

- (a) Product certification by LR's Surveyors at the supplier's works in accordance with the requirements of the Rules for Materials.
- (b) Agreed Inspection Procedures at the manufacturer's plant combined with documentary evidence of vendor assessments, vendor rating records and annual surveillance visits to the suppliers.
- (c) Recognition of quality agreements between the manufacturer and his suppliers which are to provide for initial vendor assessments and regular surveillance visits (a minimum of four per year). The quality agreement must identify the individual in the supplier's plant who is charged with the responsibility for release of materials or components and the procedures to be adopted.

**6.3.2** The alternatives proposed in 6.3.1(b) and (c) are not acceptable to LR for the following items:

- (a) Engine components for which testing is a Rule requirement; and
  - (i) the cylinder bore is equal to or exceeds 300 mm; or
  - (ii) which are made by open forging techniques.
- (b) Cast crankshafts where the journal diameter exceeds 85 mm.

**6.3.3** Where the manufacturer's system for control of purchased material is based upon 6.3.1(b) or (c) the Surveyors shall also make surveillance visits to the supplier's works at the minimum specified intervals. The manufacturer is also to make available to the Surveyors documentary evidence of the operation of quality agreements or Agreed Inspection Procedures where applicable.

### 6.4 Information required for approval

**6.4.1** Manufacturers applying for approval under this scheme are to submit the following information:

- (a) A description of the products for which certification is required including, where applicable, model or type number.
- (b) Applicable plans and details of material used.
- (c) An outline description of all important manufacturing plant and equipment.

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- (d) A summary of equipment used for measuring and testing during manufacture and completion.
- (e) The Quality Manual.
- (f) A typical production flow chart and quality plan covering all stages from ordering of materials to delivery of the finished product.
- (g) The system used for the identification of raw materials, semi-finished and finished products.
- (h) The number and qualifications of all staff engaged in testing, inspection and quality control duties.
- (j) A list of suppliers of components and manufacturers, proposed procedures to ensure compliance with LR's requirements for certification of materials and components at the supplier's plant.

### 6.5 Assessment of works

6.5.1 After receipt and appraisal of the information requested in 6.4 an inspection of the works is to be carried out by the Surveyors to examine in detail all aspects of production, and in particular the arrangements for quality control.

6.5.2 The Surveyors will not specify in detail acceptable quality control procedures, but will consider the arrangements proposed by the works in relation to the manufacturing processes and products.

6.5.3 In the event of procedures being considered inadequate, the Surveyors will advise the manufacturer how such procedures are to be revised in order to be acceptable to LR.

6.5.4 Gauging, measuring and testing devices are to be made available to the Surveyors, and where appropriate, personnel for the operation of such devices.

### 6.6 Approval of works

6.6.1 If the initial assessment of the works confirms that the manufacturing and quality control procedures are satisfactory, the Committee will issue to the manufacturer a Quality Assurance Approval Certificate which will include details of the products for which approval has been given. This Certificate will be valid for three years with renewal subject to satisfactory performance and to a satisfactory triennial re-assessment.

6.6.2 An extension of approval in respect of product type may be given at the discretion of the Committee without any additional survey of the works.

6.6.3 LR will publish a list of manufacturers whose works have been approved.

### 6.7 Maintenance of approval

6.7.1 The arrangements authorised at each works are to be kept under review by the Surveyors in order to ensure that the approved procedures for manufacture and quality control are being maintained in a satisfactory manner. This is to be carried out by:

- (a) regular and systematic surveillance;
- (b) intermediate audits at intervals of six months;
- (c) triennial re-assessment of the entire quality system.

6.7.2 For the purpose of regular and systematic surveillance the Surveyors are to visit the works at intervals determined by the type of product and the rate of production. The Surveyors are to advise a senior member of the quality control department in regard to any matter with which they are not satisfied.

6.7.3 When minor deficiencies in the approved procedures are disclosed during the systematic surveillance the Surveyors may, at their discretion, apply more intensive supervision, including the direct inspection of products.

6.7.4 Any noteworthy departures from the approved plans of specifications are to be reported to the Surveyors and their written approval obtained prior to despatch of the item.

6.7.5 Minor alterations in the approved procedures may be permitted provided that the Surveyors are advised and their prior concurrence obtained.

6.7.6 In addition to the regular visits by the Surveyors, an intermediate audit is to be carried out every six months. This will normally be carried out by Surveyors other than those regularly in attendance at the works. This audit is to consist of an examination of part of the manufacturer's quality system. An audit plan will be established indicating those areas of the quality system which will be examined during every intermediate audit and the frequency of examination of other areas such that all areas are subject to audit before re-assessment is due.

6.7.7 The manufacturer's entire quality system is to be subject to re-assessment at three-yearly intervals. This is to be conducted by Surveyors nominated by Headquarters.

### 6.8 Suspension or withdrawal of approval

6.8.1 When the Surveyors have drawn attention to significant faults or deficiencies in the manufacturing or quality control procedures and these have not been rectified, approval of the works will be suspended. In these circumstances the manufacturer will be notified in writing of the Committee's reasons for the suspension of approval.

6.8.2 When approval has been suspended and the manufacturer does not effect corrective measures within a reasonable time, the Committee will withdraw the Quality Assurance Approval Certificate.

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### 6.9 Identification of products

6.9.1 In addition to the normal marking by the manufacturer, all certified products are to be hard stamped on a principal component with a suitable identification, LR's brand and the number of the approved works.

6.9.2 After issue of the Quality Assurance Approval Certificate, products may be dispatched with certificates signed on behalf of the manufacturer by an authorised senior member of the quality control department or by an authorised deputy. These certificates are to be countersigned by the Surveyor to certify that the approved arrangements are being kept under review by regular and systematic auditing of the manufacturer's quality system.

6.9.3 The following declarations are to be included on each certificate:

- (a) 'This is to certify that the items described above have been constructed and tested with satisfactory results in accordance with the Rules of Lloyd's Register.  
Signed.....  
Manager of QC Department.'
- (b) 'This certificate is issued by the manufacturer in accordance with the arrangements authorised by Lloyd's Register in Quality Assurance Approval Certificate No. QA.M..... I certify that these arrangements are being kept under review by regular and systematic auditing of the approved manufacturing and quality control procedures.  
Signed.....  
Surveyor to Lloyd's Register'.

6.9.4 In the event of noteworthy departures from the approved plan or specification being accepted, a standard 'Concession' form is to be completed and signed by the following authorised persons: the Design Manager, the Quality Control Manager or their deputies. In all cases, where strength or functioning may be affected, the form is to be submitted to the Surveyors for approval and endorsement.

### 7.2 Guidance for spare parts

7.2.1 For general guidance purposes, spare parts for main and auxiliary machinery installations are shown in the LR's *Spare Gear Guidance* located on Class Direct Live.

## ■ Section 7 Spare gear for machinery installations

### 7.1 Application

7.1.1 Adequate spare parts for the propelling and essential auxiliary machinery, together with the necessary tools for maintenance and repair, are to be readily available for use.

7.1.2 The spare parts to be supplied and their location is to be the responsibility of the Owner, but they must take into account the design and arrangement of the machinery and the intended service and operation of the ship. Account must also be taken of the recommendations of the manufacturers and any applicable statutory requirement of the country of registration of the ship.

## Section

1	<b>Plans and particulars</b>
2	<b>Materials</b>
3	<b>Design</b>
4	<b>Electronically controlled engines</b>
5	<b>Construction and welded structures</b>
6	<b>Turning gear</b>
7	<b>Control and monitoring of main, auxiliary and emergency diesel engines</b>
8	<b>Piping</b>
9	<b>Starting arrangements</b>
10	<b>Safety arrangements</b>
11	<b>Program for trials of diesel engines to assess operational capability</b>
12	<b>Component tests</b>
13	<b>Mass produced engines</b>
14	<b>Turbo-chargers</b>
15	<b>Mass produced turbo-chargers</b>
16	<b>Air compressors</b>
17	<b>Type testing – General</b>
18	<b>Type testing procedure for crankcase explosion relief valves</b>
19	<b>Type testing procedure for crankcase oil mist detection and alarm equipment</b>

## ■ Scope

The requirements of this Chapter are applicable to oil engines (generally known as diesel engines) for main propulsion and to engines intended for essential auxiliary services. Section 3 is not applicable to auxiliary engines having powers of less than 110 kW.

The requirements for type testing of engines at the manufacturer's works are also included.

Arrangements for dual fuel engines will be specially considered.

Primary exhaust gas emissions abatement plant (where fitted) is to meet the requirements of this Chapter; additionally, it is to meet the requirements of Chapter 24. Where secondary exhaust gas emissions abatement systems are fitted to engines, they are to meet the requirements of Chapter 24.

## ■ Section 1 Plans and particulars

### 1.1 Plans

1.1.1 The following plans and particulars as applicable are to be submitted for consideration:

- Crankshaft assembly plan (for each crank-throw).
- Crankshaft details plan (for each crank-throw).
- Thrust shaft or intermediate shaft (if integral with engine).
- Output shaft coupling bolts.
- Main engine securing arrangements where non-metallic chocks are used.
- Type and arrangement of crankcase explosion relief valves.
- Arrangement and welding specifications with details of the procedures for fabricated bedplate, thrust bearing bedplate, crankcases, frames and entablatures. Details of materials welding consumables, fit-up conditions fabrication sequence and heat treatments are to be included.
- Schematic layouts of the following systems:
  - Starting air.
  - Oil fuel.
  - Lubricating oil.
  - Cooling water.
  - Control and safety.
  - Hydraulic oil (for valve lift).
- Shielding of high pressure fuel pipes.
- Combustion pressure-displacement relationship.
- Crankshaft design data as outlined in Section 3.
- High pressure parts for fuel oil injection system with specification of pressures, pipe dimensions and materials.
- For new engine types that have not been approved by LR, the proposed type test programme.
- The type test report on completion of type testing for a new engine type. For mass produced engines a separate report is to be submitted for each engine requiring approval, see 17.2.
- Additionally, for mass produced engines:
  - (a) For consideration of an engine type to be approved:
    - (i) Engine specification, see 13.1.4.
    - (ii) Manufacturing processes and quality control information, see 13.2.3.
    - (iii) List of sub-contractors for main parts.
    - (iv) Procedures for configuring during commissioning.
  - (b) For engines of an approved type to be installed on a ship, a compliance and inspection certificate, see 13.4.
- For engine control, alarm monitoring and safety systems, the plans and information required by Pt 6, Ch 1,1.2.
- For electronically controlled engines, the plans and information required by 1.1.6 and 1.1.7.
- Schematic layouts showing details and arrangements of oil mist detection/monitoring and alarm systems.
- Diesel generator test results that state the engine maximum load steps which satisfy the quality of power supply requirements specified in Pt 6, Ch 2,1.7.
- Planned operating profiles for the vessel at sea and during manoeuvring as agreed with the operators.



# Oil Engines

## Part 5, Chapter 2

Section 1

1.1.2 The following plans are to be submitted for information:

- Longitudinal and transverse cross-section.
- Cast bedplate, thrust bearing bedplate, crankcase and frames.
- Cylinder head assembly.
- Cylinder liner.
- Piston assembly.
- Tie rod.
- Connecting rod, piston rod, and crosshead assemblies.
- Camshaft drive and camshaft general arrangement.
- Shielding and insulation of exhaust pipes.
- Details of turbochargers, see Section 14.
- Operation and service manuals.
- Vibration dampers/detuners and moment compensators.
- Thrust bearing assembly (if integral with engine and not integrated in the bedplate).
- Counterweights, where attached to crank-throw, including fastening.
- Main engine holding down arrangement (metal chocks).

1.1.3 Material specifications covering the listed components in 1.1.1 and 1.1.2 are to be forwarded together with details of any surface treatments, non-destructive testing and hydraulic tests.

1.1.4 Plans and details for dead ship condition starting arrangements are to be submitted for appraisal, see 9.1.

1.1.5 For engine types built under license it is intended that the above documentation be submitted by the Licensor. Each Licensee is then to submit the following:

- A list, based on the above, of all documents required with the relevant drawing numbers and revision status from both Licensor and Licensee.
- The associated documents where the Licensee proposes design modifications to components. In such cases a statement is to be made confirming the Licensor's acceptance of the proposed changes.

In all cases a complete set of endorsed documents will be required by the Surveyor(s) attending the Licensee's works.

- Diesel generator test results that state the engine maximum load steps which satisfy the quality of power supply requirements specified in Pt 6, Ch 2, 1.7.
- Planned operating profiles for the vessel at sea and during manoeuvring as agreed with the operators.

1.1.6 Where engines incorporate electronic control systems the following additional information is to be submitted:

- (a) A general overview of the operating principles, supported by schematics explaining the functionality of individual systems and sub-systems. The information is to relate to the engine capability and functionality under defined operating and emergency conditions such as recovery from a failure or malfunction, with particular reference to the functioning of programmable electronic systems and any sub-systems. The information is also to indicate if the engine has different modes of operation, such as to limit exhaust gas emissions and/or to run under an economic fuel consumption mode or any other mode that is electronically controlled.

- (b) Operating manuals which describe the particulars of each system and, together with maintenance instructions, include reference to the functioning of sub-systems.
- (c) A risk-based analysis of the mechanical, pressure containing, electrical, electronic and programmable electronic systems and arrangements that support the operation of the engine. The analysis is to demonstrate that suitable risk mitigation has been achieved in accordance with 4.2.
- (d) Details of hydraulic systems for actuation of subsystems (fuel injection or exhaust), to include details of the design/construction of pipes, pumps, valves, accumulators and the control of valves/pumps. Details of pump drive arrangements are also to be included.
- (e) Quality plan for sourcing, design, installation and testing of all components used in the oil fuel and hydraulic oil systems installed with the engine for engine operation.
- (f) Fatigue analysis for all high pressure oil fuel and hydraulic oil piping arrangements required for engine operation where failure of the pipe or its connection or a component would be the cause of engine unavailability. The analysis is to concentrate on high pressure components and sub-systems and recognise the pressures and fluctuating stresses that the pipe system may be subject to in normal service.
- (g) Evidence of type testing of the engine with the programmable electronic system, or a proposed test plan at the engine builders with the programmable electronic system functioning, to verify the functionality and behaviour under normal operating and fault conditions of the programmable electronic control system.
- (h) Schedule of testing at engine builders, pre-sea trial commissioning and sea trials. The test schedules are to identify all modes of engine operation and the sea trials are to include typical port manoeuvres under the intended engine operating modes. The schedule is to include:
  - (i) testing and trials to demonstrate that the engine is capable of operating as described in (a);
  - (ii) tests to verify that the response of the complete mechanical, hydraulic, electrical and electronic system is as predicted for the intended operational modes; and
  - (iii) testing required to verify the conclusions of the risk-based analysis.

The scope of these tests is to be agreed with LR.

1.1.7 In addition to the applicable plans and particulars required by Pt 6, Ch 1, 1.2.3 to 1.2.6 the following information for control, alarm, monitoring and safety systems relating to the operation of an electronically controlled engine is to be submitted:

- (a) Engine configuration details, see 4.3.2.
- (b) Software quality plans, including configuration management documents.
- (c) Software safety evidence.
- (d) Software assessment inspection report.

1.1.8 Emergency diesel-generator engine plans, information and test schedules, required for design appraisal, are to be in accordance with Pt 6, Ch 1.

1.1.9 The following plans and particulars are to be submitted for information:

- Cross sectional plans of the assembled turbocharger with main dimensions.
- Fully dimensioned plans of the rotor.
- Material particulars with details of welding and surface treatments.
- Turbo-charger operating and test data.
- A selected turbocharger is to be type tested.
- Manufacturer's burst test assessment.

1.1.10 Where considered necessary Lloyd's Register (hereinafter referred to as 'LR') may require additional documentation to be submitted.

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## ■ Section 2 Materials

### 2.1 Crankshaft materials

2.1.1 The specified minimum tensile strength of castings and forgings for crankshafts is to be selected within the following general limits:

- (a) Carbon and carbon-manganese steel castings – 400 to 550 N/mm<sup>2</sup>
- (b) Carbon and carbon-manganese steel forgings (normalised and tempered) – 400 to 600 N/mm<sup>2</sup>
- (c) Carbon and carbon-manganese steel forgings (quenched and tempered) – not exceeding 700 N/mm<sup>2</sup>
- (d) Alloy steel castings – not exceeding 700 N/mm<sup>2</sup>
- (e) Alloy steel forgings – not exceeding 1000 N/mm<sup>2</sup>
- (f) Spheroidal or nodular graphite iron castings – 370 to 800 N/mm<sup>2</sup>.

2.1.2 Where it is proposed to use alloy castings, micro alloyed or alloy steel forgings or iron castings, details of the chemical composition, heat treatment and mechanical properties are to be submitted for approval.

### 2.2 Material test and inspections

2.2.1 Components for engines are to be tested as indicated in Table 2.2.1 and in accordance with the relevant requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

2.2.2 For components of novel design special consideration will be given to the material test and non-destructive testing requirements.

# Oil Engines

# Part 5, Chapter 2

Sections 2 & 3

**Table 2.2.1 Test requirements for oil engine components**

Component	Material tests	Non-destructive tests	
		Magnetic particle or Liquid penetrant	Ultrasonic
Crankshaft	all	all	all
Crankshaft coupling flange (non-integral) for main propulsion engines	above 400 mm bore	—	—
Crankshaft coupling bolts	above 400 mm bore	—	—
Steel piston crowns	above 400 mm bore	above 400 mm bore	all
Piston rods	above 400 mm bore	above 400 mm bore	above 400 mm bore
Connecting rods, including bearing caps	all	all	above 400 mm bore
Crosshead	above 400 mm bore	—	—
Cylinder liner	above 300 mm bore	—	—
Cylinder cover	above 300 mm bore	above 400 mm bore	all
Steel castings for welded bedplates	all	all	all
Steel forgings for welded bedplates	all	—	—
Plates for welded bedplates, frames and entablatures	all	—	—
Crankcases, welded or cast	all	—	—
Tie rods	all	above 400 mm bore	—
Turbo-charger, shaft and rotor	above 300 mm bore	—	—
Bolts and studs for cylinder covers, crossheads, main bearings, connecting rod bearings	above 300 mm bore	above 400 mm bore	—
Steel gear wheels for camshaft drives	above 400 mm bore	above 400 mm bore	—
<p><b>NOTES</b></p> <ol style="list-style-type: none"> <li>1. For closed-die forged crankshafts the ultrasonic examination may be confined to the initial production and to subsequent occasional checks.</li> <li>2. Magnetic particle or liquid penetrant testing of tie rods may be confined to the threaded portions and the adjacent material over a length equal to that of the thread.</li> <li>3. Cylinder covers and liners manufactured from spheroidal or nodular graphite iron castings may not be suitable for ultrasonic NDE, depending upon the grain size and geometry. An alternative NDE procedure is to be agreed with LR.</li> <li>4. Bore dimensions refer to engine cylinder bores.</li> <li>5. All required material tests are to be witnessed by the Surveyor unless alternative arrangements have been specifically agreed by LR.</li> <li>6. For mass produced engines, see Section 13.</li> </ol>			

## Section 3 Design

### 3.1 Scope

**3.1.1** The formulae given in this Section are applicable to solid, or semi-built crankshafts, having a main support bearing adjacent to each crankpin, and are intended to be applied to a single crankthrow analysed by the static determinate method.

**3.1.2** Alternative methods, including a fully documented stress analysis, will be specially considered.

**3.1.3** Calculations are to be carried out for the maximum continuous power rating for all intended operating conditions.

**3.1.4** Designs of crankshafts not included in this scope will be subject to special consideration.

### 3.2 Information to be submitted

**3.2.1** In addition to detailed dimensioned plans, the following information is required to be submitted:

- Engine type – 4SCSA/2SCSA/in-line/vee.
- Output power at maximum continuous rating (MCR), in kW.
- Output speed at maximum continuous power, in rpm.
- Maximum cylinder pressure, in bar g.
- Mean indicated pressure, in bar g.
- Cylinder air inlet pressure, in bar g.
- Digitised gas pressure/crank angle cycle for MCR.
- Maximum pressure/speed relationship.
- Compression ratio.
- Vee angle and firing interval (if applicable), in degrees.
- Firing order numbered from driving end, see Fig. 2.3.1.
- Cylinder diameter, in mm.
- Piston stroke, in mm.
- Mass of connecting rod (including bearings), in kg.
- Centre of gravity of connecting rod from large end centre, in mm.
- Radius of gyration of connecting rod, in mm.



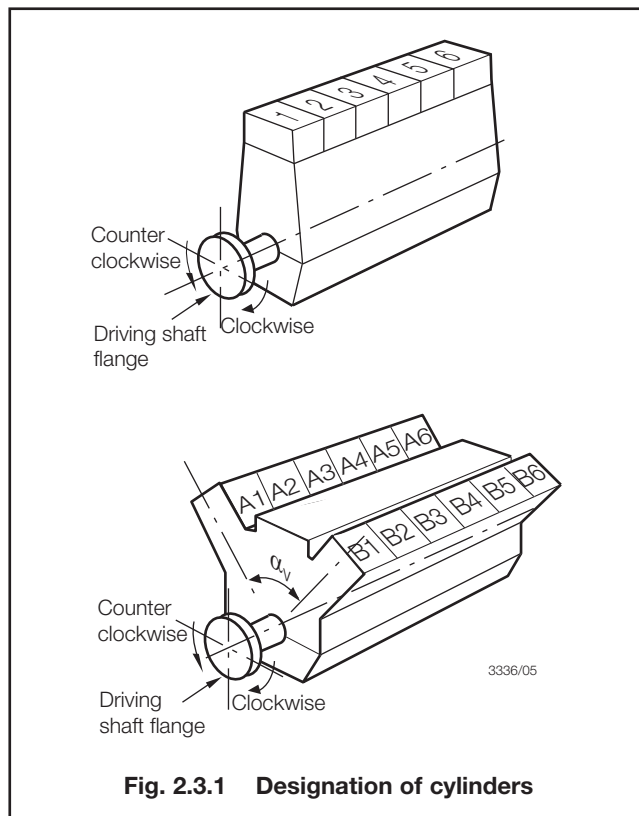


Fig. 2.3.1 Designation of cylinders

- Length of connecting rod between bearing centres, in mm.
- Mass of single crankweb (indicate if webs either side of pin are of different mass values), in kg.
- Centre of gravity of crankweb mass from shaft axis, in mm.
- Mass of counterweights fitted (for complete crankshaft) indicate positions fitted, in kg.
- Centre of gravity of counterweights (for complete crankshaft) measured from shaft axis, in mm.
- Mass of piston (including piston rod and crosshead where applicable), in kg.

- All individual reciprocating masses acting on one crank, in kg.
- Material specification(s).
- Specified minimum UTS, in N/mm<sup>2</sup>.
- Specified minimum yield strength, in N/mm<sup>2</sup>.
- Method of manufacture.
- Details of fatigue enhancement process (if applicable).
- For semi-built crankshafts – minimum and maximum diametral interference, in mm.

### 3.3 Symbols

3.3.1 For the purposes of this Chapter the following symbols apply, see also Fig. 2.3.2:

- $h$  = radial thickness of web, in mm
- $k_e$  = bending stress factor
- $B$  = transverse breadth of web, in mm
- $D_p, D_j$  = outside diameter of pin or main journal, in mm
- $D_{pi}, D_{ji}$  = internal diameter of pin or main journal, in mm
- $D_s$  = shrink diameter of main journal in web, in mm
- $d_o$  = diameter of radial oil bore in crankpin, in mm
- $F$  = alternating force at the web centreline, in N
- $K_1$  = fatigue enhancement factor due to manufacturing process
- $K_2$  = fatigue enhancement factor due to surface treatment
- $M_b$  = alternating bending moment at web centreline, in N-mm (NOTE: alternating is taken to be  $1/2$  range value)
- $M_{BON}$  = alternating bending moment calculated at the outlet of crankpin oil bore
- $M_p, M_j$  = undercut of fillet radius into web measured from web face, in mm
- $R_p, R_j$  = fillet radius at junction of web and pin or journal, in mm
- $S$  = stroke, in mm
- $T$  = axial thickness of web, in mm
- $T_a$  = alternating torsional moment at crankpin or crank journal, in N-mm (NOTE: alternating is taken to be  $1/2$  range value)

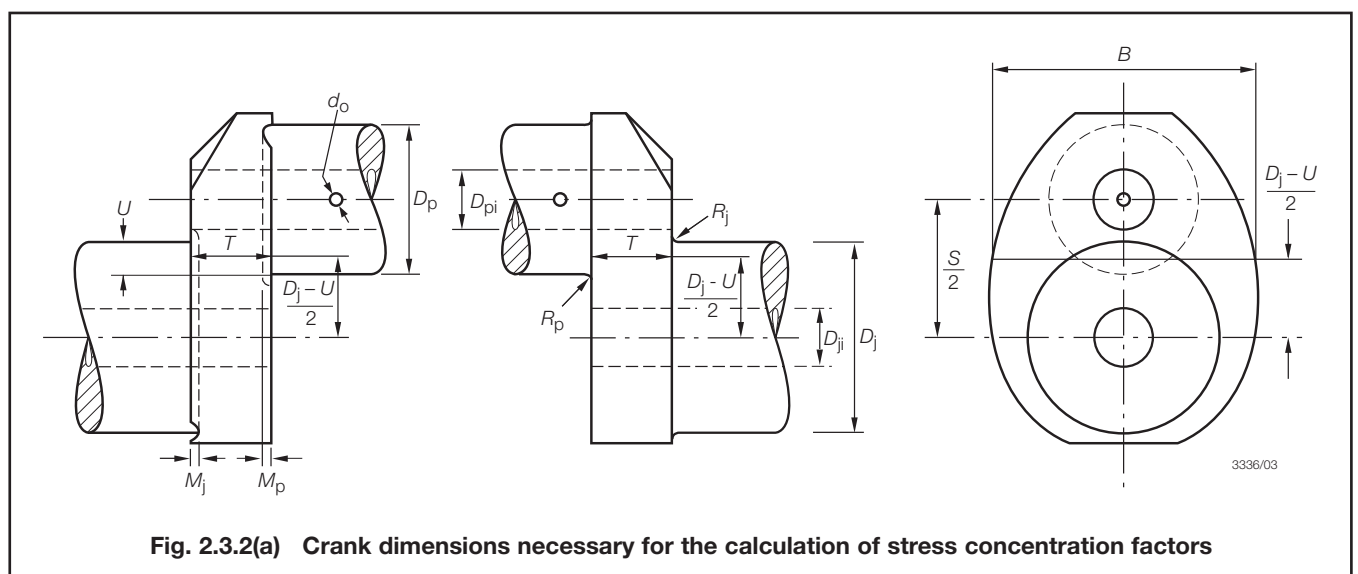
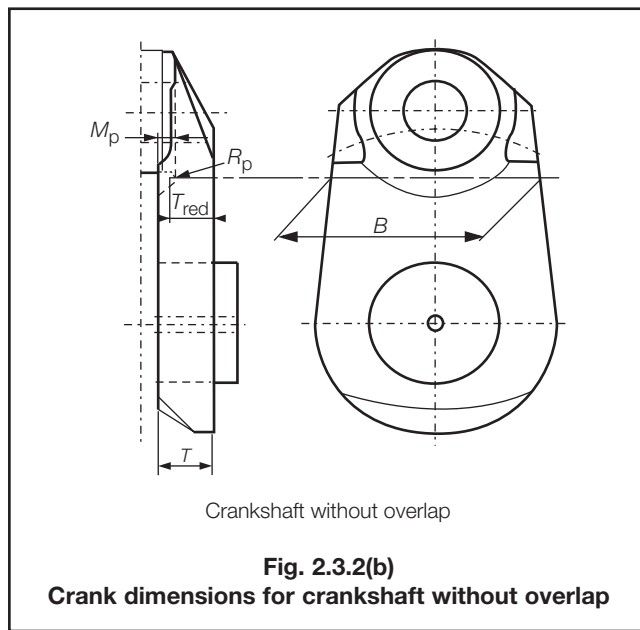


Fig. 2.3.2(a) Crank dimensions necessary for the calculation of stress concentration factors



$$U = \text{pin overlap} \\ = \frac{(D_p + D_j - S)}{2} \text{ mm}$$

- $\alpha_B$  = bending stress concentration factor for crankpin  
 $\alpha_T$  = torsional stress concentration factor for crankpin  
 $\beta_B$  = bending stress concentration factor for main journal  
 $\beta_Q$  = direct shear stress concentration factor for main journal  
 $\beta_T$  = torsional stress concentration factor for main journal  
 $\gamma_B$  = bending stress concentration factor for radially drilled oil hole in the crankpin  
 $\gamma_T$  = torsional stress concentration factor for radially drilled oil hole in the crankpin  
 $\sigma_{ax}$  = alternating axial stress, in N/mm<sup>2</sup>  
 $\sigma_b$  = alternating bending stress, in N/mm<sup>2</sup>  
 $\sigma_{BON}$  = alternating bending stress in the outlet of the oil bore, in N/mm<sup>2</sup>  
 $\sigma_p, \sigma_j$  = maximum bending stress in pin and main journal taking into account stress raisers, in N/mm<sup>2</sup>  
 $\sigma_{BO}$  = maximum bending stress in the outlet of the oil bore, in N/mm<sup>2</sup>  
 $\sigma_Q$  = alternating direct stress, in N/mm<sup>2</sup>  
 $\sigma_U$  = specified minimum UTS of material, in N/mm<sup>2</sup>  
 $\sigma_y$  = specified minimum yield stress of material, in N/mm<sup>2</sup>  
 $\tau_a$  = alternating torsional stress, in N/mm<sup>2</sup>  
 $\tau_p, \tau_j$  = maximum torsional stress in pin and main journals taking into account stress raisers, in N/mm<sup>2</sup>  
 $\tau_{tob}$  = maximum torsional stress in outlet of crankpin oil bore taking into account stress raisers, in N/mm<sup>2</sup>.

### 3.4 Stress concentration factors

**3.4.1 Geometric factors.** Crankshaft variables to be used in calculating the geometric stress concentrations together with their limits of applicability are shown in Table 2.3.1.

**Table 2.3.1 Crankshaft variables**

Variable	Range	
	Lower	Upper
$b = B/D_p$	1,10	2,20
$d_j = D_{ji}/D_p$	0,00	0,80
$d_p = D_{pi}/D_p$	0,00	0,80
$m_j = M_j/D_p$	0,00	$r_{jB}$
$m_p = M_p/D_p$	0,00	$r_p$
$r_{jB} = R_j/D_p$	0,03	0,13
$r_{jT} = R_j/D_j$	0,03	0,13
$r_p = R_p/D_p$	0,03	0,13
$t = T/D_p$	0,20	0,80
$t = T_{red}/D_p$ see Note 3	0,20	0,80
$d = d_o/D_p$	0,00	0,20
$u = U/D_p$ see Note 2		0,50

#### NOTES

- Where variables fall outside the range, alternative methods are to be used and full details submitted for consideration.
- A lower limit of  $u$  can be extended down to large negative values provided that:
  - If calculated  $f(\text{rec}) < 1$  then the factor  $f(\text{rec})$  is not to be considered ( $f(\text{rec}) = 1$ )
  - If  $u < -0,5$  then  $f(\text{ut})$  and  $f(\text{ru})$  are to be evaluated replacing actual value of  $u$  by  $-0,5$ .
- For crankshafts without overlap see also 3.4.6.

#### 3.4.2 Crankpin stress concentration factors:

##### • Bending

$$\alpha_B = 2,70 f(\text{ut}). f(t). f(b). f(r). f(d_p). f(d_j). f(\text{rec})$$

where

$$f(\text{ut}) = 1,52 - 4,1t + 11,2t^2 - 13,6t^3 + 6,07t^4 - u(1,86 - 8,26t + 18,2t^2 - 18,5t^3 + 6,93t^4) - u^2(3,84 - 25,0t + 70,6t^2 - 87,0t^3 + 39,2t^4)$$

$$f(t) = 2,18t^{0,717}$$

$$f(b) = 0,684 - 0,0077b + 0,147b^2$$

$$f(r) = 0,208r_p^{(-0,523)}$$

$$f(d_p) = 1 + 0,315(d_p) - 1,52(d_p)^2 + 2,41(d_p)^3$$

$$f(d_j) = 1 + 0,27d_j - 1,02(d_j)^2 + 0,531(d_j)^3$$

$$f(\text{rec}) = 1 + (m_p + m_j)(1,8 + 3,2u)$$

valid only between  $u = -0,5$  and  $0,5$ .

##### • Torsion

$$\alpha_T = 0,8 f(\text{ru}). f(b). f(t)$$

where

$$f(\text{ru}) = r_p^{-(0,22 + 0,1u)}$$

$$f(b) = 7,9 - 10,65b + 5,35b^2 - 0,857b^3$$

$$f(t) = t^{(-0,145)}.$$

#### 3.4.3 Crank journal stress concentration factors (not applicable to semi-built crankshafts):

##### • Bending

$$\beta_B = 2,71 f_B(\text{ut}). f_B(t). f_B(b). f_B(r). f_B(d_j). f_B(d_p). f(\text{rec})$$

where

$$f_B(\text{ut}) = 1,2 - 0,5t + 0,32t^2 - u(0,80 - 1,15t + 0,55t^2) - u^2(2,16 - 2,33t + 1,26t^2)$$

$$f_B(t) = 2,24t^{0,755}$$

$$f_B(b) = 0,562 + 0,12b + 0,118b^2$$

$$f_B(r) = 0,191r_{jB}^{(-0,557)}$$

$$f_B(d_j) = 1 - 0,644d_j + 1,23(d_j)^2$$

$$f_B(d_p) = 1 - 0,19d_p + 0,0073(d_p)^2$$

$$f(\text{rec}) = 1 + (m_p + m_j)(1,8 + 3,2u)$$

valid only between  $u = -0,5$  and  $0,5$ .

- Direct shear  
 $\beta_Q = 3,01f_Q(u) \cdot f_Q(t) \cdot f_Q(b) \cdot f_Q(r) \cdot f_Q(dp) \cdot f(\text{rec})$   
 where  
 $f_Q(u) = 1,08 + 0,88u - 1,52u^2$   
 $f_Q(t) = \frac{t}{0,0637 + 0,937t}$   
 $f_Q(b) = b - 0,5$   
 $f_Q(r) = 0,533r_{JB}^{(-0,204)}$   
 $f_Q(dp) = 1 - 1,19d_p + 1,74(d_p)^2$   
 $f(\text{rec}) = 1 + (m_p + m_j)(1,8 + 3,2u)$   
 valid only between  $u = -0,5$  and  $0,5$ .
- Torsion  
 where  
 $\beta_T = 0,8f(r_u) \cdot f(b) \cdot f(t)$   
 $f(r_u) = r_{JT}^{(-0,22 + 0,1u)}$   
 $f(b) = 7,9 - 10,65b + 5,35b^2 - 0,857b^3$   
 $f(t) = t^{(-0,145)}$ .

3.4.4 Crankpin oil bore stress concentration factors for radially drilled oil holes:

- Bending  
 $\gamma_B = 3 - 5,88 \cdot \frac{d_o}{D_p} + 34,6 \cdot \left(\frac{d_o}{D_p}\right)^2$
- Torsion  
 $\gamma_T = 4 - 6 \cdot \frac{d_o}{D_p} + 30 \cdot \left(\frac{d_o}{D_p}\right)^2$

3.4.5 Where experimental measurements of the stress concentrations are available these may be used. The full documented analysis of the experimental measurements is to be submitted for consideration.

3.4.6 In the case of semi-built crankshafts when  $M_p > R_p$  the web thickness is to be taken as:

$T_{\text{red}} = T - (M_p - R_p)$  and the web width  $B$  is to be taken in way of the crankpin fillet radius centre see Fig. 2.3.2.

## 3.5 Nominal stresses

3.5.1 The nominal alternating bending stress,  $\sigma_b$ , is to be calculated from the maximum and minimum bending moment at the web centreline taking into account all forces being applied to the crank throw in one working cycle with the crank throw simply supported at the mid length of the main journals.

3.5.2 Nominal bending stresses are referred to the web bending modulus.

3.5.3 Nominal alternating bending stress:

$$\sigma_b = \pm \frac{M_b}{Z_{\text{web}}} k_e \quad \text{N/mm}^2$$

$$Z_{\text{web}} = \frac{BT^2}{6} \quad \text{mm}^3$$

$$k_e = 0,8 \text{ for crosshead engines} \\ = 1,0 \text{ for trunk piston engines.}$$

3.5.4 Nominal alternating bending stress in the outlet of the crankpin oil bore:

$$\sigma_{\text{BON}} = \pm \frac{M_{\text{BON}}}{Z_{\text{crankpin}}}$$

where

$M_{\text{BON}}$  is taken as the  $\frac{1}{2}$  range value  $M_{\text{BON}} = \pm \frac{1}{2} (M_{\text{BOMax}} - M_{\text{BOMin}})$

and

$M_{\text{BO}} = (M_{\text{BTO}} \cos \psi + M_{\text{BRO}} \sin \psi)$ , see Fig. 2.3.3

The two relevant bending moments are taken in the crankpin cross-section through the oil bore.

$M_{\text{BRO}}$  = bending moment of the radial component of the connecting-rod force

$M_{\text{BTO}}$  = bending moment of the tangential component of the connecting-rod force

$$Z_{\text{crankpin}} = \frac{\pi}{32} \frac{D^4 - d^4}{D} \quad Z_{\text{crankpin}} \text{ related to the cross-section of axially bored crankpin.}$$

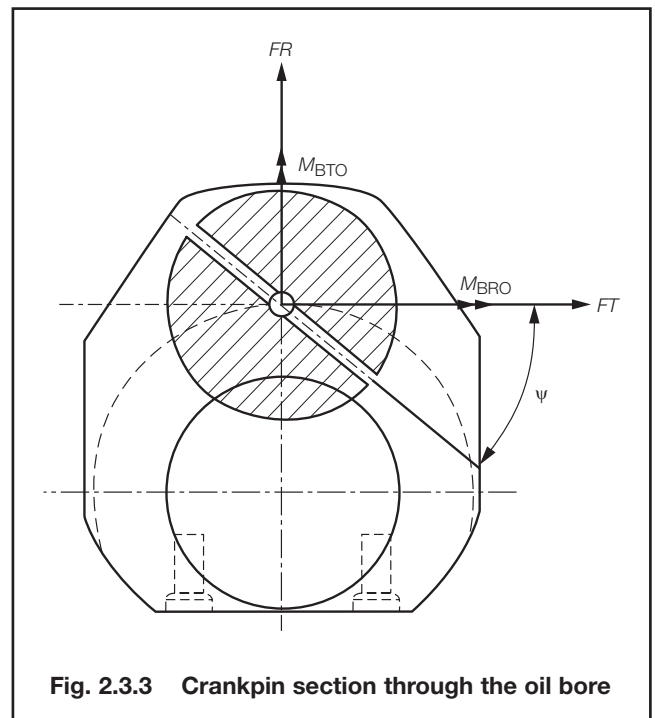


Fig. 2.3.3 Crankpin section through the oil bore

3.5.5 The nominal direct shear stress in the web for the purpose of assessing the main journal is to be added algebraically to the bending stress, using the alternating forces which have been used in deriving  $M_b$  in 3.5.3.

3.5.6 Nominal stress is referred to the web cross-section area or the pin cross-section area as applicable.

3.5.7 Nominal alternating direct shear stress:

$$\sigma_Q = \pm \frac{F}{A_{\text{web}}} k_e \quad \text{N/mm}^2$$

where

$$A_{\text{web}} = BT \text{ mm}^2.$$

**3.5.8** The nominal alternating torsional stress,  $\tau_a$ , is to be taken into consideration. The value is to be derived from forced-damped vibration calculations of the complete dynamic system. Alternative methods will be given consideration. The engine designer is to advise the maximum level of alternating vibratory stress that is permitted.

**3.5.9** The results of torsional vibration calculations for the full dynamic system, carried out in accordance with Ch 8,2.2, are to be submitted.

**3.5.10** Nominal alternating torsional stress:

$$\tau_a = \pm \frac{T_a}{Z_T} \text{ N/mm}^2$$

where

$Z_T$  = torsional modulus of crankpin and main journal

$$= \frac{\pi}{16} \left[ \frac{(D^4 - d^4)}{D} \right] \text{ mm}^3$$

$D$  = outside diameter of crankpin or main journal, in mm

$d$  = inside diameter of crankpin or main journal, in mm

$\tau_a$  is to be ascertained from assessment of the torsional vibration calculations where the maximum and minimum torques are determined for every mass point of the complete dynamic system and for the entire speed range by means of a harmonic synthesis of the forced vibrations from the 1st order up to and including the 15th order for 2-stroke cycle engines and from the 0,5th order up to and including the 12th order for 4-stroke cycle engines. Whilst doing so, allowance must be made for the damping that exists in the system and for unfavourable conditions (misfiring in one of the cylinders when no combustion occurs but only compression cycle). The speed step calculation shall be selected in such a way that any resonance found in the operational speed range of the engine shall be detected.

**3.5.11** For the purpose of the crankshaft assessment, the nominal alternating torsional stress considered in calculations is to be the highest calculated value, according to the method described in 3.5.9, occurring at the most torsionally loaded mass point of the crankshaft system.

**3.5.12** The approval of the crankshaft will be based on the installation having the largest nominal alternating torsional stress (but not exceeding the maximum figure specified by the engine manufacturer). For each installation it is to be ensured by calculation that the maximum approved nominal alternating torsional stress is not exceeded.

**3.5.13** In addition to the bending stress,  $\sigma_b$ , the axial vibratory stress,  $\sigma_{ax}$ , is to be taken into consideration, for crosshead type engines. For trunk type engines,  $\sigma_{ax} = 0$ . The value is to be derived from forced-damped vibration calculations of the complete dynamic system. Alternative methods will be given consideration. The engine designer is to advise the maximum level of alternating vibratory stress that is permitted. The corresponding crankshaft free-end deflection is also to be stated.

## 3.6 Maximum stress levels

**3.6.1** Crankpin fillet.

- Maximum alternating bending stress:

$$\sigma_p = \alpha_B (\sigma_b + \sigma_{ax}) \text{ N/mm}^2$$

where

$\alpha_B$  = bending stress concentration, see 3.4.2

- Maximum alternating torsional stress:

$$\tau_p = \alpha_T \tau_a \text{ N/mm}^2$$

where

$\alpha_T$  = torsional stress concentration, see 3.4.2

$\tau_a$  = nominal alternating torsional stress in crankpin N/mm<sup>2</sup>.

**3.6.2** Outlet of crankpin oil bore.

- Maximum alternating bending stress:

$$\sigma_{BO} = \gamma_B (\sigma_{BON} + \sigma_{ax}) \text{ N/mm}^2$$

where

$\gamma_B$  = bending stress concentration factor, see 3.4.4

- Maximum alternating torsional stress:

$$\tau_{tob} = \gamma_T \tau_a \text{ N/mm}^2$$

where

$\gamma_T$  = torsional stress concentration factor, see 3.4.4

$\tau_a$  = nominal alternating torsional stress in crankpin N/mm<sup>2</sup>.

**3.6.3** Crank journal fillet (not applicable to semi-built crankshafts).

- Maximum alternating bending stress:

$$\sigma_j = \beta_B (\sigma_b + \sigma_{ax}) + \beta_Q \sigma_Q \text{ N/mm}^2$$

where

$\beta_B$  = bending stress concentration, see 3.4.3

$\beta_Q$  = direct stress concentration, see 3.4.3

- Maximum alternating torsional stress:

$$\tau_j = \beta_T \tau_a \text{ N/mm}^2$$

where

$\beta_T$  = torsional stress concentration, see 3.4.3

$\tau_a$  = nominal alternating torsional stress in main journal N/mm<sup>2</sup>.

## 3.7 Equivalent alternating stress

**3.7.1** Equivalent alternating stress of the crankpin,  $\sigma_{ep}$ , or crank journal  $\sigma_{ej}$ , is defined as:

$$\sigma_{ep}, \sigma_{ej} = \sqrt{(\sigma + 10)^2 + 3\tau^2} \text{ N/mm}^2$$

where

$$\sigma = \sigma_p \text{ or } \sigma_j \text{ N/mm}^2$$

$$\tau = \tau_p \text{ or } \tau_j \text{ N/mm}^2.$$

**3.7.2** Equivalent alternating stress for the outlet of the crankpin oil bore  $\sigma_{eob}$ , is defined as:

$$\sigma_{eob} = \pm \frac{1}{3} \sigma_{bo} \left( 1 + 2 \sqrt{1 + \frac{9}{4} \frac{\tau_{to}}{\sigma_{bo}}} \right)^2 \text{ N/mm}^2$$

# Oil Engines

# Part 5, Chapter 2

Section 3

## 3.8 Fatigue strength

3.8.1 The fatigue strength of a crankshaft is based upon the crankpin and crank journal as follows:

$$\sigma_{fp} = K_1 K_2 (0,42\sigma_u + 39,3)$$

$$\left(0,264 + 1,073D_p^{-0,2} + \frac{785 - \sigma_u}{4900} + \frac{196}{\sigma_u} \sqrt{\frac{1}{R_p}}\right)$$

To calculate the fatigue strength in the oil bore area, replace  $R_p$  with  $\frac{1}{2}d_o$  and  $\sigma_{fp}$  with  $\sigma_{fob}$ .

$$\sigma_{fj} = K_1 K_2 (0,42\sigma_u + 39,3)$$

$$\left(0,264 + 1,073D_j^{-0,2} + \frac{785 - \sigma_u}{4900} + \frac{196}{\sigma_u} \sqrt{\frac{1}{R_j}}\right)$$

where

$\sigma_u$  = UTS of crankpin or crank journal as appropriate

$K_1$  = fatigue endurance factor appropriate to the manufacturing process

= 1,05 for continuous grain-flow (CGF) or die-forged

= 1,0 for freeform forged (without CGF)

= 0,93 for cast steel manufactured using a LR approved cold rolling process

$K_2$  = fatigue enhancement factor for surface treatment.

These treatments are to be applied to the fillet radii

A value for  $K_2$  will be assigned upon application by the engine designers. Full details of the process, together with the results of full scale fatigue tests will be required to be submitted for consideration. Alternatively, the following values may be taken (surface hardened sone to include fillet radii):

$K_2$  = 1,15 for induction hardened

= 1,25 for nitrided

Where a value of  $K_1$  or  $K_2$  greater than unity is to be applied then details of the manufacturing process are to be submitted.

## 3.9 Acceptability criteria

3.9.1 The acceptability factor, Q, is to be greater than 1,15:

$$Q = \frac{\sigma_f}{\sigma_e} \text{ for crankpin, journal and the outlet of crankpin oil bore}$$

where

$\sigma_f$  =  $\sigma_{fp}$  or  $\sigma_{fj}$  or  $\sigma_{fob}$

$\sigma_e$  =  $\sigma_{ep}$  or  $\sigma_{ej}$  or  $\sigma_{eob}$ .

## 3.10 Oil hole

3.10.1 The junction of the oil hole with the crankpin or main journal surface is to be formed with an adequate radius and smooth surface finish down to a minimum depth equal to 1,5 times the oil bore diameter.

3.10.2 Fatigue strength calculations or alternatively fatigue test results may be required to demonstrate acceptability.

3.10.3 When journal diameter is equal or larger than the crankpin diameter, the outlets of main journal oil bores are to be formed in a similar way to the crankpin oil bores, otherwise separate fatigue strength calculations or, alternatively, fatigue test results may be required.

## 3.11 Shrink fit of semi-built crankshafts

3.11.1 The maximum permissible internal diameter in the journal pin is to be calculated in accordance with the following formula:

$$D_{ji} = D_s \sqrt{1 - \frac{4000\text{FoS } M_{\max}}{\mu \pi D_s^2 L_s \sigma_{yj}}}$$

where the symbols are as defined in 3.11.7.

3.11.2 When 3.11.1 cannot be complied with, then 3.11.7 is not applicable. In such cases  $\delta_{\min}$  and  $\delta_{\max}$  are to be established from FEM calculations.

3.11.3 The following formulae are applicable to crankshafts assembled by shrinking main journals into the crankwebs.

3.11.4 In general, the radius of transition,  $R_j$ , between the main journal diameter,  $D_j$ , and the shrink diameter,  $D_s$ , is to be not less than  $0,015D_j$  or  $0,5(D_s - D_j)$ .

3.11.5 The distance,  $y$ , between the underside of the pin and the shrink diameter should be greater than  $0,05D_s$ .

3.11.6 Deviations from these parameters will be specially considered.

3.11.7 The proposed diametral interference is to be within the following limits, see also Fig. 2.3.4:

The minimum required diametral interference is to be taken as the greater of:

$$\delta_{\min} = \frac{12,156 \times 10^6 (\text{FoS})}{TD_s \mu E} \frac{P}{R} (1 + C) \frac{k^2 - l^2}{(k^2 - 1)(1 - l^2)} \text{ mm}$$

or

$$\delta_{\min} = \frac{\sigma_y D_s}{E} \text{ mm}$$

where

$h$  = minimum radial thickness of the web around the diameter  $D_s$ , mm

$$k = \frac{D_o}{D_s}$$

$$l = \frac{D_{ji}}{D_s}$$

$C$  = ratio of torsional vibratory torque to the mean transmitted torque at the P/R rating being considered

$D_o$  =  $D_s + 2h$ , in mm

$D_s$  = shrink diameter, in mm

$E$  = Young's modulus of elasticity of crankshaft material, in N/mm<sup>2</sup>

FoS = Factor of Safety against rotational slippage to be taken as 2,0. A value less than 2,0 may be used where documented by experiments to demonstrate acceptability

$P$  = output power, in kW

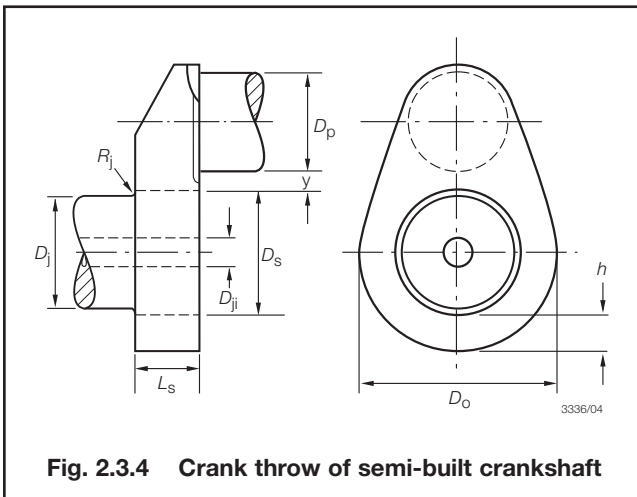
$R$  = speed at associated power, in rpm

$T$  = crankweb thickness, in mm

$\mu$  = coefficient of static friction to be taken as 0,2 for degreased surfaces. A value greater than 0,2 may be used where documented by experiments to demonstrate acceptability

$\sigma_{yj}$  = minimum yield strength of material for journal pin





**Fig. 2.3.4 Crank throw of semi-built crankshaft**

$M_{\max}$  = absolute maximum value of the torque taking Ch 8,2 into consideration

$L_s$  = length of shrink fit, in mm.

Maximum diametral interference,  $\delta_{\max}$ , is not to be greater than:

$$\delta_{\max} = \frac{\sigma_y D_s}{E} + \frac{0,8 D_s}{1000} \text{ mm.}$$

3.11.8 Reference marks are to be provided on the outer junction of the crankwebs with the journals.

### 3.12 Alternative method for calculation of stress concentration factors

3.12.1 LR will give consideration to crankshaft design using an alternative method given in LR's *ShipRight procedures for alternative method for calculation of stress concentration factors in the web fillet radii of crankshafts by utilising Finite Element*.

## Section 4

### Electronically controlled engines

#### 4.1 General

4.1.1 The requirements of this Section are applicable to engines for propulsion, auxiliary or emergency power purposes with programmable electronic systems implemented and used to control fuel injection timing and duration, and which may also control combustion air or exhaust systems. The requirements of this Section also apply to programmable electronic systems used to control other functions (e.g. starting and control air, cylinder lubrication etc.) where essential for the operation of the engine.

4.1.2 These engines may be of the slow, medium or high-speed type. They generally have no direct camshaft driven fuel systems, but have common rail fuel/hydraulic arrangements and may have hydraulic actuating systems for the functioning of the exhaust systems.

4.1.3 The operation of these engines relies on the effective monitoring of a number of parameters such as crank angle, engine speed, temperatures and pressures using programmable electronic systems to provide the services essential for the operation of the engine such as fuel injection, air inlet, exhaust and speed control.

4.1.4 Details of proposals to deviate from the requirements of this Section are to be submitted and will be considered on the basis of a technical justification produced by the Enginebuilder.

4.1.5 Each engine is to be configured for the specified performance and is to satisfy the relevant requirements for propulsion, auxiliary or emergency engines.

4.1.6 During the life of the engine details of any proposed changes to control, alarm, monitoring or safety systems which may affect safety and the reliable operation of the engine are to be submitted to LR for approval.

#### 4.2 Risk-based analysis

4.2.1 An analysis is to be carried out in accordance with relevant standards acceptable to LR to demonstrate compliance with the applicable requirements of this sub-Section appropriate to the engine application. The analysis is to be a risk-based consideration of engine operation and ship and personnel safety, and is to demonstrate adequate risk mitigation through fault tolerance and/or reliability in accordance with the specified criteria in 4.2.2 to 4.2.4 relevant to the engine application.

4.2.2 For ships with a single main propulsion engine, a Failure Mode and Effects Analysis (FMEA), or alternative recognised analysis of system reliability, is to be carried out and is to demonstrate that an electronic control system failure:

- will not result in the loss of the ability to provide the services essential for the operation of the engine, see Pt 6, Ch 1,2.5.8 and 2.13.2;
- will not affect the normal operation of the services essential for the operation of the engine other than those services dependent upon the failed part, see Pt 6, Ch 1,2.14.4 and 2.14.5; and
- will not leave either the engine, or any equipment or machinery associated with the engine, or the ship in an unsafe condition, see Pt 6, Ch 1,2.3.14, 2.4.6, 2.5.4, 2.10.3, 2.10.4 and 2.14.5.

4.2.3 A risk-based analysis is to be carried out for:

- main engines on ships with multiple main engines or other means of providing propulsion power; and/or
- auxiliary engines intended to drive electric generators forming the ship's main source of electrical power or otherwise providing power for essential services.

The analysis is to demonstrate that adequate hazard mitigation has been incorporated in electronically controlled engine systems or the overall ship installation with respect to personnel safety and providing propulsion power and/or power for essential services for the safety of the ship. Arrangements satisfying the criteria of 4.2.2(a) to (c) will also be acceptable.

**4.2.4** For engines for emergency power purposes, a risk-based analysis is to be carried out to demonstrate that the design incorporates adequate hazard mitigation such that the likelihood of an electronic control system failure resulting in the loss of the ability to provide emergency power when required has been reduced to a level considered acceptable by LR and that means are provided to detect failures and permit personnel to restore engine availability to operate on demand. Failures which would result in engine failure and/or damage or loss of availability are to be identified and the report is to include documentation of:

- (a) component reliability evidence;
- (b) failure detection and alarms; and
- (c) failure response required to restore engine availability and maintain personnel safety.

**4.2.5** The risk-based analysis report is to:

- (a) Identify the standards used for analysis and system design.
- (b) Identify the engine, its purpose and the associated objectives of the analysis.
- (c) Identify any assumptions made in the analysis.
- (d) Identify the equipment, system or sub-system, mode of operation and the equipment.
- (e) Identify potential failure modes and their causes.
- (f) Evaluate the local effects (e.g., fuel injection failure) and the effects on the system as a whole (e.g., loss of propulsion power) of each failure mode.
- (g) Identify measures for reducing the risks associated with each failure mode (e.g., system design, failure detection and alarms, redundancy, quality control procedures for sourcing, manufacture and testing, etc.).
- (h) Identify trials and testing necessary to prove conclusions.

**4.2.6** At sub-system level it is acceptable to consider failure of equipment items and their functions, e.g. failure of a pump to produce flow or pressure head. It is not required that the failure of components within that pump be analysed, and failure need only be dealt with as a cause of failure of the pump.

## 4.3 Control engineering systems

**4.3.1** Control, alarm, monitoring, safety and programmable electronic systems are to comply with Pt 6, Ch 1 as applicable.

**4.3.2** The engine control, alarm monitoring and safety systems are to be configured to comply with the relevant requirements (e.g., operating profile, alarms, shutdowns, etc.) of this Chapter and Pt 6, Ch 1 for an engine for main, auxiliary or emergency power purposes. Details of the engine configuration are to be submitted for consideration identifying:

- (a) Local and remote means to carry out system configuration.

- (b) Enginebuilder procedures for undertaking configuring.
- (c) Roles and responsibilities for configuration (e.g., Enginebuilder, engine packager, system integrator or other nominated party) with accompanying schedule.
- (d) Configurable settings and parameters (including those not to be modified from a default value).
- (e) Configuration for propulsion, auxiliary or emergency engine application.

Configuration records are to be maintained and are to be made available to the Surveyor at testing and trials and on request in accordance with Pt 6, Ch 1, 1.4 and 7.1.3.

## 4.4 Software

**4.4.1** Software lifecycle activities are to be carried out in accordance with an acceptable quality management system, see Pt 6, Ch 1, 2.13.2 and 2.13.7.

**4.4.2** Appropriate safety related processes, methods, techniques and tools are to be applied to software development and maintenance by the Enginebuilder. Selection and application of techniques and measures in accordance with Annex A of IEC 61508-3, *Functional safety of electrical/electronic/programmable electronic systems: Software requirements*, or other relevant standards or codes acceptable to LR, will generally be acceptable.

**4.4.3** To demonstrate compliance with 4.4.1 and 4.4.2:

- (a) software quality plans and safety evidence are to be submitted for consideration, see 4.2.2(b) and (c); and
- (b) an assessment inspection of the Enginebuilder's completed development is to be carried out by LR. The inspection is to be tailored to verify application of the standards and codes used in software safety assurance accepted by LR.

## Section 5 Construction and welded structures

### 5.1 Crankcases

**5.1.1** Crankcases and their doors are to be of robust construction to withstand anticipated crankcase pressures that may arise during a crankcase explosion, taking into account the installation of explosion relief valves required by Section 6 and the doors are to be securely fastened so that they will not be readily displaced by a crankcase explosion.

### 5.2 Welded joints

**5.2.1** Bedplates and major components of engine structures are to be made with a minimum number of welded joints.

**5.2.2** Double welded butt joints are to be adopted wherever possible in view of their superior fatigue strength.

# Oil Engines

# Part 5, Chapter 2

Sections 5 &amp; 6

5.2.3 Girders and frame assemblies should, so far as possible, be made from one plate or slab, shaped as necessary, rather than by welding together a number of small pieces.

5.2.4 Steel castings are to be used for parts which would otherwise require complicated weldments.

5.2.5 Care is to be taken to avoid stress concentrations such as sharp corners and abrupt changes in section.

5.2.6 Joints in parts of the engine structure which are stressed by the main gas or inertia loads are to be designed as continuous full strength welds and for complete fusion of the joint. They are to be so arranged that, in general, welds do not intersect, and that welding can be effected without difficulty and adequate inspection can be carried out. Abrupt changes in plate section are to be avoided and where plates of substantially unequal thickness are to be butt welded, the thickness of the heavier plate is to be gradually tapered to that of the thinner plate. Tee joints are to be made with full bevel or equivalent weld preparation to ensure full penetration.

5.2.7 In single plate transverse girders the castings for main bearing housings are to be formed with web extensions which can be butt welded to the flange and vertical web plates of the girder. Stiffeners in the transverse girder are to be attached to the flanges by full penetration welds.

## 5.3 Materials and construction

5.3.1 Plates, sections, forgings and castings are to be of welding quality in accordance with the requirements of the Rules for Materials, and with a carbon content generally not exceeding 0,23 per cent. Steels with higher carbon contents may be approved subject to satisfactory results from welding procedure tests.

5.3.2 Welding is to be carried out in accordance with the requirements of Chapter 13 of the Rules for Materials, using welding procedures and welders that have been qualified in accordance with Chapter 12 of the Rules for Materials.

5.3.3 Before welding is commenced the component parts of bedplates and framework are to be accurately fitted and aligned.

5.3.4 The welding is to be carried out in positions free from draughts and is to be downhand (flat) wherever practicable. Welding consumables are to be suitable for the materials being joined. Preheating is to be adopted when heavy plates or sections are welded. The finished welds are to have an even surface and are to be free from undercutting.

5.3.5 Welds attaching bearing housings to the transverse girders are to have a smooth contour and, if necessary, are to be made smooth by grinding.

## 5.4 Post-weld heat treatment

5.4.1 Bedplates are to be given a stress relieving heat treatment except engine types where the bedplate as a whole is not subjected to direct loading from the cylinder pressure. For these types, only the transverse girder assemblies need be stress relieved.

5.4.2 Stress relieving is to be carried out by heating the welded structure uniformly and slowly to a temperature between 580°C and 620°C, holding that temperature for not less than one hour per 25 mm of maximum plate thickness and thereafter allowing the structure to cool slowly in the furnace.

5.4.3 Omission of post-weld heat treatment of bedplates and their sub-assemblies will be considered on application by the Enginebuilder with supporting evidence in accordance with Ch 13,2.10.4 of the Rules for Materials.

## 5.5 Inspection

5.5.1 Welded engine structures are to be examined during fabrication, special attention being given to the fit of component parts of major joints prior to welding.

5.5.2 Inspection of welds is to be in accordance with the requirements of Ch 13,1.11 of the Rules for Materials.

5.5.3 Welds in transverse girder assemblies are to be crack detected by an approved method to the satisfaction of the Surveyors. Other joints are to be similarly tested if required by the Surveyors.

## Section 6 Turning gear

### 6.1 General requirements

6.1.1 Turning gear is to be provided for all engines to facilitate operating and maintenance regimes as required by the manufacturer.

6.1.2 The turning gear for all main propulsion engines is to be power-driven and, if electric, is to be continuously rated at a value to ensure protection to the weakest part of the machinery.

6.1.3 The turning gear for auxiliary engines may be hand operated (manual) except where this is not practicable, in which case the provision of 6.1.2 is to be complied with.

6.1.4 The turning gear for all engines is to be fitted with safety interlocks which prevent engine operation when engaged, see Ch 1,3.10. Indication of engaged/not engaged is to be provided at all start positions.

6.1.5 The remote control device of power-driven turning gear is to be so designed that power is removed from the turning gear when the operating switch is released.



6.1.6 Means are to be provided to secure the turning gear when disengaged.

6.1.7 Overload protection arrangements are to be provided to prevent damage to the electric motor and the turning gear train.

## Section 7 Control and monitoring of main, auxiliary and emergency diesel engines

### 7.1 General

7.1.1 Control engineering systems are to be in accordance with the requirements of Pt 6, Ch 1.

7.1.2 Oil mist detection, or engine bearing temperature monitors or alternative methods for crankcase protection are to be provided:

- When arrangements are fitted to override the automatic shut-down for excessive reduction of the lubricating oil supply pressure.
- For engines of 2250 kW and above or having cylinders of more than 300 mm bore.

#### NOTES

- For medium and high speed engines, automatic shut-down of the engine is to occur.
- For slow speed engines, automatic slow-down is to occur.
- Where arrangements are made to override the automatic slow-down or shut-down due to high oil mist or bearing temperature, the override is to be independent of other overrides.
- Where the bearing temperature monitoring method is chosen, all bearings in the crankcase are to be monitored where practicable, e.g., main, crankpin, crosshead.
- Where engine bearing temperature monitors or alternative methods are provided for the prevention of the build-up of oil mist that may lead to a potentially explosive condition within the crankcase, details are to be submitted for consideration. The submission is to demonstrate that the arrangements are equivalent to those provided by oil mist detection, see 10.8.14.

7.1.3 All main and auxiliary engines intended for essential services are to be provided with means of indicating the lubricating oil pressure supply to them. Where such engines are of more than 37 kW (50 shp), audible and visual alarms are to be fitted to give warning of an appreciable reduction in pressure of the lubricating oil supply. Further, these alarms are to be actuated from the outlet side of any restrictions, such as filters, coolers, etc.

### 7.2 Main engine governors

7.2.1 An efficient governor is to be fitted to each main engine so adjusted that the speed does not exceed that for which the engine is to be classed by more than 15 per cent.

7.2.2 Oil engines coupled to electrical generators which are the source of power for main electric propulsion motors are to comply with the requirements for auxiliary engines in respect of governors and overspeed protection devices.

### 7.3 Auxiliary engine governors

7.3.1 Auxiliary engines intended for driving electric generators are to be fitted with governors which, with fixed setting, are to control the speed within 10 per cent momentary variation and 5 per cent permanent variation when the full load is suddenly taken off or, when after having run on no-load for at least 15 minutes, the load is suddenly applied as follows:

- For engines with BMEP less than 8 bar, full load, or
- For engines with BMEP greater than 8 bar,  $\frac{800}{\text{BMEP}}$  per

cent, but not less than one third, of full load, the full load being attained in not more than two additional equal stages as rapidly as possible.

7.3.2 If an engine cannot achieve the requirements of 7.3.1 then the actual load step is to be declared and verified through testing to ensure the requirements specified in Pt 6, Ch 2, 1.7 are satisfied.

7.3.3 Emergency engines are to comply with 7.3.1 except that the initial load required by 7.3.1(b) is to be not less than the total connected emergency statutory load, or if their total consumer load is applied in steps, the following requirements are to be met:

- the total load is supplied within 45 seconds from power failure on the main switchboard;
- the maximum step load is declared and demonstrated; and
- the power distribution system is designed such that the declared maximum step loading is not exceeded.

7.3.4 Compliance of time delays and loading sequence with the requirements of 7.3.2 is to be demonstrated at the ship's trials.

7.3.5 For alternating current installations, the permanent speed variation of the machines intended for parallel operation are to be equal within a tolerance of  $\pm 0.5$  per cent. Momentary speed variations with load changes in accordance with 7.3.1 are to return to and remain within one per cent of the final steady state speed. This should normally be accomplished within five but in no case more than eight seconds. For quality of power supplies, see Pt 6, Ch 2, 1.7.

# Oil Engines

# Part 5, Chapter 2

Section 7

## 7.4 Overspeed protective devices

7.4.1 Each main engine developing 220 kW (300 shp) or over which can be declutched or which drives a controllable pitch propeller, and also each auxiliary engine developing 220 kW (300 shp) and over for driving an electric generator, is to be fitted with an approved overspeed protective device.

7.4.2 The overspeed protective device, including its driving mechanism, is to be independent of the governor required by 7.2 or 7.3 and is to be so adjusted that the speed does not exceed that for which the engine and its driven machinery are to be classed by more than 20 per cent for main engines and 15 per cent for auxiliary engines.

## 7.5 Unattended machinery

7.5.1 Where main and auxiliary diesel engines are fitted with automatic or remote controls so that under normal operating conditions they do not require any manual intervention by the operators, they are to be provided with the alarms and safety arrangements required by 7.5 to 7.7, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

7.5.2 Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions which could hazard the machinery.

7.5.3 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

7.5.4 Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm.

7.5.5 Means are to be provided to prevent leaks from high pressure oil fuel injection piping for main and auxiliary engines dripping or spraying onto hot surfaces or into machinery air inlets. Such leakage is to be collected and, where practicable, led to a collector tank(s) fitted in a safe position. An alarm is to be provided to indicate that leakage is taking place. These requirements may also be applicable to high pressure hydraulic oil piping, depending upon the location.

## 7.6 Oil engines for propulsion purposes

7.6.1 Alarms and safeguards are indicated in 7.6.2 to 7.6.8 and Tables 2.7.1(a) and (b).

7.6.2 Alarms are to operate for the fault conditions shown in Table 2.7.1(a). Where applicable, indication is to be given at the relevant control stations that the speed or power of the main propulsion engine(s) is to be manually reduced or has been reduced automatically.

7.6.3 Alarms are to operate, and automatic shut-down of machinery is to occur for the fault conditions shown in Table 2.7.1(b).

7.6.4 The following engine services are to be fitted with automatic temperature controls so as to maintain steady state conditions throughout the normal operating range of the propulsion engine(s).

- (a) Lubricating oil supply.
- (b) Oil fuel supply, see also 7.6.5.
- (c) Piston coolant supply, where applicable.
- (d) Cylinder coolant supply, where applicable.
- (e) Fuel valve coolant supply, where applicable.

7.6.5 The oil fuel supply may be fitted with an automatic control for viscosity instead of the temperature control required by 7.6.4.

7.6.6 Indication of the starting air pressure is to be provided at each control station from which it is possible to start the main propulsion engine(s).

7.6.7 The number of automatic consecutive attempts which fail to produce a start is to be limited to three. For reversible engines which are started and stopped for manoeuvring purposes, means are to be provided to maintain sufficient starting air in the air receivers. For electric starting, see 16.4.

7.6.8 Prolonged running in a restricted speed range is to be prevented automatically or, alternatively, an indication of restricted speed ranges is to be provided at each control station.

## 7.7 Auxiliary engines

7.7.1 Alarms and safeguards are indicated in Table 2.7.2.

7.7.2 For engines operating on heavy oil fuel, automatic temperature or viscosity controls are to be provided.

## 7.8 Emergency diesel engines

7.8.1 Alarms and safeguards are to be fitted in accordance with Table 2.7.3.

7.8.2 The safety and alarm systems are to be designed to 'fail safe'. The characteristics of the 'fail safe' operation are to be evaluated on the basis not only of the system and its associated machinery, but also the complete installation, as well as the ship.

7.8.3 Regardless of the engine output power, if shut-downs additional to those specified in Table 2.7.3 are provided except for the overspeed shut-down, they are to be automatically overridden when the engine is in automatic or remote control mode during navigation.

7.8.4 Grouped alarms of at least those items listed in Table 2.7.3 are to be arranged on the bridge.

# Oil Engines

## Part 5, Chapter 2

Section 7

**Table 2.7.1(a) Oil engines for propulsion purposes: Alarms and slow-downs** (see continuation)

Item	Alarm	Note
Lubricating oil sump level	Low	Engines
Lubricating oil inlet pressure*	1st stage low	Engines. Slow-down
Lubricating oil inlet temperature*	High	Engines
Lubricating oil filters differential pressure	High	—
Oil mist concentration in crankcase or bearing temperature	High	Automatic slow-down of slow speed engines, see 7.1.2. One sensor per lubricator unit. Slow-down (automatic on medium and high speed engines)
Cylinder lubricator flow	Low	
Thrust bearing temperature*	High	Slow-down
Common rail servo oil pressure	Low	—
Piston coolant inlet pressure	Low	If a separate system. Slow-down
Piston coolant outlet temperature*	High	Per cylinder (if a separate system). Slow-down
Piston coolant outlet flow*	Low	Per cylinder (if a separate system)
Cylinder coolant inlet pressure or flow*	Low	Slow-down (automatic on medium and high speed engines)
Cylinder coolant outlet temperature*	1st stage high	Per cylinder (if a separate system). Slow-down (automatic on medium and high speed engines)
Engine cooling water system – oil content	High	Where engine cooling water used in oil/water heat exchangers
Sea-water cooling pressure	Low	—
Fuel valve coolant pressure	Low	If a separate system
Fuel valve coolant temperature	High	If a separate system
Oil fuel pressure from booster pump	Low	—
Oil fuel temperature or viscosity*	High and Low	Heavy oil only
Oil fuel high pressure piping*	Leakage	See 7.5.5
Common rail fuel oil pressure	Low	—
Charge air cooler outlet temperature	High and Low	4-stroke medium and high speed engines
Scavenge air temperature (fire)	High	Per cylinder (2-stroke engines). Slow-down
Scavenge air receiver water level	High	—

7.8.5 In addition to the fuel oil control from outside the space, a local means of engine shut-down is to be provided.

7.8.6 Local indications of at least those items listed in Table 2.7.3 are to be provided within the same space as the diesel engines and are to remain operational in the event of failure of the alarm and safety systems.

# Oil Engines

## Part 5, Chapter 2

Section 7

**Table 2.7.1(a) Oil engines for propulsion purposes: Alarms and slow-downs (conclusion)**

Item	Alarm	Note
Exhaust gas temperature*	High	Per cylinder. Slow-down (automatic on medium and high speed engines), see Note 5
Exhaust gas temperature deviation from average*	High	Per cylinder, see Note 5
Turbo-charger exhaust gas inlet temperature	High	Each turbo-charger See Note 6
Turbo-charger exhaust gas outlet temperature*	High	Each turbo-charger
Turbo-charger lubricating oil inlet pressure	Low	If system not integral with turbo-charger
Turbo-charger lubricating oil outlet temperature	High	Each bearing, if system not integral with turbo-charger. See Note 7
Starting air pressure*	Low	Before engine manoeuvring valve
Control air pressure	Low	—
Direction of rotation	Wrong way	Reversible engines, see also 7.6.7
Automatic start of engine	Failure	See 7.6.7
Electrical starting battery charge level	Low	—
Feed water or water/thermal fluid forced circulation flow (if fitted)	Low	See Ch 14,6.2.7 and Note 8
Uptake temperature	High	To monitor for soot fires. See Notes 8 and 9
<p>NOTES</p> <ol style="list-style-type: none"> <li>Where 'per cylinder' appears in this Table, suitable sensors may be situated on manifold outlets for medium and high speed engines.</li> <li>For engines and gearing of 1500 kW or less, only the items marked* are required.</li> <li>Common sensors are acceptable for alarms and slow-down functions.</li> <li>Except where stated otherwise in the Table, slow-down may be effected by either manual or automatic means, by reduction of speed or power as appropriate.</li> <li>For medium and high speed engine power &lt;500 kW/cylinder, a common sensor for exhaust gas manifold temperature may be fitted.</li> <li>May be combined with exhaust gas outlet temperature high alarm where the turbo-charger is mounted directly on the exhaust manifold.</li> <li>Where the outlet temperature for each bearing cannot be measured due to the design, details of alternative proposals in accordance with the turbo-charger manufacturer's instructions may be submitted for consideration.</li> <li>Alarm only required when an exhaust gas economiser/boiler/thermal oil heater is fitted.</li> <li>Alternatively, details of an appropriate fire detection system are to be submitted for consideration.</li> </ol>		

**Table 2.7.1(b) Oil engines for propulsion purposes: Alarms and slow-downs**

Item	Alarm	Note
Lubricating oil inlet pressure	2nd stage low	Automatic shut-down of engines, see 7.5.4
Oil mist concentration in crankcase or bearing temperature	High	Automatic shut-down of medium and high speed engines, see 7.1.2
Cylinder coolant outlet temperature	2nd stage high	Automatic shut-down of medium and high speed engines, see 7.5.4
Overspeed	High	Automatic shut-down of engine, see also 7.4. Details of alternative proposals in accordance with the manufacturer's instructions may be submitted for consideration

## Oil Engines

## Part 5, Chapter 2

Section 7

**Table 2.7.2 Auxiliary engines: Alarms and safeguards**

Item	Alarm	Note
Lubricating oil inlet temperature	High	—
Lubricating oil inlet pressure	1st stage low	—
	2nd stage low	Automatic shut-down of engine, <i>see</i> 7.5.4
Oil mist concentration in crankcase or bearing temperature	High	Automatic shut-down of engine, <i>see</i> 7.1.2
Oil fuel high pressure piping	Leakage	<i>See</i> 7.5.5
Coolant outlet temperature (for engines >220 kW)	1st stage high	—
	2nd stage high	Automatic shut-down of engine, <i>see</i> 7.5.4
Coolant pressure or flow	Low	—
Oil fuel temperature or viscosity	High and Low	Heavy oil only
Overspeed	High	Automatic shut-down of engine, <i>see also</i> 7.4. Details of alternative proposals in accordance with the manufacturer's instructions may be submitted for consideration
Common rail servo oil pressure	Low	—
Common rail fuel oil pressure	Low	—
Starting air pressure	Low	—
Electrical starting battery charge level	Low	—
Exhaust gas temperature (for engines >500 kW/cylinder)	High	Per cylinder.
Feed water or water/thermal fluid forced circulation flow (if fitted)	Low	<i>See</i> Ch 14,6.2.7 and Note 3
Uptake temperature	High	To monitor for soot fires. <i>See</i> Notes 3 and 4
NOTES		
1. For emergency diesel engines, including engines used for the emergency source of electrical power required by SOLAS, <i>see</i> Ch 2,16.		
2. The arrangements are to comply with the requirements of the National Authority concerned.		
3. Alarm only required when an exhaust gas economiser/boiler/thermal oil heater is fitted.		
4. Alternatively, details of an appropriate fire detection system are to be submitted for consideration.		

**Table 2.7.3 Emergency diesel engines: Alarms and safeguards**

Item	Alarm for engine power <220 kW	Alarm for engine power ≤ 220kW	Note
Fuel oil leakage from pressure pipes	Leakage	Leakage	<i>See</i> 7.1.2
Lubricating oil temperature	—	High	—
Lubricating oil pressure	Low	Low	—
Oil mist concentration in crankcase	—	High	<i>See</i> Note
Coolant pressure or flow	—	Low	—
Coolant temperature (can be air)	High	High	—
Overspeed	—	High	Automatic shut-down
NOTE			
For engines having a power of more than 2250 kW or a cylinder bore of more than 300 mm.			

# Oil Engines

## Part 5, Chapter 2

Section 8

### ■ Section 8 Piping

#### 8.1 Oil fuel, hydraulic and high pressure oil systems

8.1.1 Oil fuel and hydraulic oil piping systems arrangements are to comply with Chapters 12 and 14 as applicable.

8.1.2 Oil fuel pipe systems in general, tanks and their fittings are to comply with the requirements of Chapter 14 and Part 3.

8.1.3 Where pumps are essential for engine operation, not less than two oil fuel and two hydraulic oil pressure pumps are to be provided for their respective service and arranged such that failure of one pump does not render the other inoperative. Each oil fuel pump and hydraulic oil pump is to be capable of supplying the quantity of oil for engine operation at its maximum continuous rating and arranged ready for immediate use.

8.1.4 All external high pressure fuel delivery lines between the high pressure fuel pumps and fuel injectors are to be protected with a jacketed piping system capable of containing fuel from a high pressure line failure. If flexible hoses are used for shielding purposes, these arrangements are to be approved.

8.1.5 The hydraulic oil pressure piping between the high pressure hydraulic pumps and hydraulic actuators is to be protected with a jacketed piping system capable of containing hydraulic oil leakage from a high pressure pipe failure.

8.1.6 Where flammable oils are used in high pressure systems, the oil pipe lines between the high pressure oil pump and actuating oil pistons are to be protected with a jacketed piping system capable of preventing oil spray from a high-pressure line failure.

8.1.7 Accumulators and associated high pressure piping are to be designed, manufactured and tested in accordance with a standard applicable to the maximum pressure and temperature rating of the system.

8.1.8 Diesel engine fuel system components are to be designed to accommodate the maximum peak pressures experienced in service. In particular this applies to the fuel injection pump supply and spill line piping which may be subject to high-pressure pulses from the pump. Connections on such piping systems should be chosen to minimise the risk of pressurised oil fuel leaks.

8.1.9 The protection is to prevent oil fuel or oil fuel mist from reaching a source of ignition on the engine or its surroundings. Suitable drainage arrangements are to be made for draining any oil fuel leakage to collector tank(s) fitted in a safe position. An alarm is to be provided to indicate that leakage is taking place.

8.1.10 Where multi-engined installations are supplied from the same fuel source, means of isolating the fuel supply and spill piping to individual engines are to be provided. These means of isolation are not to affect the operation of the other engines and are to be operable from a position not rendered inaccessible by a fire on any of the engines.

8.1.11 All valves, cocks and screwed connections are to be of a type-tested type applicable to the maximum service conditions anticipated in normal service.

8.1.12 Isolating valves and cocks are to be located as near as practicable to the equipment to be isolated. All valves forming part of the oil fuel and hydraulic oil installation are to be capable of being controlled from readily accessible positions above the working platform.

8.1.13 High pressure oil fuel and high pressure hydraulic oil piping systems are to be provided with high pressure alarms with set points that do not exceed the system design pressures.

8.1.14 High pressure oil fuel and high pressure hydraulic piping systems are to be provided with suitable relief valves on any part of the system that can be isolated and in which pressure can be generated. The settings of the relief valves are not to exceed the design pressures. The valves are to be of adequate size and so arranged as to avoid an undue rise in pressure above the design pressures.

8.1.15 Equipment fitted for monitoring pressures and temperatures in the high pressure oil fuel and high pressure hydraulic oil systems is to comply with a Recognised Standard suitable to the anticipated vibration and temperature conditions.

8.1.16 A fatigue analysis is to be carried out in accordance with a standard applicable to the system under consideration and all anticipated pressure, pulsation and vibration loads are to be addressed. The analysis is to demonstrate that the design and arrangements are such that the likelihood of failure is as low as reasonably practicable. The analysis is to identify all assumptions made and standards to be applied during manufacture and testing of the system. Any potential weak points which may develop due to incorrect construction or assembly are also to be identified.

8.1.17 For high pressure oil containing and mechanical power transmission systems, the quality plan for sourcing, design, installation and testing of components is to address the following issues:

- (a) Design and manufacturing standard(s) applied.
- (b) Materials used for construction of key components and their sources.
- (c) Details of the quality control system applied during manufacture and testing.
- (d) Details of type approval, type testing or approved type status assigned to the machinery or equipment.
- (e) Details of installation and testing recommendations for the machinery or equipment.



## 8.2 Exhaust systems

8.2.1 Where the surface temperature of the exhaust pipes and silencer may exceed 220°C, they are to be water cooled or efficiently lagged to minimise the risk of fire and to prevent damage by heat. Where lagging covering the exhaust piping system including flanges is oil-absorbing or may permit penetration of oil, the lagging is to be encased in sheet metal or equivalent. In locations where the Surveyor is satisfied that oil impingement could not occur, the lagging need not be encased.

8.2.2 Where the exhaust is led overboard near the waterline, means are to be provided to prevent water from being siphoned back to the engine. Where the exhaust is cooled by water spray, the exhaust pipes are to be self-draining overboard.

8.2.3 Where the exhausts of two or more engines are led to a common silencer or exhaust gas-heated boiler or economiser, an isolating device is to be provided in each exhaust pipe.

8.2.4 For alternatively fired furnaces of boilers using exhaust gases and oil fuel, the exhaust gas inlet pipe is to be provided with an isolating device and interlocking arrangements whereby oil fuel can only be supplied to the burners when the isolating device is closed to the boiler.

8.2.5 In two-stroke main engines fitted with exhaust gas turbo-blowers which operate on the impulse system, provision is to be made to prevent broken piston rings entering the turbine casing and causing damage to blades and nozzle rings.

## 8.3 Starting air pipe systems and safety fittings

8.3.1 In designing the compressed air installation, care is to be taken that the compressor air inlets will be located in an atmosphere reasonably free from oil vapour or, alternatively, an air duct from outside the machinery space is to be led to the compressors.

8.3.2 The air discharge pipe from the compressors is to be led direct to the starting air receivers. Provision is to be made for intercepting and draining oil and water in the air discharge for which purpose a separator or filter is to be fitted in the discharge pipe between compressors and receivers.

8.3.3 The starting air pipe system from receivers to main and auxiliary engines is to be entirely separate from the compressor discharge pipe system. Stop valves on the receivers are to permit slow opening to avoid sudden pressure rises in the piping system. Valve chests and fittings in the piping system are to be of ductile material.

8.3.4 Drain valves for removing accumulations of oil and water are to be fitted on compressors, separators, filters and receivers. In the case of any low-level pipelines, drain valves are to be fitted to suitably located drain pots or separators.

8.3.5 The starting air piping system is to be protected against the effects of explosions by providing an isolating non-return valve or equivalent at the starting air supply to each engine.

8.3.6 In direct reversing engines bursting discs or flame arresters are to be fitted at the starting valves on each cylinder; in non-reversing and auxiliary engines at least one such device is to be fitted at the supply inlet to the starting air manifold on each engine. The fitting of bursting discs or flame arresters may be waived in engines where the cylinder bore does not exceed 230 mm.

8.3.7 Alternative safety arrangements may be submitted for consideration.

## Section 9 Starting arrangements

### 9.1 Dead ship condition starting arrangements

9.1.1 Means are to be provided to ensure that machinery can be brought into operation from the dead ship condition without external aid.

9.1.2 Dead ship condition for the purpose of 9.1.1 is to be understood to mean a condition under which the main propulsion plant, boilers and auxiliaries are not in operation. In restoring propulsion, no stored energy for starting and operating the propulsion plant is assumed to be available. Additionally, neither the main source of electrical power nor other essential auxiliaries are assumed to be available for starting and operating the propulsion plant.

9.1.3 Where the emergency source of power is an emergency generator which fully complies with the requirements of Pt 6, Ch 2, this generator may be used for restoring operation of the main propulsion plant, boilers and auxiliaries where any power supplies necessary for engine operation are also protected to a similar level as the starting arrangements.

9.1.4 Where there is no emergency generator installed or an emergency generator does not comply with Pt 6, Ch 2, the arrangements for bringing main and auxiliary machinery into operation are to be such that the initial charge of starting air or initial electrical power and any power supplies for engine operation can be developed on board ship without external aid. If for this purpose an emergency air compressor or an electric generator is required, these units are to be powered by a hand-starting oil engine or a hand-operated compressor. The arrangements for bringing main and auxiliary machinery into operation are to have capacity such that the starting energy and any power supplies for engine operation are available within 30 minutes of a dead ship condition.

9.1.5 For cargo ships of less than 500 gross tons and which are not required to comply with the *International Convention for the Safety of Life at Sea, 1974*, as amended (SOLAS 74), alternative arrangements to those specified in 9.1.3 or 9.1.4 may be proposed for consideration. Details of the alternative arrangements are to be included in the plans and details required by 1.1.5 and are to demonstrate that the arrangements provide for starting from the dead ship condition and are in accordance with any applicable statutory requirements of the National Authority of the country in which the ship is to be registered.

# Oil Engines

## Part 5, Chapter 2

Section 9

### 9.2 Air receiver capacity

9.2.1 Where the main engine is arranged for air starting the total air receiver capacity is to be sufficient to provide without replenishment, not less than 12 consecutive starts of the main engine, alternating between ahead and astern if of the reversible type and not less than 6 consecutive starts if of the non-reversible type. At least two air receivers of approximately equal capacity are to be provided. For scantlings and fittings of air receivers, see Chapter 11.

9.2.2 For multi-engine installations, the number of starts required for each engine are to be as follows:

- (a) Two engines through common reduction gearing:  
6 starts per engine for fixed pitch propeller/propellers;  
3 starts per engine for controllable pitch propeller/propellers.
- (b) Three engines or more through common reduction gearing:  
3 starts per engine.

9.2.3 No engine is to have fewer than 3 starts for any arrangement. For electric propulsion arrangements, a minimum of 3 starts per engine with a minimum capacity of 12 starts of the largest start air consumption engine in total are required.

### 9.3 Electric starting

9.3.1 Where main engines are fitted with electric starters, two batteries are to be fitted. Each battery is to be capable of starting the engines when cold and the combined capacity is to be sufficient without recharging to provide the number of starts of the main engines as required by 9.2. In other respects batteries are to comply with the requirements of Pt 6, Ch 2, 11.

9.3.2 Electric starting arrangements for auxiliary engines are to have two separate batteries or be supplied by separate circuits from the main engine batteries when such are provided. Where one of the auxiliary engines only is fitted with an electric starter one battery will be acceptable.

9.3.3 The combined capacity of the batteries for starting the auxiliary engines is to be sufficient for at least three starts for each engine.

9.3.4 Engine starting batteries are to be used only for the purposes of starting the engines and for the engines' own control, alarm, monitoring and safety arrangements. Means are to be provided to ensure that the stored energy in the batteries is maintained at a level required to start the engines, as defined in 9.3.1 and 9.3.3.

9.3.5 Where engines are fitted with electric starting batteries, an alarm is to be provided for low battery charge level.

9.3.6 For cargo ships of less than 500 gross tons which are not required to comply with the *International Convention for the Safety of Life at Sea, 1974*, as amended (SOLAS 74), the emergency source of electrical power may be used as one of the sources of energy required by 9.3.1 or 9.3.2 for electric starting. Where the emergency source of electrical power is an accumulator battery and it is to be used for

electric starting, it is to have the additional capacity required to ensure emergency supplies are not compromised and is to be adequately protected and suitably located for use in an emergency.

### 9.4 Starting of the emergency source of power

9.4.1 Emergency generators are to be capable of being readily started in their cold conditions down to a temperature of 0°C. If this is impracticable, or if lower temperatures are likely to be encountered, consideration is to be given to the provision and maintenance of heating arrangements, so that ready starting will be assured.

9.4.2 Each emergency generator that is arranged to be automatically started is to be equipped with an approved starting system having two independent sources of stored energy, each of which is sufficient for at least three consecutive starts. When hand (manual) starting is demonstrated to be effective, only one source of stored energy need be provided. However, this source of stored energy is to be protected against depletion below the level required for starting.

9.4.3 Provision is to be made to maintain continuously the stored energy at all times, and for this purpose:

- (a) Electrical and hydraulic starting systems are to be maintained from the emergency switchboard.
- (b) Compressed air starting systems may be maintained by the main or auxiliary compressed air receivers, through a suitable non-return valve, or by an emergency air compressor energised by the emergency switchboard.
- (c) All these starting, charging and energy storing devices are to be located in the emergency generator room. These devices are not to be used for any purpose other than the operation of the emergency generator.

9.4.4 When automatic starting is not required by the Rules and where it can be demonstrated as being effective, hand (manual) starting is permissible, such as manual cranking, inertial starters, manual hydraulic accumulators, powder charge cartridges.

9.4.5 When hand (manual) starting is not practicable, the provisions under 9.4.2 and 9.4.3 are to be complied with except that starting may be manually initiated.

9.4.6 Electric starting arrangements are also to satisfy 9.3.2 to 9.3.5.

### 9.5 Engine control, alarm monitoring and safety system power supplies

9.5.1 Power supplies are to be arranged so that power for electrically powered control, alarm, monitoring and safety systems required for engine starting and operation will remain available in the event of a failure. Power is to remain available to permit starting attempts for the number of starts specified by this Section for each individual source of stored energy.

9.5.2 Where adequate battery and charging capacity exists, an engine starting battery may be used as one source of electrical power required by 9.5.1.



9.5.3 An alarm is to be activated in the event of failure of a power supply and, where applicable, low battery charge level. Manual power supply changeover facilities are permitted.

## Section 10 Safety arrangements

### 10.1 Relief valves

10.1.1 Scavenge spaces in open connection with cylinders are to be provided with explosion relief valves.

10.1.2 Crankcases are to be provided with lightweight spring-loaded valves or other quick-acting and self-closing devices, to relieve the crankcases of pressure in the event of an internal explosion and to prevent any inrush of air thereafter. The valves are to be designed and constructed to open quickly and be fully open at a pressure not greater than 0,2 bar.

10.1.3 The valve lids are to be made of ductile material capable of withstanding the shock of contact with stoppers at the full open position.

10.1.4 Each valve is to be fitted with a flame arrester that permits flow for crankcase pressure relief and prevents the passage of flame following a crankcase explosion. The valves are to be type tested in a configuration that represent the installation arrangements that will be used on an engine and in accordance with Section 18. The valves are to be positioned on engines to minimise the possibility of danger and damage arising from emission of the crankcase atmosphere. Where shielding from the emissions is fitted to a valve, the valve is to be type tested to demonstrate that the shielding does not adversely affect the operational effectiveness of the valve.

10.1.5 The valves are to be provided with a copy of the manufacturer's installation and maintenance manual for the size and type of valve being supplied for installation on a particular engine. The manual is to contain the following information:

- Description of valve with details of function and design limits.
- Copy of type test certification.
- Installation instructions.
- Maintenance and in service instructions to include testing and renewal of any sealing arrangements.
- Actions required after a crankcase explosion.

10.1.6 A copy of the installation and maintenance manual required by 10.1.5 is to be provided on board the ship.

10.1.7 Plans showing details and arrangements of the relief valves are to be submitted for approval, see 1.1.

10.1.8 The valves are to be provided with suitable markings that include the following information:

- Name and address of manufacturer.
- Designation and size.
- Month/Year of manufacture.
- Approved installation orientation.

### 10.2 Number of relief valves

10.2.1 In engines having cylinders not exceeding 200 mm bore or having a crankcase gross volume not exceeding 0,6 m<sup>3</sup>, relief valves may be omitted.

10.2.2 In engines having cylinders exceeding 200 mm but not exceeding 250 mm bore, at least two relief valves are to be fitted; each valve is to be located at or near the ends of the crankcase. Where the engine has more than eight crankthrows an additional valve is to be fitted near the centre of the engine.

10.2.3 In engines having cylinders exceeding 250 mm but not exceeding 300 mm bore, at least one relief valve is to be fitted in way of each alternate crankthrow with a minimum of two valves. For engines having 3, 5, 7, 9, etc., crankthrows, the number of relief valves is not to be less than 2, 3, 4, 5, etc., respectively.

10.2.4 In engines having cylinders exceeding 300 mm bore at least one valve is to be fitted in way of each main crankthrow.

10.2.5 Additional relief valves are to be fitted for separate spaces on the crankcase, such as gear or chaincases for camshaft or similar drives, when the gross volume of such spaces exceeds 0,6 m<sup>3</sup>.

### 10.3 Size of relief valves

10.3.1 The combined free area of the crankcase relief valves fitted on an engine is to be not less than 115 cm<sup>2</sup>/m<sup>3</sup> based on the volume of the crankcase.

10.3.2 The free area of each relief valve is to be not less than 45 cm<sup>2</sup>.

10.3.3 The free area of the relief valve is the minimum flow area at any section through the valve when the valve is fully open.

10.3.4 In determining the volume of the crankcase for the purpose of calculating the combined free area of the crankcase relief valves, the volume of the stationary parts within the crankcase may be deducted from the total internal volume of the crankcase.

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Section 10

## 10.4 Vent pipes

**10.4.1** Through ventilation, and any arrangement which could produce a flow of external air within the crankcase, is in principle not permitted except for trunk piston type dual fuel engines where crankcase ventilation is to be provided. Where crankcase vent or breather pipes are fitted, they are to be made as small as practicable and/or as long as possible to minimise the inrush of air after an explosion. Vents or breather pipes from crankcases of main engines are to be led to a safe position on deck or other approved position.

**10.4.2** If provision is made for the extraction of gases from within the crankcase, e.g. for oil mist detection purposes, the vacuum within the crankcase is not to exceed 25 mm of water.

**10.4.3** Lubricating oil drain pipes from engine sump to drain tank are to be submerged at their outlet ends. Where two or more engines are installed, vent pipes, if fitted, and lubrication oil drain pipes are to be independent to avoid intercommunication between crankcases.

## 10.5 Warning notice

**10.5.1** A warning notice is to be fitted in a prominent position, preferably on a crankcase door on each side of the engine, or alternatively at the engine room control station. This warning notice is to specify that whenever overheating is suspected in the crankcase, the crankcase doors or sight holes are not to be opened until a reasonable time has elapsed after stopping the engine, sufficient to permit adequate cooling within the crankcase.

## 10.6 Crankcase access and lighting

**10.6.1** Where access to crankcase spaces is necessary for inspection purposes, suitably positioned rungs or equivalent arrangements are to be provided as considered appropriate.

**10.6.2** When interior lighting is provided it is to be flame-proof in relation to the interior and details are to be submitted for approval. No wiring is to be fitted inside the crankcase.

## 10.7 Fire-extinguishing system for scavenge manifolds

**10.7.1** Crosshead type engine scavenge spaces in open connection with cylinders are to be provided with approved fixed or portable fire-extinguishing arrangements which are to be independent of the fire-extinguishing system of the engine room.

## 10.8 Oil mist detection

**10.8.1** Where crankcase oil mist detection arrangements are fitted, they are to be of a type approved by LR, tested in accordance with Section 19 and comply with 10.8.2 to 10.8.15.

**10.8.2** The oil mist detection system and arrangements are to be installed in accordance with the engine designer's and oil mist detection equipment manufacturer's instructions/recommendations. The following particulars are to be included in the instructions:

- (a) A schematic layout of the engine oil mist detection and alarm system showing locations of engine crankcase sample points and cabling/piping arrangements together with pipe dimensions to the detector.
- (b) Evidence of study to justify the selected locations of sample points and sample extraction rate (if applicable) in consideration of the crankcase arrangements and geometry and the predicted crankcase atmosphere where oil mist can accumulate.
- (c) The manufacturer's maintenance and test manual.
- (d) Information relating to type or in-service testing of the engine with engine protection system test arrangements having approved types of oil mist detection equipment.

**10.8.3** A copy of the oil mist detection equipment maintenance and test manual required by 10.8.2 is to be provided on board ship.

**10.8.4** Oil mist detection and alarm information is to be capable of being read from a safe location away from the engine.

**10.8.5** In the case of multi engine installations, each engine is to be provided with individual, dedicated oil mist detection arrangements and alarm(s).

**10.8.6** Oil mist detection and alarm systems are to be capable of being tested on the test bed and on board when the engine is at a standstill and when the engine is running at normal operating conditions in accordance with test procedures that are acceptable to LR.

**10.8.7** Alarms and safeguards for the oil mist detection system are to be in accordance with Pt 6, Ch 1 as applicable.

**10.8.8** The oil mist detection arrangements are to provide an alarm indication in the event of a foreseeable functional failure in the equipment and installation arrangements. See Pt 6, Ch 1,2.4.6.

**10.8.9** The oil mist detection system is to provide an indication that any lenses fitted in the equipment and used in determination of the oil mist level have been partially obscured to a degree that will affect the reliability of the information and alarm indication.

**10.8.10** Where oil mist detection equipment includes the use of programmable electronic systems, the arrangements are to be in accordance with Pt 6, Ch 1 as applicable.

**10.8.11** Schematic layouts showing details and arrangements of oil mist detection and alarm systems are to be submitted. See Pt 5, Ch 1,1.

**10.8.12** The equipment together with detectors is to be tested when installed on the test bed and on board ship to demonstrate that the detection and alarm system functions correctly. The testing arrangements are to be to the satisfaction of the Surveyor.

10.8.13 Where sequential oil mist detection arrangements are provided, the sampling frequency and time is to be as short as reasonably practicable.

10.8.14 Where alternative methods are provided for the prevention of the build-up of oil mist that may lead to a potentially explosive condition within the crankcase, detailed information is to be submitted for consideration. The information is to include:

- (a) Engine particulars – type, power, speed, stroke, bore and crankcase volume.
- (b) Details of arrangements designed to prevent the build up of potentially explosive conditions within the crankcase, e.g., bearing temperature monitoring, oil splash temperature monitoring, crankcase pressure monitoring, and recirculation arrangements.
- (c) Evidence to demonstrate that the arrangements are effective in preventing the build up of potentially explosive conditions together with details of in-service experience.
- (d) Operating instructions and the maintenance and test instructions.

10.8.15 Where it is proposed to use the introduction of inert gas into the crankcase to minimise a potential crankcase explosion, details of the arrangements are to be submitted for consideration.

## ■ Section 11 Program for trials of diesel engines to assess operational capability

### 11.1 Works trials (acceptance test)

11.1.1 Diesel engines which are to be subjected to trials on the test bed at the manufacturer's works and under attendance by the Surveyor(s) are to be tested in accordance with the scope of works trials specified in 11.1.2 to 11.1.10. The scope of the trials is to be agreed between the LR Surveyor and the manufacturer prior to testing. At the discretion of the Surveyor, the scope of the trials may be extended depending on the engine application.

11.1.2 For electronically controlled engines:

- (a) works tests in accordance with 1.1.6(h); and
- (b) verification of engine configuration, see 4.3.2, and that the approved software quality plans, including the software configuration management process, are being applied.

11.1.3 For all stages of the works trials the pertaining operation values are to be measured and recorded by the engine manufacturer. All results are to be compiled in an acceptance protocol to be issued by the engine manufacturer.

11.1.4 In each case given in Table 2.11.1, all measurements conducted at the various load points shall be carried out at steady operating conditions. The readings for 100 per cent power (rated power at rated speed) are to be taken twice at an interval of at least 30 minutes.

11.1.5 The data to be measured and recorded, when testing the engine at various load points, are to include all necessary parameters for the engine operation. The crankshaft deflection is to be checked when this check is required by the manufacturer during the operating life of the engine. Crankshaft deflection measurements are to be taken before (cold condition) and after (hot condition) works acceptance trials.

11.1.6 Checks of components to be presented for inspection after the works trials are left to the discretion of the Surveyor.

11.1.7 The Surveyor may require that after the trials the fuel delivery system is restricted so as to limit the engines to run at not more than 100 per cent power. The setting of the restriction is to be made as applicable to the intended fuel. Any restriction settings, and other changes to the engine's fuel injection equipment required for operation on special fuels, are to be recorded and included by the engine manufacturer.

11.1.8 For the duration of the acceptance test, no interventions or adjustments will be made to the machinery under test.

11.1.9 The testing of exhaust gas emissions is to comply with MARPOL as applicable.

11.1.10 For all stages that the engine is to be tested and where no duration is specified in Table 2.11.1, the load point is to be maintained for a sufficient period to allow pertaining values to be measured and recorded when the engine has achieved a steady operating condition.

### 11.2 Shipboard trials

11.2.1 After the conclusion of the running-in programme prescribed by the engine manufacturer, engines are to undergo shipboard trials as specified in Table 2.11.2. The scope of the trials is to be agreed between the LR Surveyor and the Shipyard prior to testing.

11.2.2 Engines driving generators or important auxiliaries are to be subjected to an operational test for at least 4 hours. During the test, the set concerned is required to operate at its rated power for an extended period. It is to be demonstrated that the engine is capable of supplying 100 per cent of its rated power, and in the case of shipboard generating sets account shall be taken of the times needed to actuate the generator's overload protection system.

11.2.3 In addition to 11.2.2, for engines driving generators for electric propulsion motors as well as auxiliaries, an operational test is to be carried out of at least 4 hours duration at a load which corresponds to 100 per cent of the electric propulsion motor(s) rated power. The astern/ahead manoeuvring capability of the propulsion system is to be demonstrated.

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Section 11

**Table 2.11.1 Scope of works trials for diesel engines**

Main engines driving propellers and waterjets		
Trial condition	Duration	Note
100% power (rated power) at rated engine speed, $R$	$\geq 60$ minutes	After having reached steady conditions
110% power at engine speed corresponding to $1,032 \cdot R$	30–45 minutes	After having reached steady conditions (1)
90% (or maximum continuous power), 75%, 50% and 25%	—	Powers in accordance with the nominal propeller curve
Starting and reversing manoeuvres	—	—
Testing of governor and independent overspeed protective device	—	See 7.2
Shut down device	—	See 7.4
Engines driving generators		
Trial condition	Duration	Note
100% power (rated power) at rated engine speed, $R$	$\geq 50$ minutes	After having reached steady conditions (2)
110% power	30 minutes	After having reached steady conditions (2) (3)
75%, 50% and 25% power and idle run	—	(2)
Start-up tests	—	—
Testing of governor and independent overspeed protective device	—	See 7.3
Shut-down device	—	See 7.4
<b>NOTES</b> 1. After running on the test bed, the fuel delivery system of main engines is normally to be so adjusted that overload power cannot be given in service. 2. The test is to be performed at rated speed with a constant governor setting. 3. After running on the test bed, the fuel delivery system of diesel engines driving generators must be adjusted such that overload (110%) power can be given in service after installation on board, so that the governing characteristics including the activation of generator protective devices can be fulfilled at all times.		

**11.2.4** Trials are to include demonstration of engine control, monitoring, alarm and safety system operation to confirm that they have been provided, installed and configured as intended and in accordance with the relevant requirements for main, auxiliary or emergency engines.

**11.2.5** For electronically controlled engines:

- shipboard tests in accordance with 1.1.6(h); and
- verification of engine configuration, see 4.3.2, and that the approved software quality plans, including the software configuration management process, are being applied.

**11.2.6** The suitability of an engine to burn residual or other special fuels is to be demonstrated, if the machinery installation is arranged to burn such fuels in service. See also Pt 6, Ch 1,7.2.1.

**11.2.7** At the discretion of the attending Surveyor, the scope of the trials may be expanded in consideration of special operating conditions, such as towing, trawling, etc.

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## Part 5, Chapter 2

Section 11

**Table 2.11.2 Scope of shipboard trials for diesel engines**

Main engines driving fixed-pitch propellers (1) (2)		
Trial condition	Duration	Note
At rated engine speed, $R$	$\geq 4$ hours	—
At engine speed corresponding to normal continuous power	$\geq 2$ hours	—
At engine speed corresponding to $1,032 \cdot R$	30 minutes	Where the engine adjustment permits, see 11.1.7
At minimum on-load speed	—	—
Starting and reversing manoeuvres	—	See Sections 9 and 16
In reverse direction of propeller rotation during the dock or sea trials at a minimum engine speed of $0,7 \cdot R$	10 minutes	—
Control monitoring, alarms and safety systems	—	Operation to be demonstrated
Where imposed, test to ensure engine can pass safely through barred speed range	—	—
Single engine driving a generator for propulsion only		
Trial condition	Duration	Note
100% power (rated propulsion power), see 11.2.3	$\geq 4$ hours	(3) (4)
At normal continuous propulsion power	$\geq 2$ hours	(3) (4)
110% power (rated propulsion power)	30 minutes	—
In reverse direction of propeller rotation at a minimum speed of 70% of the nominal propeller speed	10 minutes	(3) (4)
Starting manoeuvres	—	—
Control monitoring, alarms and safety systems	—	Operation to be demonstrated
<b>NOTES</b> 1. For main propulsion engines driving controllable pitch propellers, waterjets or reversing gears, the tests for main engines driving fixed-pitch propellers apply as appropriate. 2. Controllable pitch propellers are to be tested with various propeller pitches. 3. The tests are to be performed at rated speed with a constant governor setting. 4. Tests are to be based on the rated electrical powers of the electric propulsion motors.		

## Section 12 Component tests

### 12.1 Hydraulic tests

12.1.1 In general, items are to be tested by hydraulic pressure as indicated in Table 2.12.1. Where design features are such that modifications to the test requirements shown in Table 2.12.1 are necessary, alternative proposals for hydraulic tests are to be submitted for special consideration.

12.1.2 Where a manufacturer has demonstrated to LR that they have an acceptable quality management system, a manufacturer's hydraulic test certificate may be accepted for engine driven pumps as detailed in Table 2.12.1. Recognition and acceptance of the works quality control processes can be by one of the following routes:

- Approval under the LR Quality Scheme for Machinery.
- Approval of an alternative quality scheme recognised by LR.
- Approval by LR through auditing of the manufacturer's quality system.

### 12.2 Alignment gauges

12.2.1 All main and auxiliary oil engines exceeding 220 kW (300 shp) are to be provided with an alignment gauge which may be either a bridge wear-down gauge, or a micro-meter clock gauge for use between the crankwebs. Only one micrometer clock gauge need be supplied for each ship provided the gauge is suitable for use on all engines.

### 12.3 Auto frettage

12.3.1 The following documents and information are to be submitted in support of components subject to autofrettage:

- Drawings and other related documents/information, including material grade, dimensions and autofrettage pressure.
- Calculations and tests undertaken to define pressures, times and other parameters relevant for the autofrettage process.
- Calculations and tests verifying increased fatigue endurance of components treated by autofrettage.
- Place of manufacture and sub-suppliers.
- Description of manufacturing QA process including control of suppliers.
- Description detailing how repeatability and reliability of autofrettage process is achieved.
- Methods and documents for recording results.
- Finished component and/or system testing.

12.3.2 LR certificates are to be issued for components subject to autofrettage, provided the attending Surveyors are satisfied that the accepted QA process has been applied.

**Table 2.12.1 Test pressures for oil engine components**

Item	Test pressure
Fuel injection system { Pump body, pressure side Valve Pipe }	The lesser of $1,5p$ or $p + 300$ bar
Cylinder cover, cooling space Cylinder liner, over the whole length of cooling space Piston crown, cooling space (where piston rod seals cooling space, test after assembly)	7,0 bar
Cylinder jacket, cooling space Exhaust valve, cooling space Turbo-charger, cooling space Exhaust pipe, cooling space Coolers, each side Engine driven pumps (oil, water, fuel, bilge)	The greater of 4,0 bar or $1,5p$
Air compressor, including cylinders, covers, intercoolers and aftercoolers	Air side: $1,5p$ Water side: The greater of 4,0 bar or $1,5p$
Scavenge pump cylinder	4,0 bar
Hydraulic systems (piping, pumps, actuators)	$1,5p$
<b>NOTES</b> 1. $p$ is the maximum working pressure in the item concerned. 2. Pumps used in jerk or timed pump systems need only have the assembled high pressure-containing components hydraulically tested. 3. Turbo-charger air coolers need only be tested on the water side. 4. For forged steel cylinder covers and piston crowns alternative testing methods may be specially considered. 5. For hydraulic systems where design features are such that modifications to the test requirements are necessary, alternative proposals for hydraulic tests are to be submitted for special consideration. 6. Where components are subjected to an autofrettage process approved by LR, the component test pressure may be omitted. The assembled system containing such components is to be shown, where practicable, to be pressure-tight as required for Hydraulic systems.	



## ■ Section 13 Mass produced engines

### 13.1 Definition

13.1.1 Mass produced engines, for main and auxiliary purposes, are defined as those which are produced under the following criteria:

- (a) In quantity under strict quality control of material and parts, according to a quality assurance scheme acceptable to LR.
- (b) By the use of jigs and automatic machine tools designed to machine parts to specified tolerances for interchangeability, and which are verified on a regular inspection basis.
- (c) By assembly with parts taken from stock and requiring little or no fitting.
- (d) With bench tests carried out on individual assembled engines according to a specified programme.
- (e) With appraisal by final examination of engines selected at random after workshop testing.

13.1.2 Castings, forgings and other parts for use in mass produced engines are also to be produced by methods similar to those given in 13.1.1(a), (b) and (c), with appropriate inspection.

13.1.3 Pressure testing of components is to comply with 12.1.1.

13.1.4 The specification of a mass produced engine is to define the limits of manufacture of all component parts. The total production output is to be certified by the manufacturer and verified as may be required, by LR in accordance with the agreed manufacturer's quality assurance scheme, see 13.1.1(a).

### 13.2 Procedure for approval of mass produced engines

13.2.1 The procedure outlined in 13.2.2 to 13.2.5 applies to the inspection and certification of mass produced oil engines having a bore not exceeding 300 mm.

13.2.2 For the approval of a mass produced engine type, the manufacturer is to submit:

- (a) The plans and particulars required by 1.1 for assessment.
- (b) The information required by 3.2 for assessment.
- (c) A list of subcontractors for main parts.
- (d) Procedures for the configuring of control, alarm monitoring and safety systems during engine commissioning.

13.2.3 The manufacturer is to supply full information regarding the manufacturing processes and quality control procedures applied in the workshops. The information is to address the following:

- (a) Organisation of quality control systems.
- (b) Recording of quality control operations.
- (c) Qualification and independence of personnel in charge of quality control.

13.2.4 A running type test of at least 100 hours duration is to be carried out on an engine chosen from the production line. The type testing is to comply with 13.5.

13.2.5 LR reserves the right to limit the duration of validity of approval of a mass produced engine. LR is to be informed, without delay, of any change in the design of the engine, including changes to the software and control, alarm monitoring or safety systems, in the manufacturing or quality control processes, in the selection of materials or in the list of subcontractors for main parts.

### 13.3 Continuous review of production

13.3.1 LR Surveyors are to be provided free access to the manufacturer's workshops and to the quality control files.

13.3.2 The control of production, which is subject to survey, is to include the following:

- (a) Inspection and testing records are to be maintained to the satisfaction of the Surveyor.
- (b) The system for identification of parts is to be in accordance with recognised practice, and acceptable to LR.
- (c) The manufacturer is to provide full information about the quality control of the parts supplied by subcontractors for which certification may be required. LR reserves the right to apply direct and individual inspection procedures for parts supplied by subcontractors when deemed necessary.
- (d) At the request of an attending LR Surveyor, a workshop test may be required for an individual engine.

### 13.4 Compliance and inspection certificate

13.4.1 Each engine which is to be installed on a ship classed by LR is to be supplied with a statement certifying that the engine is identical to the one which underwent the tests specified in 13.2.4, and state the test and inspection results. The statement is to be made on a form agreed with LR. Each statement is to include the identification number which appears on the engine. A copy of this statement is to be submitted to LR.

13.4.2 The certificate is to include reference to the manufacturer's procedures to be followed during commissioning for configuring control, alarm monitoring and safety systems for multi-purpose engines or other engine types that require parameters and settings to be adjusted for the intended application.

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Sections 14 & 15

## ■ Section 14 Turbo-chargers

### 14.1 Dynamic balancing

14.1.1 All rotors are to be dynamically balanced on final assembly to the Surveyor's satisfaction.

### 14.2 Overspeed test

14.2.1 All fully bladed rotor sections and impeller/inducer wheels are to be overspeed tested for three minutes at either 20 per cent above the maximum permissible speed at room temperature or 10 per cent above the maximum permissible speed at the normal working temperature.

### 14.3 Mechanical running test

14.3.1 Turbo-chargers are to be given a mechanical running test of 20 minutes duration at the maximum permissible speed.

14.3.2 Upon application, with details of an historical audit covering previous testing of turbo-chargers manufactured under an approved quality assurance scheme, consideration will be given to confining the test outlined in 14.3.1 to a representative sample of turbochargers.

15.2.3 The manufacturer will supply full information regarding the material and quality control system used in the organisation as well as the inspection methods, the way of recording and proposed frequency, and the method of material testing of important parts.

15.2.4 A Type test, see 14.2, is to be carried out on a standard unit taken from the assembly line and is to be witnessed by the Surveyor. The performance data which may have to be verified are to be made available at the time of the type test. For manufacturers who have facilities for testing the turbo-charger unit on an engine for which the turbo-charger is intended, substitution of the hot running test by a test run of one hour's duration at overload (110 per cent of the rated output) may be considered.

15.2.5 LR reserves the right to limit the duration of validity of approval of a mass produced turbo-charger. LR is to be informed, without delay, of any change in the design of the turbo-charger, in the manufacturing or control processes, in the selection of materials or in the list of subcontractors for main parts.

### 15.3 Continuous inspection of individual units

15.3.1 LR Surveyors are to be provided with free access to the manufacturer's workshop to inspect at random the quality control measures and to witness the tests required by 15.3.3 to 15.3.7 as deemed necessary, and to have free access to all control records and subcontractor's certificates.

15.3.2 Each individual unit is to be tested in accordance with 15.3.4 to 15.3.7 by the maker who is to issue a final certificate.

15.3.3 Rotating parts of the turbo-charger blower are to be marked for easy identification with the appropriate certificate.

15.3.4 Material tests of the rotating parts are to be carried out by the maker or his subcontractor in accordance with the requirements of the Rules for Materials as applicable. The relevant certificate is to be produced and filed to the satisfaction of the Surveyor.

15.3.5 Pressure tests are to be carried out in accordance with Table 2.12.1. Special consideration will be given where design or testing features may require modification of the test requirements.

15.3.6 Dynamic balancing and overspeed tests are to be carried out, see 14.1 and 14.2, in accordance with the approved procedure for quality control. If each forged wheel is individually controlled by an approved non-destructive examination method, then no overspeed test may be required except for wheels of the type test unit.

## ■ Section 15 Mass produced turbo-chargers

### 15.1 Application

15.1.1 The following procedure applies to the inspection of exhaust driven turbo-chargers which are manufactured on the basis of mass production methods similar to 13.1 as applicable and for which the maker has requested the approval.

### 15.2 Procedure for approval of mass produced turbo-chargers

15.2.1 The procedure outlined in 15.2.2 to 15.2.5 applies to the inspection and certification of mass produced turbo-chargers when a simplified method of inspection has been requested by the manufacturers.

15.2.2 For the approval of a mass produced turbo-charger, the manufacturer is to submit, in addition to the plans and particulars required by 1.1.10, a list of main current suppliers and subcontractors for rotating parts and an operation and maintenance manual.



15.3.7 A mechanical running test, see 14.3, is to be carried out. The duration of the running test may be reduced to 10 minutes provided that the manufacturer is able to verify the distribution of defects established during the running tests on the basis of a sufficient number of tested turbo-chargers. For manufacturers who have facilities in their works for testing the turbo-chargers on an engine for which the turbo-chargers are intended, the bench test may be replaced by a test run of 20 minutes at overload (110 per cent of the rated output) on this engine.

## 15.4 Compliance and certificate

15.4.1 For every turbo-charger unit liable to be installed on an engine intended for a ship classed by LR, the manufacturer is to supply a statement certifying that the turbo-charger is identical with one that underwent the tests specified in 15.2.4 and that prescribed tests were carried out. Results of these tests are to be also stated. This statement is to be made on a form agreed with LR and a copy is to be sent to LR. Each statement must have a number which is to appear on the turbo-charger.

## Section 16 Air compressors

### 16.1 General requirements

16.1.1 The requirements of this Section are applicable to reciprocating air compressors intended for starting main engines and auxiliary engines providing essential services.

16.1.2 Two or more air compressors are to be fitted having a total capacity, together with a topping-up compressor where fitted, capable of charging the air receivers within 1 hour from atmospheric pressure, to the pressure sufficient for the number of starts required by 16.12. At least one of the air compressors is to be independent of the main propulsion unit and the capacity of the main air compressors is to be approximately equally divided between them. The capacity of an emergency compressor which may be installed to satisfy the requirements of 9.1 is to be ignored.

16.1.3 The compressors are to be so designed that the temperature of the air discharged to the starting air receivers will not substantially exceed 93°C in service. A small fusible plug or an alarm device operating at 121°C is to be provided on each compressor to give warning of excessive air temperature. The emergency air compressor is excepted from these requirements.

16.1.4 Each compressor is to be fitted with a safety valve so proportioned and adjusted that the accumulation with the outlet valve closed will not exceed 10 per cent of the maximum working pressure. The casings of the cooling water spaces are to be fitted with a safety valve or bursting disc so that ample relief will be provided in the event of the bursting of an air cooler tube. It is recommended that compressors be cooled by fresh water.

### 16.2 Plans and particulars

16.2.1 Detailed plans, particulars, dimensional drawings and material specifications for compressor crankshafts are to be submitted in triplicate. Plans and particulars for other parts and calculations where applicable are to be submitted to LR upon request.

16.2.2 Where compressors of a special type or design are proposed, the requirements of Pt 7, Ch 16 are to be applied.

### 16.3 Materials

16.3.1 The specified minimum tensile strength of castings and forgings for compressor crankshafts are to be within the limits given in 2.1.1 and for grey cast iron to be not less than 300 N/mm<sup>2</sup>.

16.3.2 Where it is proposed to use materials outside the ranges specified in 16.3.1, details of the chemical composition, heat treatment and mechanical properties are to be submitted for approval.

16.3.3 Materials for components are to be tested as indicated in 2.2.

16.3.4 For crankshafts with a calculated crank pin diameter equal to or greater than 50 mm, they are to be manufactured and tested in accordance with the requirements of the LR Rules for Materials. For calculated crank pin diameters less than 50 mm, a manufacturers' certificate may be accepted, see Ch 1, 3.1.3(c) of the LR Rules for Materials.

### 16.4 Design and construction

16.4.1 A fully documented fatigue strength analysis is to be submitted indicating a factor of safety of 1,5 at the design loads based on a suitable fatigue strength criterion. Alternatively, the requirements of 16.4.2 to 16.4.6 may be used.

16.4.2 The diameter,  $d_p$ , of a compressor crankshaft is to be not less than  $d$ , determined by the following formula, when all cranks on the shaft are located between two main bearings only:

$$d = V_c \left( \frac{D^2 p Z}{78,5} \left( \frac{S}{16} + \frac{a b}{a + b} \right) \right)^{1/3} \text{ mm}$$

where

$a$  = distance between inner edge of one main bearing and the centreline of the crankpin nearest the centre of the span, in mm

$b$  = distance from the centreline of the same crankpin to the inner edge of the adjacent main bearing, in mm

$a+b$  = span between inner edges of main bearings, in mm

$d_p$  = proposed minimum diameter of crankshaft, in mm

$p$  = design pressure, in bar g, as defined in Ch 12, 1.3.1

$D$  = diameter of cylinder, in mm

$S$  = length of stroke, in mm

$V_c$  = 1,0 for shafts having one cylinder per crank, or

**Table 2.16.1 Angle between cylinders**

Number of crankpins	Number of cylinders per crank	Angle between cylinders, in degrees		
1 or 2	2	45	60	90
3	2	45	60	—
4	2	45	60	—
1	3	45	60	90
2	3	45	60	—
3	3	45	—	—
1	4	45	60	—
2	4	45	—	—

$= 1,05$  for  $90^\circ$   
 $= 1,18$  for  $60^\circ$   
 $= 1,25$  for  $45^\circ$

} between adjacent  
 cylinders on the  
 same crankpin

for the shaft and cylinder arrangements as detailed in Table 2.16.1

$$Z = \frac{560}{\sigma_u + 160} \text{ for steel}$$

$$Z = \frac{700}{\sigma_u + 260 - 0,059d_p} \text{ for spheroidal or nodular graphite cast iron}$$

$$Z = \frac{700}{\sigma_u + 260 - 0,069d_p} \text{ for grey cast iron}$$

$\sigma_u$  = specified minimum tensile strength of crankshaft material, in N/mm<sup>2</sup>.

**16.4.3** Where the shaft is supported additionally by a centre bearing, the diameter is to be evaluated from the half shaft between the inner edges of the centre and outer main bearings. The diameter so found for the half shaft is to be increased by six per cent for the full length shaft diameter.

**16.4.4** The dimensions of crankwebs are to be such that  $Bt^2$  is to be not less than given by the following formulae:

$0,4d^3$  for the web adjacent to the bearing

$0,75d^3$  for intermediate webs

where

$B$  = breadth of web, in mm

$d$  = minimum diameter of crankshaft as required by 16.4.2, in mm

$t$  = axial thickness of web which is to be not less than  $0,45d$  for the web adjacent to the bearing, or  $0,60d$  for intermediate webs, in mm.

**16.4.5** Fillets at the junction of crankwebs with crankpins or journals are to be machined to a radius not less than  $0,05d$ . Smaller fillets, but of a radius not less than  $0,025d$ , may be used provided the diameter of the crankpin or journal is not less than  $cd$ ,

where

$$c = 1,1 - 2 \frac{r}{d} \text{ but to be taken as not less than } 1,0$$

$d$  = minimum diameter of crankshaft as required by 16.4.2, in mm

$r$  = fillet radius, in mm.

**16.4.6** Fillets and oil holes are to be rounded to an even contour and smooth finish.

**16.4.7** An oil level sight glass or oil level indicator is to be fitted to the crankcase.

**16.4.8** The crankcases of compressors are to be designed to withstand a pressure equal to the maximum working pressure of the system.

**16.4.9** Compressors with shaft power exceeding 500 kW are to have torsional vibration analysis determined in accordance with Ch 8,2 as applicable.

**16.4.10** The cooler dimensions for sea-water cooled stage air coolers are to be based on an inlet temperature of not less than  $32^\circ\text{C}$ . Where fresh water cooling is used, the cooling water inlet temperature is not to be greater than  $40^\circ\text{C}$ .

**16.4.11** The cooler dimensions for air cooled stage air coolers are to be based on an air temperature of not less than  $45^\circ\text{C}$ .

**16.4.12** The piping to and from the air compressor is to be arranged to prevent condensation from entering the cylinders.

## 16.5 Testing

**16.5.1** Cylinders and liners of air compressors are to be subjected to hydraulic pressure tests at 1,5 times the final pressure of the stage concerned.

**16.5.2** The compressed air chambers of the intercoolers and after coolers of air compressors are to be subjected to hydraulic pressure tests at 1,5 times the final pressure of the stage concerned.

## 16.6 Safety arrangements and monitoring

**16.6.1** Air compressors are to be arranged and located so as to minimise the intake of air contaminated by oil or water.

**16.6.2** Where one compressor stage comprises several cylinders which can be shut off individually, each cylinder shall be equipped with a safety valve and a pressure gauge.

**16.6.3** After the final stage, all air compressors are to be equipped with a water trap and after cooler. The water traps, after coolers and the compressed air spaces between the stages are to be provided with discharge devices at their lowest points.

**16.6.4** Each compressor stage shall be fitted with a suitable pressure gauge, the scale of which must indicate the relevant maximum permissible working pressure.

## 16.7 Crankcase relief valves

**16.7.1** In compressors having cylinders not exceeding 200 mm bore or having a crankcase gross volume not exceeding  $0,6 \text{ m}^3$ , crankcase relief valves may be omitted.

16.7.2 Crankcases are to be provided with lightweight spring-loaded valves or other quick-acting and self-closing devices to relieve the crankcases of pressure in the event of an internal explosion and to prevent any inrush of air thereafter. The valves are to be designed and constructed to open quickly and be fully open at a pressure not greater than 0,2 bar.

16.7.3 The valve lids are to be made of ductile material capable of withstanding the shock of contact with stoppers at the full open position.

16.7.4 Each valve is to be fitted with a flame arrester that permits flow for crankcase pressure relief and prevents the passage of flame following a crankcase explosion.

16.7.5 The valves are to be provided with a copy of the manufacturer's installation and maintenance manual for the size and type of valve being supplied. The manual is to contain the following information:

- (a) Description of valve with details of function and design limits.
- (b) Copy of type test certification.
- (c) Installation instructions.
- (d) Maintenance and in-service instructions to include testing and renewal of any sealing arrangements.
- (e) Actions required after a crankcase explosion.

16.7.6 A copy of the installation and maintenance manual required by 16.7.3 is to be provided on board the ship.

16.7.7 Plans showing details and arrangements of the crankcase relief valves are to be submitted for approval, see 1.1.

16.7.8 The valves are to be provided with suitable markings that include the following information:

- (a) Name and address of manufacturer.
- (b) Designation and size.
- (c) Month/Year of manufacture.
- (d) Approved installation orientation.

## 16.8 Number of crankcase relief valves

16.8.1 In compressors having cylinders exceeding 200 mm but not exceeding 250 mm bore, at least two relief valves are to be fitted; where more than one relief valve is required, the valves are to be located at or near the ends of the crankcase.

16.8.2 In compressors having cylinders exceeding 250 mm but not exceeding 300 mm bore, at least one relief valve is to be fitted in way of each alternate crankthrow with a minimum of two valves. For compressors having 3, 5, 7, 9, etc., crankthrows, the number of relief valves is not to be less than 2, 3, 4, 5, etc., respectively.

16.8.3 In compressors having cylinders exceeding 300 mm bore, at least one valve is to be fitted in way of each main crankthrow.

16.8.4 Additional relief valves are to be fitted for separate spaces on the crankcase, such as gear or chain cases, when the gross volume of such spaces exceeds 0,6 m<sup>3</sup>.

## 16.9 Size of crankcase relief valves

16.9.1 The combined free area of the crankcase relief valves fitted on a compressor is to be not less than 115 cm<sup>2</sup>/m<sup>3</sup> based on the volume of the crankcase.

16.9.2 The free area of each relief valve is to be not less than 45 cm<sup>2</sup>.

16.9.3 The free area of the relief valve is the minimum flow area at any section through the valve when the valve is fully open.

16.9.4 In determining the volume of the crankcase for the purpose of calculating the combined free area of the crankcase relief valves, the volume of the stationary parts within the crankcase may be deducted from the total internal volume of the crankcase.

## 16.10 Vent pipes

16.10.1 Where crankcase vent or breather pipes are fitted, they are to be made as small as practicable and/or as long as possible to minimise the inrush of air after an explosion.

## Section 17 Type testing – General

### 17.1 Engines

17.1.1 New engine types or developments of existing types are to be subjected to an agreed programme of type testing to complement the design appraisal and review of documentation.

17.1.2 Guidelines for type testing of engines will be supplied on application.

17.1.3 Wherever practical, type tests are to be conducted with the engine control systems operational in the approved configuration, see 1.1.4 and 1.1.5. Configuration management documents are to be reviewed at testing for validity and referenced in the type test report.

17.1.4 An engine type is defined in terms of:

- basic engine data: e.g. bore, stroke
- working cycle: 2 stroke, 4 stroke
- cylinder arrangement: in-line, vee
- cylinder rating
- fuel supply: e.g. direct, or indirect injection, dual fuel
- gas exchange: natural aspiration, pressure charging arrangement.

**17.1.5** Where an engine type has subsequently proved satisfactory in service with a number of applications a maximum uprating of 10 per cent may be considered without a further complete type test.

**17.1.6** A type test will be considered to cover engines of a given design for a range of cylinder numbers in a given cylinder arrangement.

## 17.2 Mass produced engines

**17.2.1** The requirements in this section are applicable to the type testing of mass produced internal combustion engines where the manufacturer has requested approval. Omission or simplification of the type test requirements will be considered by LR for engines of an established type on application by the manufacturer.

**17.2.2** The engine to be tested is to be selected from the production line and agreed by LR.

**17.2.3** The type tests are to be conducted with the engine control systems operational in the approved configuration, see 1.1.4 and 1.1.5. Configuration management documents are to be reviewed at testing for validity and referenced in the type test report.

**17.2.4** The duration and programme of type tests is to include the following:

- (a) 80 h at rated output.
- (b) 8 h at 110 per cent overload.
- (c) 10 h at varying partial loads (25 per cent, 50 per cent, 75 per cent and 90 per cent of rated output).
- (d) 2 h at maximum intermittent loads.
- (e) Starting tests.
- (f) Reverse running of direct reversing engines.
- (g) Testing of speed governor.
- (h) Testing of overspeed device.
- (j) Testing of lubricating oil system failure alarm device.
- (k) Testing of the engine with turbo-charger out of action when applicable.
- (l) Testing of minimum speed for main propulsion engines and the idling speed for auxiliary engines.

**17.2.5** The type tests in 17.2.4 at the required outputs are to be combined together in working cycles for the whole duration within the limits indicated. *See also* 17.2.11 and 17.2.12.

**17.2.6** The overload testing required by 17.2.4 is to be carried out with the following conditions:

- (a) 110 per cent of rated power at 103 per cent revolutions per minute for engines directly driving propellers.
- (b) 110 per cent of rated power at 100 per cent revolutions per minute for engines driving electrical generators or for other auxiliary purposes.

**17.2.7** For prototype engines, the duration and programme of tests are to be specially agreed between the manufacturer and LR.

**17.2.8** As far as practicable during type testing the following particulars are to be continuously recorded:

- (a) Ambient air temperature.
- (b) Ambient air pressure.
- (c) Atmospheric humidity.
- (d) External cooling water temperature.
- (e) Fuel and lubrication oil characteristics.

**17.2.9** In addition to the particulars stated in 17.2.8 and as far as practicable, the following are also to be continuously measured and recorded:

- (a) Engine revolutions per minute.
- (b) Brake power.
- (c) Torque.
- (d) Maximum combustion pressure.
- (e) Indicator pressure diagrams where practicable.
- (f) Exhaust smoke (with an approved smoke meter).
- (g) Lubricating oil pressure and temperature.
- (h) Exhaust gas temperature in exhaust manifold, and, where facilities are available, from each cylinder.
- (j) For turbocharged engines:
  - Turbocharger revolutions per minute.
  - Air temperature and pressures before and after turbo-blower and charge cooler.
  - Exhaust gas temperature and pressures before and after the turbine.
  - The cooling water inlet temperature to the charge air cooler.

**17.2.10** After the type test, the main parts and especially those subject to wear are to be dismantled for examination by LR Surveyors.

**17.2.11** For engines that are required to be approved for different purposes (multi-purpose engines), and that have different performances profiles and control, alarm monitoring and safety systems configurations for each purpose, the programme and duration of test is to be modified to cover the whole range of the engine performance, taking into account the most severe conditions and intended purpose(s).

**17.2.12** The rated output for which the engine is to be tested is the output corresponding to that declared by the manufacturer and agreed by LR, i.e. actual maximum power which the engine is capable of delivering continuously between the normal maintenance intervals stated by the manufacturer at the rated speed and under the stated ambient conditions.

## 17.3 Turbo-chargers

**17.3.1** A type test is to consist of a hot gas running test of at least one hour duration at the maximum permissible speed and maximum permissible temperature. Following the test the turbo-charger is to be completely dismantled for examination of all parts.

**17.3.2** Alternative arrangements will be specially considered.

## ■ Section 18

### Type testing procedure for crankcase explosion relief valves

#### 18.1 Scope

18.1.1 To specify type tests and identify standard test conditions using methane gas and air mixture to demonstrate that LR requirements are satisfied for crankcase explosion relief valves intended to be fitted to engines and gear cases.

18.1.2 The test procedure is only applicable to explosion relief valves fitted with flame arresters. Where internal oil wetting of a flame arrester is a design feature of an explosion relief valve, alternative testing arrangements that demonstrate compliance with these requirements may be proposed by the manufacturer. The alternative testing arrangements are to be submitted to LR for approval.

#### 18.2 Purpose

18.2.1 The purpose of type testing crankcase explosion relief valves is fourfold:

- (a) To verify the effectiveness of the flame arrester.
- (b) To verify that the valve closes after an explosion.
- (c) To verify that the valve is gas/air tight after an explosion.
- (d) To establish the level of overpressure protection provided by the valve.

#### 18.3 Test facilities

18.3.1 Test houses carrying out type testing of crankcase explosion relief valves are to meet the following requirements:

- (a) The test houses where testing is carried out are to be accredited to a National or International Standard for the testing of explosion protection devices such as ISO/IEC 17025.
- (b) The test facilities are to be acceptable to LR.
- (c) The test facilities are to be equipped so that they can perform and record explosion testing in accordance with this procedure.
- (d) The test facilities are to have equipment for controlling and measuring a methane gas in air concentration within a test vessel to an accuracy of  $\pm 0,1$  per cent.
- (e) The test facilities are to be capable of effective point-located ignition of a methane gas in air mixture.
- (f) The pressure measuring equipment is to be capable of measuring the pressure in the test vessel in at least two positions, one at the valve and the other at the test vessel centre. The measuring arrangements are to be capable of measuring and recording the pressure changes throughout an explosion test at a frequency recognising the speed of events during an explosion. The result of each test is to be documented by video recording and by recording with a heat sensitive camera.
- (g) The test vessel for explosion testing is to have documented dimensions. The dimensions are to be such that the vessel is not pipe-like with the distance between dished ends being not more than 2,5 times the diameter. The internal volume of the test vessel is to include any standpipe arrangements.

- (h) The test vessel is to be provided with a flange, located centrally at one end at 90 degrees to the vessel longitudinal axis for mounting the explosion relief valve. The test vessel is to be arranged in an orientation consistent with how the valve will be installed in service, i.e., in the vertical plane or the horizontal plane.
- (j) A circular flat plate is to be provided for fitting between the pressure vessel flange and valve to be tested with the following dimensions:
  - (i) Outside diameter of 2 times the outer diameter of the valve top cover.
  - (ii) Internal bore having the same internal diameter as the valve to be tested.
- (k) The test vessel is to have connections for measuring the methane in air mixture at the top and bottom.
- (l) The test vessel is to be provided with a means of fitting an ignition source at a position as specified in 18.4.3.
- (m) The test vessel volume is to be as far as practicable, related to the size and capability of the relief valve to be tested. In general, the volume is to correspond to the requirement in 10.3.1 for the free area of explosion relief valve to be not less than  $115 \text{ cm}^2/\text{m}^3$  of crankcase gross volume, e.g., the testing of a valve having  $1150 \text{ cm}^2$  of free area, would require a test vessel with a volume of  $10 \text{ m}^3$ . The following is to apply:
  - (i) Where the free area of relief valves is greater than  $115 \text{ cm}^2/\text{m}^3$  of the crankcase gross volume, the volume of the test vessel is to be consistent with the design ratio.
  - (ii) In no case is the volume of the test vessel to vary by more than  $\pm 15$  per cent from the design  $\text{cm}^2/\text{m}^3$  volume ratio.

#### 18.4 Explosion test process

18.4.1 All explosion tests to verify the functionality of crankcase explosion relief valves are to be carried out using an air and methane mixture with a volumetric methane concentration of 9,5 per cent  $\pm 0,5$  per cent. The pressure in the test vessel is to be not less than atmospheric and is not to exceed the opening pressure of the relief valve.

18.4.2 The concentration of methane in the test vessel is to be measured at the top and bottom of the vessel and these concentrations are not to differ by more than 0,5 per cent.

18.4.3 The ignition of the methane and air mixture is to be made at the centreline of the test vessel at a position approximately one third of the height or length of the test vessel opposite to where the valve is mounted.

18.4.4 The ignition is to be made using a maximum 100 joule explosive charge.

#### 18.5 Valves to be tested

18.5.1 The valves used for type testing (including testing specified in 18.5.3) are to be selected from the manufacturer's normal production line for such valves by the LR Surveyor witnessing the tests.



# Oil Engines

## Part 5, Chapter 2

Section 18

18.5.2 For approval of a specific valve size, three valves are to be tested in accordance with 18.5.3 and 18.6. For a series of valves, see 18.8.

18.5.3 The valves selected for type testing are to have been previously tested at the manufacturer's works to demonstrate that the opening pressure is in accordance with the specification within a tolerance of  $\pm 20$  per cent and that the valve is air tight at a pressure below the opening pressure for at least 30 seconds. This test is to verify that the valve is air tight following assembly at the manufacturer's works and that the valve begins to open at the required pressure demonstrating that the correct spring has been fitted.

18.5.4 The type testing of valves is to recognise the orientation in which they are intended to be installed on the engine or gear case. Three valves of each size are to be tested for each intended installation orientation, i.e. in the vertical and/or horizontal positions.

### 18.6 Method

18.6.1 The following requirements are to be satisfied at explosion testing:

- (a) The explosion testing is to be witnessed by a LR Surveyor.
- (b) Where valves are to be installed on an engine or gear case with shielding arrangements to deflect the emission of explosion combustion products, the valves are to be tested with the shielding arrangements fitted.
- (c) Successive explosion testing to establish a valve's functionality is to be carried out as quickly as possible during stable weather conditions.
- (d) The pressure rise and decay during all explosion testing is to be recorded.
- (e) The external condition of the valves is to be monitored during each test for indication of any flame release by video and heat sensitive camera.

18.6.2 The explosion testing is to be in three stages for each valve that is required to be approved as being type tested.

18.6.3 **Stage 1.** Two explosion tests are to be carried out in the test vessel with the circular plate as specified in 18.3.1(j) fitted and the opening in the plate covered by a 0,05 mm thick polythene film. These tests establish a reference pressure level for determination of the capability of a relief valve in terms of pressure rise in the test vessel, see 18.7.1(f).

#### 18.6.4 Stage 2:

- (a) Two explosion tests are to be carried out on three different valves of the same size. Each valve is to be mounted in the orientation for which approval is sought i.e., in the vertical or horizontal position with the circular plate described in 18.3.1(j) located between the valve and pressure vessel mounting flange.
- (b) The first of the two tests on each valve is to be carried out with a 0,05mm thick polythene bag, having a minimum diameter of three times the diameter of the circular plate and volume not less than 30 per cent of the test vessel, enclosing the valve and circular plate. Before carrying out the explosion test the polythene bag is to be empty of air. The polythene bag is required to

provide a readily visible means of assessing whether there is flame transmission through the relief valve following an explosion. During the test, the explosion pressure will open the valve and some unburned methane/air mixture will be collected in the polythene bag. When the flame reaches the flame arrester and if there is flame transmission through the flame arrester, the methane/air mixture in the bag will be ignited and this will be visible.

- (c) Provided that the first explosion test successfully demonstrated that there was no indication of combustion outside the flame arrester and there are no signs of damage to the flame arrester or valve, a second explosion test without the polythene bag arrangement is to be carried out as quickly as possible after the first test. During the second explosion test, the valve is to be visually monitored for any indication of combustion outside the flame arrester and video records are to be kept for subsequent analysis. The second test is required to demonstrate that the valve can still function in the event of a secondary crankcase explosion.
- (d) After each explosion, the test vessel is to be maintained in the closed condition for at least 10 seconds to enable the tightness of the valve to be ascertained. The tightness of the valve can be verified during the test from the pressure/time records or by a separate test after completing the second explosion test.

18.6.5 **Stage 3.** Carry out two further explosion tests as described in Stage 1. These further tests are required to provide an average baseline value for assessment of pressure rise, recognising that the test vessel ambient conditions may have changed during the testing of the explosion relief valves in Stage 2.

### 18.7 Assessment and records

18.7.1 For the purposes of verifying compliance with the requirements of this Section, the assessment and records of the valves used for explosion testing is to address the following:

- (a) The valves to be tested are to have evidence of appraisal/approval by LR, see also 18.5.1.
- (b) The designation, dimensions and characteristics of the valves to be tested are to be recorded. This is to include the free area of the valve and of the flame arrester and the amount of valve lift at 0,2 bar.
- (c) The test vessel volume is to be determined and recorded.
- (d) For acceptance of the functioning of the flame arrester there is not to be any indication of flame or combustion outside the valve during an explosion test.
- (e) The pressure rise and decay during an explosion is to be recorded, with indication of the pressure variation showing the maximum overpressure and steady under-pressure in the test vessel during testing. The pressure variation is to be recorded at two points in the pressure vessel.

- (f) The effect of an explosion relief valve in terms of pressure rise following an explosion is ascertained from maximum pressures recorded at the centre of the test vessel during the three stages. The pressure rise within the test vessel due to the installation of a relief valve is the difference between average pressure of the four explosions from Stages 1 and 3 and the average of the first tests on the three valves in Stage 2. The pressure rise is not to exceed the limit specified by the manufacturer.
- (g) The valve tightness is to be ascertained by verifying from the records at the time of testing that an under-pressure of at least 0,3 bar is held by the test vessel for at least 10 seconds following an explosion. This test is to verify that the valve has effectively closed and is reasonably gas-tight following dynamic operation during an explosion.
- (h) After each explosion test in Stage 2, the external condition of the flame arrester is to be examined for signs of serious damage and/or deformation that may affect the operation of the valve.
- (j) After completing the explosion tests, the valves are to be dismantled and the condition of all components ascertained and documented. In particular, any indication of valve sticking or uneven opening that may affect the operation of the valve is to be noted. Photographic records of the valve condition are to be taken and included in the report.

## 18.8 Design series qualification

18.8.1 The qualification of quenching devices to prevent the passage of flame can be evaluated for other similar devices of identical type where one device has been tested and found satisfactory.

18.8.2 The quenching ability of a flame arrester depends on the total mass of quenching lamellas/mesh. Provided the materials, thickness of materials, length of lamellas/thickness of mesh layer and the quenching gaps are the same, then the same quenching ability can be qualified for different size of flame arresters subject to (a) and (b) being satisfied.

$$(a) \quad \frac{n_1}{n_2} = \sqrt{\frac{S_1}{S_2}}$$

$$(b) \quad \frac{A_1}{A_2} = \frac{S_1}{S_2}$$

where

- $n_1$  = total depth of flame arrester corresponding to the number of lamellas of size 1 quenching device for a valve with a relief area equal to  $S_1$
- $n_2$  = total depth of flame arrester corresponding to the number of lamellas of size 2 quenching device for a valve with a relief area equal to  $S_2$
- $A_1$  = free area of quenching device for a valve with a relief area equal to  $S_1$
- $A_2$  = free area of quenching device for a valve with a relief area equal to  $S_2$ .

18.8.3 The qualification of explosion relief valves of larger sizes than that which has been previously satisfactorily tested in accordance with 18.6 and 18.7 can be evaluated where valves are of identical type and have identical features of construction subject to the following:

- (a) The free area of a larger valve does not exceed three times +5 per cent that of the valve that has been satisfactorily tested.
- (b) One valve of the largest size, subject to (a), requiring qualification is subject to satisfactory testing required by 18.5.3 and 18.6.4 except that a single valve will be accepted in 18.6.4(a) and the volume of the test vessel is not to be less than one-third of the volume required by 18.3.1(m).
- (c) The assessment and records are to be in accordance with 18.7, noting that 18.7.1(f) will only be applicable to Stage 2 for a single valve.

18.8.4 The qualification of explosion relief valves of smaller sizes than that which has been previously satisfactorily tested in accordance with 18.6 and 18.7 can be evaluated where valves are of identical type and have identical features of construction subject to the following:

- (a) The free area of a smaller valve is not less than one third of that of the valve that has been satisfactorily tested.
- (b) One valve of the smallest size, subject to (a), requiring qualification is subject to satisfactory testing required by 18.5.3 and 18.6.4 except that a single valve will be accepted in 18.6.4(a) and the volume of the test vessel is not to be more than the volume required by 18.3.1(m).
- (c) The assessment and records are to be in accordance with 18.7, noting that 18.7.1(f) will only be applicable to Stage 2 for a single valve.

## 18.9 The report

18.9.1 The test house is to deliver a full report that includes the following information and documents:

- (a) Test specification.
- (b) Details of test pressure vessel and valves tested.
- (c) The orientation in which the valve was tested, (vertical or horizontal position).
- (d) Methane in air concentration for each test.
- (e) Ignition source.
- (f) Pressure curves for each test.
- (g) Video recordings of each valve test.
- (h) The assessment and records stated in 18.7.

## 18.10 Approval

18.10.1 The approval of an explosion relief valve is at the discretion of LR based on the appraisal of plans and particulars and the test facility's report of the results of type testing.

## Section 19

### Type testing procedure for crankcase oil mist detection and alarm equipment

#### 19.1 Scope

19.1.1 To specify the tests required to demonstrate that crankcase oil mist detection and alarm equipment intended to be fitted to diesel engines satisfy LR requirements.

19.1.2 This test procedure is also applicable to oil mist detection and alarm arrangements intended for gear cases.

#### 19.2 Purpose

19.2.1 The purpose of type testing crankcase oil mist detection and alarm equipment is seven fold:

- To verify the functionality of the system.
- To verify the effectiveness of the oil mist detectors.
- To verify the accuracy of oil mist detectors.
- To verify the alarm set points.
- To verify time delays between oil mist leaving the source and alarm activation.
- To verify functional failure detection.
- To verify the influence of optical obscuration on detection.

#### 19.3 Test facilities

19.3.1 Test houses carrying out type testing of crankcase detection and alarm equipment are to satisfy the following criteria:

- A full range of facilities for carrying out the environmental and functionality tests required by this procedure shall be available and be acceptable to LR.
- The test house that verifies the functionality of the equipment is to be equipped so that it can control, measure and record oil mist concentration levels in terms of mg/l to an accuracy of  $\pm 10$  per cent in accordance with this procedure.

#### 19.4 Equipment testing

19.4.1 The range of tests is to include the following for the alarm/monitoring panel:

- Functional tests described in 19.5.
- Electrical power supply failure test.
- Power supply variation test.
- Dry heat test.
- Damp heat test.
- Vibration test.
- EMC test.
- Insulation resistance test.
- High voltage test.
- Static and dynamic inclinations, if moving parts are contained.

19.4.2 The range of tests is to include the following for the detectors:

- Functional tests described in 19.5.
- Electrical power supply failure test.
- Power supply variation test.
- Dry heat test.
- Damp heat test.
- Vibration test.
- EMC test.
- Insulation resistance test.
- High voltage test.
- Static and dynamic inclinations.

#### 19.5 Functional tests

19.5.1 All tests to verify the functionality of crankcase oil mist detection and alarm equipment are to be carried out in accordance with 19.5.2 to 19.5.6 with an oil mist concentration in air, known in terms of mg/l to an accuracy of  $\pm 10$  per cent.

19.5.2 The concentration of oil mist in the test chamber is to be measured in the top and bottom of the chamber and these concentrations are not to differ by more than 10 per cent. See 19.7.2(a).

19.5.3 The oil mist monitoring arrangements are to be capable of detecting oil mist in air concentrations of between 0 and 10 per cent of the lower explosive limit (LEL), which corresponds to an oil mist concentration of approximately 50 mg/l (13 per cent oil-air mixture) or between 0 and a percentage corresponding to a level not less than twice the maximum oil mist concentration alarm set point.

19.5.4 The alarm set point for oil mist concentration in air is to provide an alarm at a maximum setting corresponding to not more than 5 per cent of the LEL or approximately 2,5 mg/l.

19.5.5 Where alarm set points can be altered, the means of adjustment and indication of set points are to be verified against the equipment manufacturer's instructions.

19.5.6 Where oil mist is drawn into a detector via piping arrangements, the time delay between the sample leaving the crankcase and operation of the alarm is to be determined for the longest and shortest lengths of pipes recommended by the manufacturer. The pipe arrangements are to be in accordance with the manufacturer's instructions/recommendations.

19.5.7 Detector equipment that is in contact with the crankcase atmosphere and may be exposed to oil splash and spray from engine lubricating oil is to be tested to demonstrate that openings do not occlude or become blocked under continuous oil splash or spray conditions. Testing is to be in accordance with arrangements proposed by the manufacturer and agreed by LR.



19.5.8 Detector equipment may be exposed to water vapour from the crankcase atmosphere which may affect the sensitivity of the equipment, it is to be demonstrated that exposure to such conditions will not affect the functional operation of the detector equipment. Where exposure to water vapour and/or water condensation has been identified as a possible source of equipment malfunctioning, testing is to demonstrate that any mitigating arrangements such as heating are effective. Testing is to be in accordance with arrangements proposed by the manufacturer and agreed by LR. This testing is in addition to that required by 19.4.2(e) and is concerned with the effects of condensation caused by the detection equipment being at a lower temperature than the crankcase atmosphere.

## 19.6 Detectors and alarm equipment to be tested

19.6.1 The detectors and alarm equipment selected for the type testing are to be selected from the manufacturer's normal production line by the LR Surveyor witnessing the tests.

19.6.2 Two detectors are to be tested. One is to be tested in the clean condition and the other in a condition representing the maximum level of lens obscuration specified by the manufacturer.

## 19.7 Method

19.7.1 The requirements of 19.7 are to be satisfied at type testing.

19.7.2 Oil mist generation is to satisfy the following:

- (a) Oil mist is to be generated with suitable equipment using an SAE 80 monograde mineral oil or equivalent and supplied to a test chamber having a volume of not less than 1 m<sup>3</sup>. The oil mist produced is to have a maximum droplet size of 5 µm. The oil droplet size is to be checked using the sedimentation method.
- (b) The oil mist concentrations used are to be ascertained by the gravimetric deterministic method or equivalent. For this test, the gravimetric deterministic method is a process where the difference in weight of a 0,8 µm pore size membrane filter is ascertained from weighing the filter before and after drawing 1 litre of oil mist through the filter from the oil mist test chamber. The oil mist chamber is to be fitted with a recirculating fan.
- (c) Samples of oil mist are to be taken at regular intervals and the results plotted against the oil mist detector output. The oil mist detector is to be located adjacent to where the oil mist samples are drawn off.
- (d) The results of a gravimetric analysis are considered invalid and are to be rejected if the resultant calibration curve has an increasing gradient with respect to the oil mist detection reading. This situation occurs when insufficient time has been allowed for the oil mist to become homogeneous. Single results that are more than 10 per cent below the calibration curve are to be rejected. This situation occurs when the integrity of the filter unit has been compromised and not all of the oil is collected on the filter paper.

- (e) The filters require to be weighed to a precision of 0,1 mg and the volume of air/oil mist sampled to 10 ml.

19.7.3 The testing is to be witnessed by an LR Surveyor where type testing approval is required by LR.

19.7.4 Oil mist detection equipment is to be tested in the orientation (vertical, horizontal or inclined) in which it is intended to be installed on an engine or gear case as specified by the equipment manufacturer.

19.7.5 Type testing is to be carried out for each type of oil mist detection and alarm equipment for which a manufacturer seeks LR approval. Where sensitivity levels can be adjusted, testing is to be carried out at the extreme and mid-point level settings.

## 19.8 Assessment

19.8.1 Assessment of oil mist detection equipment devices after testing is to address the following:

- (a) The equipment to be tested is to have evidence of design appraisal/approval by LR, *See also* 19.6.1.
- (b) Details of the detection equipment to be tested are to be recorded, such as name of manufacturer, type designation, oil mist concentration assessment capability and alarm settings.
- (c) After completing the tests, the detection equipment is to be examined and the condition of all components ascertained and documented. Photographic records of the monitoring equipment condition are to be taken and included in the report.

## 19.9 Design series qualification

19.9.1 The approval of one type of detection equipment may be used to qualify other devices having identical construction details. Proposals are to be submitted for consideration.

## 19.10 The report

19.10.1 The test house is to provide a full report which includes the following information and documents:

- (a) Test specification.
- (b) Details of equipment tested.
- (c) Results of tests.

## 19.11 Acceptance

19.11.1 Acceptance of crankcase oil mist detection equipment is at the discretion of LR based on the appraisal of plans and particulars and the test house report of the results of type testing.

19.11.2 The following information is to be submitted to LR for acceptance of oil mist detection equipment and alarm arrangements:

- (a) Description of oil mist detection equipment and system including alarms.
- (b) Copy of the test house report identified in 19.10.
- (c) Schematic layout of engine oil mist detection arrangements showing location of detectors/sensors and piping arrangements and dimensions.
- (d) Maintenance and test manual which is to include the following information:
  - Intended use of equipment and its operation.
  - Functionality tests to demonstrate that the equipment is operational and that any faults can be identified and corrective actions notified.
  - Maintenance routines and spare parts recommendations.
  - Limit setting and instructions for safe limit levels.
  - Where necessary, details of configurations in which the equipment is and is not to be used.

## ■ Cross-references

The pumping arrangements, including cooling water and lubricating oil systems, are to comply with the requirements of Chapter 14.

For spare gear, see Chapter 1,7.

# Steam Turbines

# Part 5, Chapter 3

Sections 1, 2 & 3

## Section

- 1 **Plans and particulars**
- 2 **Materials**
- 3 **Design and construction**
- 4 **Safety arrangements**
- 5 **Emergency arrangements**
- 6 **Control and monitoring of main and auxiliary steam turbines**
- 7 **Tests and equipment**

## ■ Scope

The requirements of this Chapter are applicable to steam turbines for main propulsion and also, where powers exceed 110 kW (150 shp), to those for essential auxiliary services.

## ■ Section 1 Plans and particulars

### 1.1 Plans

1.1.1 The following plans are to be submitted for consideration, together with particulars of materials, maximum shaft powers and revolutions per minute, see Ch 1,3.3. The pressures and temperatures applicable at maximum shaft power and under the emergency conditions of 5.2 are to be stated or indicated on the plans.

- General arrangement.
- Sectional assembly.
- Rotors and couplings.
- Casings.

1.1.2 For the emergency conditions of 5.3, full particulars of the means proposed for emergency propulsion are to be submitted.

1.1.3 Where rotors and castings are of welded construction, details of the welded joints are also to be submitted for consideration.

1.1.4 In general, plans for auxiliary turbines need not be submitted.

## ■ Section 2 Materials

### 2.1 General

2.1.1 In the selection of materials, consideration is to be given to their creep strength, corrosion resistance and scaling properties at working temperatures to ensure satisfactory performance and long life under service conditions.

2.1.2 Grey cast iron is not to be used for temperatures exceeding 260°C.

### 2.2 Materials for forgings

2.2.1 Turbine rotors and discs are to be of forged steel. For carbon and carbon-manganese steel forgings, the specified minimum tensile strength is to be selected within the limits of 400 and 600 N/mm<sup>2</sup> (41 and 61 kgf/mm<sup>2</sup>). For alloy steel rotor forgings, the specified minimum tensile strength is to be selected within the limits of 500 and 800 N/mm<sup>2</sup> (51 and 82 kgf/mm<sup>2</sup>). For discs and other alloy steel forgings, the specified minimum tensile strength is to be selected within the limits of 500 and 1000 N/mm<sup>2</sup> (51 and 102 kgf/mm<sup>2</sup>).

2.2.2 For alloy steels, details of the proposed chemical composition, heat treatment and mechanical properties are to be submitted for approval.

2.2.3 When it is proposed to use material of higher tensile strength, full details are to be submitted for approval.

## ■ Section 3 Design and construction

### 3.1 General

3.1.1 In the design and arrangement of turbine machinery, adequate provision is to be made for the relative thermal expansion of the various turbine parts, and special attention is to be given to minimising casing and rotor distortion under all operating conditions.

3.1.2 Turbine bearings are to be so disposed and supported that lubrication is not adversely affected by heat flow from adjacent hot parts of the turbine. Effective means are to be provided for intercepting oil leakage and preventing oil from reaching high temperature glands and casings and steam pipes. Drainage openings and drain pipes from oil baffle pockets are to be sufficiently large to prevent excessive accumulation and leakage of oil.

# Steam Turbines

## Part 5, Chapter 3

Section 3

### 3.2 Welded components

3.2.1 Turbine rotors, cylinders and associated components fabricated by means of welding will be considered for acceptance if constructed by firms whose works are properly equipped to undertake welding to equivalent standards, for rotors and cylinders respectively, to those required by the Rules for Class 1 and Class 2/1 welded pressure vessels, see Ch 17, Sections 1 to 7.

3.2.2 Welding is to be carried out in accordance with the requirements of Ch 13,4 of the *Rules for Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials) using welding procedures and welders that have been qualified in accordance with Chapter 12 of the Rules for Materials.

3.2.3 Before work is commenced, manufacturers are to submit for consideration details of proposed welding procedures and their proposals for routine examination of joints by non-destructive means.

3.2.4 Materials used in the construction of turbine rotors, cylinders, diaphragms, condensers, etc., are to be of welding quality.

3.2.5 Where it is proposed to construct rotors from two or more forged components joined by welding, full details of the chemical composition, mechanical properties and heat treatment of the materials, together with particulars of the welding consumables, an outline of the welding procedure, method of fabrication and heat treatment, are to be submitted for consideration.

3.2.6 Joints in rotors and major joints in cylinders are to be designed as full-strength welds and for complete fusion of the joint.

3.2.7 Adequate preheating is to be employed for mild steel cylinders and components and where the metal thickness exceeds 44 mm, and for all low alloy steel cylinders and components and for any part where necessitated by joint restraint.

3.2.8 Stress relief heat treatment is to be applied to all cylinders and associated components on completion of the welding of all joints and attached structures. For details of stress relief procedure, temperature and duration, see Ch 13,4.11 of the Rules for Materials.

3.2.9 For all welded components, weld procedure tests are to be in accordance with Ch 12,2.7 of the Rules for Materials.

3.2.10 Production weld tests are to be performed according to the requirements of Ch 13,4.5 of the Rules for Materials.

### 3.3 Stress raisers

3.3.1 Smooth fillets are to be provided at abrupt changes of section of rotors, spindles, discs, blade roots and tenons. The rivet holes in blade shrouds are to be rounded and radiused on top and bottom surfaces, and tenons are to be radiused at their junction with blade tips. Balancing holes in discs are to be well rounded and polished.

3.3.2 Surveyors are to be satisfied as to the workmanship and riveting of blades to shroud bands, and that the blade tenons are free from cracks, particularly with high tensile blade material. Test samples are to be sectioned and examined, and pull-off tests made if considered necessary by the Surveyors.

### 3.4 Shrunk-on rotor discs

3.4.1 Main turbine rotor discs fitted by shrinking are to be secured with keys, dowels or other approved means.

### 3.5 Vibration

3.5.1 Care is to be taken in the design and manufacture of turbine rotors, rotor discs and blades to ensure freedom from undue vibration within the operating speed range. Consideration of blade vibration should include the effect of centrifugal force, blade root fixing, metal temperature and disc flexibility where appropriate.

3.5.2 For the vibration and alignment of main propulsion systems formed by the turbines geared to the line shafting, see Chapter 8.

### 3.6 External influences

3.6.1 Pipes and ducts connected to turbine casings are to be so designed that no excessive thrust loads or moments are applied by them to the turbines. Gratings and any fittings in way of sliding feet or flexible-plate supports are to be so arranged that casing expansion is not restricted. Where main turbine seatings incorporate a tank structure, consideration is to be given to the temperature variation of the tank in service to ensure that turbine alignment will not be adversely affected.

### 3.7 Steam supply and water system

3.7.1 In the arrangement of the gland sealing system, the pipes are to be made self-draining and every precaution is to be taken against the possibility of condensed steam entering the glands and turbines. The steam supply to the gland sealing system is to be fitted with an effective drain trap. In the air ejector re-circulating water system, the connection to the condenser is to be so located that water cannot impinge on the L.P. rotor or casing.

# Steam Turbines

## Part 5, Chapter 3

Sections 3, 4 &amp; 5

### 3.8 Turning gear

3.8.1 Turning gear is to be provided for all turbines to facilitate operating and maintenance regimes as required by the manufacturer.

3.8.2 The turning gear for all propulsion turbines is to be power-driven and, if electric, is to be continuously rated.

3.8.3 The turning gear for auxiliary turbines may be hand operated (manual) except where this is not practicable, in which case the provision of 3.8.2 is to be complied with.

3.8.4 The turning gear for all turbines is to be fitted with safety interlocks which prevent steam valve actuation for turbine operation when engaged see Ch 1,3.9. Indication of engaged/not engaged is to be provided at all start positions.

3.8.5 The remote control device of power-driven turning gear is to be so designed that power is removed from the turning gear when the operating switch is released.

3.8.6 Means are to be provided to secure the turning gear when disengaged.

## Section 4 Safety arrangements

### 4.1 Low vacuum and overpressure protective devices

4.1.1 In order to provide a warning, due to excessive pressure, to personnel in the vicinity of the exhaust ends of main turbines, sentinel relief valves are to be provided at the exhaust ends or other approved positions. The relief valve discharge outlets are to be visible and suitably guarded if necessary. Where a low vacuum cut-out device is provided, the sentinel relief valve at the L.P. exhaust may be omitted.

4.1.2 In order to provide a warning, due to excessive pressure, to personnel in the vicinity of the exhaust ends of auxiliary turbines, sentinel relief valves are to be provided at the exhaust ends. The relief valve discharge outlets are to be visible and suitably guarded if necessary. Low vacuum or overpressure cut-out devices, as appropriate, are also to be provided for auxiliary turbines not installed with their own condensers.

### 4.2 Bled steam connections

4.2.1 Non-return or other means, which will prevent steam and water returning to the turbines, are to be fitted in bled steam connections.

### 4.3 Steam strainers

4.3.1 Efficient steam strainers are to be provided close to the inlets to ahead and astern high pressure turbines, or alternatively at the inlets to the manoeuvring valves.

## Section 5 Emergency arrangements

### 5.1 Lubricating oil failure

5.1.1 Arrangements are to be made for the steam to the ahead propulsion turbines to be automatically shut-off in the event of failure of the lubricating oil pressure; however, steam is to be made available at the astern turbine for braking purposes in such an emergency, see Chapter 14 for emergency oil supply.

5.1.2 Auxiliary turbine arrangements are to be such that steam supply is automatically shut-off in the event of failure of the lubricating oil pressure.

### 5.2 Single screw ships

5.2.1 In single screw ships fitted with cross compound steam turbine installations in which two or more turbines are separately coupled to the same main gear wheel, the arrangements are to be such as to enable safe navigation when the steam supply is led direct to the L.P. turbine and either the H.P. or L.P. turbine can exhaust direct to the condenser. Adequate arrangements and controls are to be provided for these emergency operating conditions so that the pressure and temperature of the steam will not exceed those which the turbines and condenser can safely withstand.

5.2.2 The necessary pipes and valves or fittings for these arrangements are to be readily available and properly marked. A fit up test of all combinations of pipes and valves is to be performed prior to the first sea trials.

5.2.3 The permissible power/speeds of the operating turbines(s) when operating without one of the turbines (all combinations) is to be specified and information provided on board.

5.2.4 The operation of the turbines under emergency conditions is to be assessed for the potential influence on shaft alignment and gear teeth loading conditions.

### 5.3 Single main boiler

5.3.1 Ships intended for unrestricted service, fitted with steam turbines and having a single main boiler, are to be provided with means to ensure emergency propulsion in the event of failure of the main boiler.

## Section 6 Control and monitoring of main and auxiliary steam turbines

### 6.1 General

6.1.1 Control engineering systems are to be in accordance with the requirements of Pt 6, Ch 1.

6.1.2 All main and auxiliary steam turbines intended for essential services are to be provided with means of indicating the lubricating oil pressure supply to them. Where such turbines are of more than 37 kW (50 shp), audible and visual alarms are to be fitted to give warning of an appreciable reduction in pressure of the lubricating oil supply. Further, these alarms are to be actuated from the outlet side of any restrictions, such as filters, coolers, etc.

### 6.2 Overspeed protective devices

6.2.1 An overspeed protective device is to be provided for main and auxiliary turbines to shut off the steam automatically and prevent the maximum designed speed being exceeded by more than 15 per cent.

6.2.2 Where two or more turbines of a compound main turbine installation are separately coupled to the same main gear wheel, and one overspeed protective device is provided, this is to be fitted to the L.P. ahead turbine. Hand trip gear for shutting off the steam in an emergency is to be provided at the manoeuvring platform.

### 6.3 Speed governors

6.3.1 Where a turbine installation incorporates a reverse gear, electric transmission or reversible propeller, a speed governor in addition to, or in combination with, the overspeed protective device is to be fitted, and is to be capable of controlling the speed of the unloaded turbine without bringing the overspeed protective device into action.

6.3.2 Auxiliary turbines intended for driving electric generators are to be fitted with speed governors which, with fixed settings, are to control the speed within 10 per cent momentary variation and 5 per cent permanent variation when full load is suddenly taken off or put on. The permanent speed variations of alternating current machines intended for parallel operations are to equalise within a tolerance of  $\pm 0,5$  per cent.

### 6.4 Unattended machinery

6.4.1 Where machinery steam turbines are fitted with automatic or remote controls so that under normal operating conditions they do not require any manual intervention by the operators, they are to be provided with the alarms and safety arrangements required by 6.4 to 6.6, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

6.4.2 Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions which could hazard the machinery.

6.4.3 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

6.4.4 Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm.

### 6.5 Steam turbine machinery for propulsion purposes

6.5.1 Alarms and safeguards are indicated in 6.5.2 to 6.5.6 and Table 3.6.1.

6.5.2 Audible and visual alarms are to operate, and indication is to be given at the relevant control stations to stop or reduce the speed of the turbine(s) for the following fault conditions:

- (a) Excessive turbine vibration.
- (b) Excessive axial movement of turbine rotor.
- (c) Low vacuum in main condenser.
- (d) High condensate level in main condenser.

6.5.3 Reduction of speed may be effected by either manual or automatic control.

6.5.4 Means are to be provided to prevent the risk of thermal distortion of the turbines, by automatic steam spinning, when the shaft is stopped in the manoeuvring mode. An audible and visual alarm is to be provided at the relevant control stations when the shaft has been stopped for a predetermined time.

6.5.5 The following turbine services are to be fitted with automatic controls so as to maintain steady state conditions throughout the normal operating range of the propulsion turbine(s):

- (a) Lubricating oil supply temperature.
- (b) Condenser condensate level.
- (c) Gland steam pressure.

6.5.6 Prolonged running in a restricted speed range is to be prevented automatically, or alternatively, indication of restricted speed ranges is to be provided at each control station.

### 6.6 Auxiliary steam turbines

6.6.1 Alarms and safeguards are indicated in Table 3.6.2.



# Steam Turbines

## Part 5, Chapter 3

Sections 6 &amp; 7

**Table 3.6.1 Steam turbine machinery: Alarms and safeguards**

Item	Alarm	Note
Lubricating oil pressure	1st stage low 2nd stage low	— Automatic shut-down, see 6.4.4
Lubricating oil temperature	High	—
Lubricating oil sump level	Low	—
Lubricating oil filters differential pressure	High	—
Bearing temperatures or bearing oil outlet temperature	High	—
Astern turbine temperature	High	—
Gland steam pressure	High and Low	—
Thrust bearing temperature	High	—
Sea-water pressure or flow	Low	—
Turbine vibration	High	—
Axial movement of turbine rotor	High	Shut-down or speed reduction or turbine(s)
Main condenser vacuum	Low	—
Main condenser condensate level	High	—
Overspeed	High	See 6.2

**Table 3.6.2 Auxiliary engines and auxiliary steam turbines: Alarms and safeguards**

Item	Alarm	Note
Lubricating oil inlet temperature	High	—
Lubricating oil inlet pressure	1st stage low 2nd stage low	— Automatic shut-down of turbine, see 6.4.4
Condenser vacuum	Low	Automatic shut-down of turbine, see 6.4.4
Axial displacement of rotor	High	—
Overspeed	High	See Ch 4,4

## Section 7 Tests and equipment

### 7.1 Stability testing of turbine rotors

7.1.1 All solid forged H.P. turbine rotors intended for main propulsion service where the inlet steam temperature exceeds 400°C are to be subjected to at least one thermal stability test. This requirement is also applicable to rotors constructed from two or more forged components joined by welding. The test may be carried out at the forge or turbine builders' works:

- (a) after heat treatment and rough machining of the forging; or
- (b) after final machining; or
- (c) after final machining and blading of the rotor.

The stabilising test temperature is to be not less than 28°C above the maximum steam temperature to which the rotor will be exposed, and not more than the tempering temperature of the rotor material. For details of a recommended test procedure and limits of acceptance, see the Rules for Materials. Other test procedures may be adopted if approved.

7.1.2 Where main turbine rotors are subjected to thermal stability tests at both forge and turbine builders' works, the foregoing requirements are applicable to both tests. It is not required that auxiliary turbine rotors be tested for thermal stability, but, if such tests are carried out, the requirement for main turbine rotors will be generally applicable.

### 7.2 Balancing

7.2.1 All rotors as finished-bladed and complete with half-coupling are to be dynamically balanced to the Surveyor's satisfaction, in a machine of sensitivity appropriate to the size of rotor.

### 7.3 Hydraulic tests

7.3.1 Manoeuvring valves are to be tested to twice the working pressure. The nozzle boxes of impulse turbines are to be tested to 1,5 times the working pressure.

7.3.2 The cylinders of all turbines are to be tested to 1,5 times the working pressure in the casing, or to 2,0 bar (2,0 kgf/cm<sup>2</sup>), whichever is the greater.



# Steam Turbines

## Part 5, Chapter 3

Section 7

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7.3.3 For test purposes, the cylinders may be subdivided with temporary diaphragms for distribution of test pressures.

7.3.4 Condensers are to be tested in the steam space to 1,0 bar (1,0 kgf/cm<sup>2</sup>). The water space is to be tested to the maximum pressure which the pump can develop at ship's full draught with the discharge valve closed plus 0,7 bar (0,7 kgf/cm<sup>2</sup>), with a minimum test pressure of 2,0 bar (2,0 kgf/cm<sup>2</sup>). Where the operating conditions are not known, the test pressure is to be not less than 3,4 bar (3,5 kgf/cm<sup>2</sup>), see Chapter 14.

### 7.4 Indicators for movement

7.4.1 Indicators for determining the axial position of rotors relative to their casings, and for showing the longitudinal expansion of casings at the sliding feet, if fitted, are to be provided for main turbines. The latter indicators should be fitted at both sides and be readily visible.

### 7.5 Weardown gauges

7.5.1 Main and auxiliary turbines are to be provided with bridge weardown gauges for testing the alignment of the rotors.

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### ■ Cross-references

The pumping arrangements, including cooling water and lubricating oil systems, are to comply with the requirements of Chapters 13 and 14.

For lists of spare gear to be carried, see Chapter 1,7.

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## Section

- 1 **General requirements**
- 2 **Particulars to be submitted**
- 3 **Materials**
- 4 **Design and construction**
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- a total pressure of 101,3 kPa;
  - an ambient temperature of 15°C;
  - a relative humidity of 60 per cent; and
- (b) for the exhaust at the turbine exhaust flange (or recuperator outlet):
- a static pressure of 101,3 kPa.

## 1.3 Power ratings

1.3.1 Where the dimensions of any particular component are determined from shaft power,  $P$ , in kW, and revolutions per minute,  $R$ , the values are those defined in Chapter 1.

## 1.4 Gas turbine type approval

1.4.1 New gas turbine types or developments of existing types are to be type approved in accordance with Lloyd's Register's (hereinafter referred to as 'LR') *Type Approval System Procedure – Test Specification GT04*.

1.4.2 Where a gas turbine type has subsequently proved satisfactory in service with a number of applications, a maximum power uprating of 10 per cent may be considered without a further complete design re-assessment and type test.

## 1.5 Inclination of vessel

1.5.1 Gas turbines are to operate satisfactorily under the conditions of inclinations as shown in Table 1.3.2 in Chapter 1.

## ■ Scope

The requirements of this Chapter are applicable to gas turbines for main propulsion and also, where powers exceed 110 kW (150 shp), to those for essential auxiliary services. The requirements do not apply to exhaust gas turbo-blowers.

Approval will be in respect of the mechanical integrity of the gas turbine (including gas generator and power turbine), intake and exhaust ducting configuration, acoustic enclosure configuration (where appropriate), fuel, lubricating oil and starter systems, control alarm and monitoring systems and other critical support systems.

Type approval of the gas turbine bare engine will be required as part of the approval process for first of type.

Primary exhaust gas emissions abatement plant (where fitted) is to meet the requirements of this Chapter; additionally, it shall meet those of Chapter 24. Where secondary exhaust gas emissions abatement systems are fitted to gas turbines, they are to meet the requirements of Chapter 24.

## ■ Section 1 General requirements

### 1.1 Application

1.1.1 This Chapter is to be read in conjunction with Chapter 1 *General Requirements for the Design and Construction of Machinery*, Pt 6, Ch 1 *Control Engineering Systems*, and Pt 6, Ch 2 *Electrical Engineering*.

### 1.2 Standard reference conditions

1.2.1 Where power, efficiency, heat rate or specific consumption refer to standard conditions (ISO 2314), such conditions are to be:

- (a) for the intake air at the compressor flange (compressor intake flare):

## ■ Section 2 Particulars to be submitted

### 2.1 Plans and information

2.1.1 The following plans are to be submitted for consideration:

- Casings.
- Combustion chambers, intercoolers and heat exchangers.
- Compressor and gas generator rotating components.
- Control engineering systems, see Pt 6, Ch 1.
- Cooling and sealing air arrangements for compressor and gas generator components: Schematic only.
- Cooling water system: Schematic only, where applicable.
- Fuel systems: Schematic only.
- Gas turbine unit acoustic enclosure, if applicable, including ventilation and drainage systems: Schematic only.
- Inlet and exhaust ducting arrangement.
- Lubricating oil systems: Schematic only.
- Nozzles, blades and blade attachments.
- Oil fuel systems: Schematic only.
- Power turbine components.
- Rotors, bearings and couplings.
- Sectional assembly.
- Securing arrangement, including details of resilient mounts, where applicable.
- Starting system: Schematic only.

2.1.2 The following information and calculations, where applicable, are to be submitted:

- (a) Operational requirements:
  - Proposed field of application and operational limitations.
  - Power/speed operational envelope.
  - Calculations and information for short-term high power operation.
  - Operation and maintenance manuals including the declared lives of critical components and overhaul schedules recommended by the manufacturer.
- (b) Calculations of the critical speeds of blade and rotor vibration, giving full details of the basic assumptions, see *also* 4.3.1.
- (c) Analysis of the effect of rotor blade release together with details of operating experience, see *also* 4.3.2.
- (d) High temperature characteristics of the materials, including (at working temperatures) the associated creep rate and rupture strength for the designed service life, fatigue strength, corrosion resistance and scaling properties.
- (e) Material requirements:
  - Particulars of heat treatment, including stress relief.
  - Material specifications covering the listed components together with details of any surface treatments, non-destructive testing and hydraulic tests.
- (f) The most onerous pressures and temperatures to which each component may be subjected are to be indicated on plans or provided as part of the design specification.
- (g) Calculations of the steady state stresses, including the effect of stress raisers, etc., in the compressor and turbine rotors and blading at the maximum speed and temperature in service. Such calculations are to indicate the designed service life and be accompanied, where possible, by test results substantiating the limiting criteria.
- (h) Details of calculations and tests to establish the service life of other stressed or safety critical components, including bearings, seals, couplings and gearing. Calculations and tests are to take account of all relevant environmental factors including the particular type of service and fuel intended to be used.
- (j) Mounting requirements:
  - Securing arrangements, including details of resilient mounts.
  - Calculations concerning the amplitude and frequency of vibration associated with resilient type mountings.
- (k) A Failure Mode and Effects Analysis (FMEA).
- (l) Miscellaneous:
  - Design standard of intake filtration for water particulate and corrosive marine salts.
  - Details of compressor washing system.
  - Fuel specification.

2.1.3 Components fabricated by means of welding will be considered for acceptance if constructed by firms whose works are properly equipped to undertake welding of the standards appropriate to the components. Details are to be submitted for consideration.

2.1.4 Before work is commenced, manufacturers are to submit for consideration details of proposed welding procedures and their proposals for routine examination of joints by non-destructive means.

2.1.5 The manufacturer's proposals for testing the gas turbine are to be submitted for consideration and are to include rotor balancing techniques, methods of determining the soundness of pressure casings and heat exchanger tests, see Section 1.

## Section 3 Materials

### 3.1 Materials for forgings

3.1.1 Details of materials for rotors and discs are to be submitted for approval.

### 3.2 Material tests and inspection

3.2.1 Components are to be tested in accordance with the relevant requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

3.2.2 For components of novel design, special consideration will be given to the material test and non-destructive testing requirements.

## Section 4 Design and construction

### 4.1 General

4.1.1 All parts of compressors, turbines, etc., are to have clearances and fits consistent with adequate provision for the relative thermal expansion of the various components. Provision is to be made to limit the distortion of the casing and rotor under all normal operating conditions.

4.1.2 Gas generator and power turbine bearings are to be so disposed and supported that lubrication is not adversely affected by heat flow from adjacent hot parts. Effective means are to be provided for intercepting oil leakage and preventing oil from reaching high temperature glands and casings.

### 4.2 Vibration

4.2.1 The design and manufacture of compressor and turbine rotors, rotor discs and rotor blades are to ensure freedom from undue vibration within the full operating speed range. Where critical speeds are found by calculation to occur within the operating speed range, vibration tests may be required in order to verify the calculations, see *also* Chapter 8.

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## Part 5, Chapter 4

Section 4

4.2.2 Vibration monitoring is to form an integral part of the gas turbine safety and control system. The vibration monitoring system is to be capable of detecting the out-of-balance of major parts with means being provided to shutdown the gas turbine, before an over-critical situation occurs, i.e. multiple rotor blade or disc release.

### 4.3 Containment

4.3.1 Gas turbines and power turbines are to be designed and installed, so far as is practicable, to contain debris in the event of rotor blade release.

4.3.2 In the event of a major component failure, when the turbine casing may not contain the debris; oil fuel, lubricating oil and other potentially hazardous systems or equipment are, where practicable, to be located outside of the plane of high speed rotating parts. This requirement also applies to fire detection and extinction equipment, see also Section 5.

4.3.3 Gas turbine ancillaries containing flammable products are to be segregated or protected from high temperature areas.

### 4.4 Intake and exhaust ducts

4.4.1 Air intakes are to be designed and located to minimise the possibility of ingestion of harmful objects. Means are also to be provided for detecting and preventing icing up of air intakes.

4.4.2 Suitable intake filtration is to be provided to control the ingestion of water, particulate and corrosive marine salts within the gas turbine manufacturer's specified limits.

4.4.3 Where an air intake enclosure forms the connection between the ship's downtake and the gas turbine installation, a suitable alarm function is to be provided to give warning when an unacceptable air intake pressure loss is reached at the air inlet (bellmouth) of the gas turbine.

4.4.4 Intakes are to be designed such that material cannot become detached due to air flow or corrosion. Fixing bolts and fastenings are to be positively locked so that they cannot work loose.

4.4.5 Multi-engine installations are to have separate intakes and exhausts so arranged as to prevent induced circulation through a stopped gas turbine unit.

4.4.6 The arrangement of the exhaust duct is to be such as to prevent, under normal conditions of ship motion and atmospheric conditions, exhaust gases being drawn into machinery spaces, air conditioning systems and intakes.

4.4.7 Where the exhaust is led overboard near the waterline, means are to be provided to prevent water from being siphoned back into the gas turbine. Where the exhaust is cooled by water spray, the exhaust pipes are to be self-draining overboard. Erosion/corrosion-resistant shut-off flaps or other devices are to be fitted on the hull side shell or pipe end with suitable arrangements made to prevent water flooding the machinery space.

### 4.5 External influences

4.5.1 Pipes and ducting connected to casings are to be so designed that they apply no excessive loads or moments to the compressors and turbines.

4.5.2 Platform gratings and fittings in way of the supports are to be so arranged that casing expansion is not restricted.

4.5.3 Where the gas turbine seating incorporates a tank structure, any temperature variation of the tank in service is not to adversely affect the gas generator and power turbine alignment.

4.5.4 For machinery fastening arrangements, including resilient mounting, see Chapter 1.

### 4.6 Corrosive deposits

4.6.1 Means are to be provided for periodic removal of salt deposits and atmospheric contaminants from blading and internal surfaces.

### 4.7 Acoustic enclosures

4.7.1 Acoustic enclosures, where fitted, are to be provided with an access door, adequate internal lighting and one or more observation windows to allow the viewing of critical parts of the gas turbine.

4.7.2 A suitable ventilation system, designed to maintain all components within their safe working temperature under all operating conditions is to be provided.

4.7.3 The ventilation system is to be fitted with shut-off flaps arranged to close automatically upon activation of the enclosure's fire detection and extinguishing system.

4.7.4 Acoustic enclosure fire safety arrangements are to comply with the requirements of Pt 6, Ch 1 and the *International Convention for the Safety of Life at Sea, 1974*, as amended (SOLAS 74), see also 8.7.1.

### 4.8 Thermal insulation

4.8.1 Where surfaces of the gas generator, power turbine and exhaust volute exceed a temperature of 220°C during operation, these are to be suitably insulated and clad to minimise the risk of fire and prevent damage by heat to adjacent components, see 5.1.5.

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Sections 4 & 5

## 4.9 Welded construction

4.9.1 Welding is to be carried out in accordance with the requirements of Chapter 13 of the Rules for Materials, using welding procedures and welders that have been qualified in accordance with Chapter 12 of the Rules for Materials.

4.9.2 Stress relief heat treatment is to be applied to all cylinders, rotors and associated components on completion of all welding, see Chapter 17.

## 4.10 Turning gear

4.10.1 Gas generator turning gear is to be provided to facilitate operating and maintenance regimes as required by the manufacturer.

4.10.2 The turning gear may be hand operated (manual) except where this is not practicable. If electrically driven, the motor is to be continuously rated.

4.10.3 The turning gear is to be fitted with safety interlocks which prevent engine operation when engaged, see Ch 1,3.9. Indication of engaged/not engaged is to be provided at all start positions.

4.10.4 The remote control device of power-driven turning gear is to be so designed that power is removed from the turning gear when the operating switch is released.

4.10.5 If permanently attached, means are to be provided to secure the turning gear when disengaged.

5.1.5 The gas turbine design and construction are to minimise the possibility of a fire fed by fuel or lubricating oil leaks.

5.1.6 In dual-fuel applications, provision is to be made for automatic isolation of both primary and standby fuel supplies to the engine in the event of a fire.

## 5.2 Oil fuel systems

5.2.1 Oil fuel arrangements are to comply with the requirements of Chapter 14.

5.2.2 All external high pressure oil fuel delivery lines between the pressure fuel pumps and fuel metering valves are to be protected with a jacketed piping system capable of containing fuel from a high pressure line failure to prevent oil fuel or oil fuel mist from reaching a source of ignition on the engine or its surroundings.

5.2.3 Suitable arrangements are to be made for draining any oil fuel leakage from the protection required by 5.2.2 and to prevent contamination of the lubricating oil by oil fuel. An alarm is to be provided to indicate that leakage is taking place.

5.2.4 At least two filters are to be fitted in the oil fuel supply lines to the gas turbine and be so arranged that any filter may be cleaned without interrupting the supply of filtered oil fuel to the gas turbine.

## 5.3 Lubricating oil systems

5.3.1 Lubricating oil arrangements are to comply with the requirements of Chapter 14.

5.3.2 Where the lubricating oil for gas turbines is circulated under pressure, provision is to be made for the efficient filtration of the oil. At least two filters are to be fitted in the lubricating oil supply lines to the gas turbine and be so arranged that any filter may be cleaned without interrupting the supply of filtered lubricating oil to the gas turbine.

## 5.4 Cooling systems

5.4.1 Cooling water arrangements are to comply with the requirements of Chapter 14, where appropriate.

## Section 5 Piping systems

### 5.1 General

5.1.1 Gas turbine piping systems are, in general, to comply with the requirements given in Chapter 12 and Chapter 14, due regard being paid to the particular type of installation. For the burning of compressed natural gas, see the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases*.

5.1.2 The materials and/or their surface treatment used for the storage and distribution of oil fuel are to be selected such that they do not introduce contamination or modify the properties of the fuel.

5.1.3 Corrosion resistant materials are to be used in all fuel pipes between the treatment and combustion systems.

5.1.4 Suitable fuel treatment systems, including filtration and centrifuging, are to be provided to control the level of water and particulate contamination within the engine manufacturer's specified limits.

# Gas Turbines

## Part 5, Chapter 4

Sections 6, 7 &amp; 8

### ■ Section 6 Starting arrangements

#### 6.1 General

6.1.1 Equipment for initial starting of gas turbines is to be provided and arranged such that the necessary initial charge of starting air, hydraulic or electrical power can be developed on board the ship without external aid. If, for this purpose, an emergency air compressor or electric generator is required, these units are to be power-driven by manually-started oil engines, except in the case of small installations where a hand-operated compressor of approved capacity may be accepted.

6.1.2 Alternatively, other devices of approved type may be accepted as a means of providing the initial start.

6.1.3 Where the integrity of the starting system is susceptible to overspeed conditions, appropriate alarm and/or trip functions are to be provided, see also Pt 6, Ch 1.

#### 6.2 Purging before ignition

6.2.1 Means are to be provided to clear all parts of the gas turbine of the accumulation of oil fuel or for purging gaseous fuel before ignition commences on starting, or recommences after failure to start. The purge is to be of sufficient duration to displace at least three times the volume of the exhaust system.

#### 6.3 Air starting

6.3.1 Where the gas turbine is arranged for air starting, the total air receiver capacity is to be sufficient to provide, without replenishment, not less than six consecutive starts. At least two air receivers of approximately equal capacity are to be provided to satisfy the plant air start requirements. For scantlings and fittings of air receivers, see Chapter 11.

6.3.2 For multi-engine installations, three consecutive starts per engine are required.

#### 6.4 Electric starting

6.4.1 Where the gas turbine is fitted with electric starters powered from batteries, two batteries are to be fitted. Each battery is to be capable of starting the gas turbine and the combined capacity is to be sufficient without recharging to provide the number of starts required by 6.3.1 or 6.3.2.

6.4.2 The requirements for battery installations are given in Pt 6, Ch 2.

#### 6.5 Hydraulic starting

6.5.1 Where the gas turbine is arranged for hydraulic starting, the capacity of the power pack is to be sufficient to provide the number of starts of the gas turbine as required by 6.3.1 or 6.3.2.

### ■ Section 7 Tests

#### 7.1 Dynamic balancing

7.1.1 All compressor and turbine rotors as finished-bladed and complete with all relevant parts such as half-couplings, are to be dynamically balanced in accordance with the manufacturer's specification in a machine of sensitivity appropriate to the size of rotor.

#### 7.2 Hydraulic testing

7.2.1 Where design permits, casings are to be tested to a hydraulic pressure equal to 1,5 times the highest pressure in the casing during normal operation, or 1,5 times the pressure during starting, whichever is the higher. For test purposes, if necessary, the casings may be subdivided with temporary diaphragms for distribution of test pressure. Where the operating temperature exceeds 300°C the test pressure is to be suitably corrected.

7.2.2 Where hydraulic testing is impracticable, 100 per cent non-destructive tests by ultrasonic or radiographic methods are to be carried out on all casing parts with satisfactory results. Where ultrasonic tests have been carried out, the manufacturer is to provide documentary evidence that ultrasonic examination has been carried out by an approved operator and that there were no indications of defects which could be expected to have a prejudicial effect on the operational performance of the gas turbine.

7.2.3 The shell and tube arrangement of intercoolers and heat exchangers are to be tested to 1,5 times their maximum working pressure.

#### 7.3 Overspeed tests

7.3.1 Before installation, it is to be satisfactorily demonstrated that the gas turbine is capable of safe operation for five minutes at 5 per cent above the nominal setting of the overspeed protective device, or 15 per cent above the maximum design speed, whichever is the higher.

7.3.2 Where it is impracticable to overspeed the complete installation, each compressor and turbine rotor completely bladed and with all relevant parts such as half-couplings, are to be overspeed-tested individually at the appropriate speed.

### ■ Section 8 Control, alarm and safety systems

#### 8.1 General

8.1.1 Control alarm and safety systems are to comply with the requirements of Pt 6, Ch 1.



**8.1.2** All gas turbines intended for essential services are to be provided with means of indicating the lubricating oil pressure supply to them. Where such turbines are of more than 37 kW (50 shp), audible and visual alarms are to be fitted to give warning of an appreciable reduction in pressure of the lubricating oil supply. Further, these alarms are to be actuated from the outlet side of any restrictions, such as filters, coolers, etc.

## 8.2 Overspeed protection and shutdown system

**8.2.1** The gas turbine is to be protected against overspeed by the provision of a suitable device(s) capable of shutting-down the gas turbine safely before a dangerous overspeed condition occurs.

## 8.3 Power turbine inlet over-temperature control

**8.3.1** The power turbine is to be protected against over-temperature by the provision of a suitable device(s) capable of controlling the temperature within acceptable limits or shutting-down the gas turbine safely to prevent damage.

## 8.4 Flameout

**8.4.1** Indication is to be provided for identifying poor combustion from each combustion chamber, flame-out and failure to ignite conditions, see *also* 6.2.1.

## 8.5 Lubricating oil system

**8.5.1** Means are to be provided to accurately determine the pressure and temperature of the lubricating oil supply to the various parts of the gas generator and power turbine, and scavenge oil and return systems to ensure safe operation.

**8.5.2** Means are to be provided to ensure that the temperature of the lubrication oil supply is automatically controlled to maintain steady-state conditions throughout the normal operating range of the gas turbine.

**8.5.3** Where the oil supply to the power turbine is fed from a separate supply system, similar arrangements to those detailed above are to be provided.

## 8.6 Hand trip arrangement

**8.6.1** Means are to be provided, at both the local and remote control/operating positions, to manually initiate the shut-down of the gas turbine in an emergency.

## 8.7 Fire detection, alarm and extinguishing systems

**8.7.1** The gas turbine installation is to be provided with a fire detection, alarm and extinguishing system. The requirements of Pt 6, Ch 1 and the *International Convention for the Safety of Life at Sea, 1974* as amended (SOLAS 74) are to be complied with.

## 8.8 Unattended machinery

**8.8.1** Where gas turbines are fitted with automatic or remote controls so that under normal operating conditions they do not require any manual intervention by the operators, they are to be provided with the alarms and safety arrangements required by 8.8 to 8.9 as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

**8.8.2** Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions which could hazard the machinery.

**8.8.3** Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

**8.8.4** Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm. LR will consider alternative arrangements which provide an equivalent level of safety.

## 8.9 Gas turbine machinery

**8.9.1** Alarms and safeguards are indicated in 8.9.2 to 8.9.4 and Table 4.8.1.

**8.9.2** The following turbine services are to be fitted with automatic temperature controls so as to maintain steady state conditions throughout the normal operating range of the turbine:

- (a) Lubricating oil supply.
- (b) Oil fuel supply, see *also* 8.9.3.
- (c) Exhaust gas.

**8.9.3** The oil fuel supply may be fitted with an automatic control for viscosity instead of the temperature control required by 8.9.2.

**8.9.4** A means of manually shutting off the fuel in an emergency is to be provided at the manoeuvring station.



# Gas Turbines

## Part 5, Chapter 4

Section 8

**Table 4.8.1 Gas turbine machinery: Alarms and safeguards**

Item	Alarm	Note
Overspeed	High	Automatic shut-down <i>see also</i> 8.2
Power turbine inlet temperature	1st stage high	Automatic power reduction
	2nd stage high	Automatic shut-down <i>see also</i> 8.3
Flame failure	Failure	Automatic shut-down, <i>see also</i> 8.4
Failure to ignite	Failure	Automatic shut-down, <i>see also</i> 8.4
Lubricating oil pressure	1st stage low	—
	2nd stage low	Automatic shut-down, <i>see also</i> 8.5
Lubricating oil temperature	High	<i>See also</i> 8.5
Lubricating oil filter differential pressure	High	—
Scavenge oil temperature	High	—
Scavenge oil pressure	Low	Automatic shut-down
Bearing temperature	High	—
Turbine vibration	1st stage high	—
	2nd stage high	Automatic shut-down, <i>see also</i> 4.2
Oil fuel supply pressure	Low	—
Oil fuel supply temperature	High	—
Oil fuel leakage	High	<i>See also</i> 5.2
Automatic starting	Failure	Automatic shut-down
Control system	Failure	Automatic shut-down
Air intake pressure	Low	<i>See also</i> 4.4.4
Feed water or water/thermal fluid forced circulation flow (if fitted)	Low	<i>See</i> Ch 14,6.2.7 and Note 4
Uptake temperature	High	To monitor for soot fires. <i>See</i> Notes 4 and 5
<b>NOTES</b> 1. For two-stage alarms, <i>see also</i> 8.8.4. 2. For requirements on purging before ignition, <i>see</i> Ch 4,6.2.1. 3. Where a requirement for disabling the automatic protection and safety system devices for machinery and engineering systems has been defined by the Owner, the consequences of using the disabling arrangements are to be established and included in the operations procedures and orders provided on board ship. Details of any disabling arrangements are to be submitted to LR for consideration in each instance. 4. Alarm is required only when suitable for operation on residual fuel grades and an exhaust gas economiser/boiler/thermal oil heater is fitted. 5. Alternatively, details of an appropriate fire detection system are to be submitted for consideration.		



# Gearing

# Part 5, Chapter 5

Sections 1 & 2

## Section

- 1 **Plans and particulars**
- 2 **Materials**
- 3 **Design**
- 4 **Construction**
- 5 **Tests**
- 6 **Control and monitoring**

## ■ Scope

The requirements of this Chapter, except where otherwise stated are applicable to oil engine gearing for main propulsion purposes and for oil engine gearing for driving auxiliary machinery which is essential for the safety of the ship or for safety of persons on board where the transmitted powers exceed 220 kW (300 shp) for propulsion drives, and 110 kW (150 shp) for auxiliary drives. Alternatively calculations using the methods defined in ISO 6336 – *Calculation of load capacity of spur and helical gears*, will be considered. In any mesh, the terms pinion and wheel refer to the smaller and larger gear respectively. For turbine gearing the loading factors  $K_A$ ,  $K_{F\alpha}$ ,  $K_{F\beta}$ ,  $K_{H\alpha}$ ,  $K_{H\beta}$  and  $K_\gamma$  will be considered. Bevel gears will be specially considered on the basis of a conversion to equivalent helical gears. For torsional vibration requirements, see Ch 8,2.3.

## ■ Section 1 Plans and particulars

### 1.1 Gearing plans

1.1.1 Particulars of the gearing are to be submitted with the plans for all propulsion gears and for auxiliary gears where the transmitted power exceeds 110 kW (150 shp), as follows:

- (a) Plans and information demonstrating conformance with the applicable Rules and Standards as stated in scope.
- (b) Shaft power and revolution for each pinion.
- (c) Number of teeth in each gear.
- (d) Reference diameters.
- (e) Helix angles at reference diameters.
- (f) Normal pitches of teeth at reference diameters.
- (g) Tip diameters.
- (h) Root diameters.
- (j) Face widths and gaps, where applicable.
- (k) Pressure angles of teeth (normal or transverse) at reference diameters.
- (l) Accuracy grade Q in accordance with ISO 1328 or an equivalent Standard.
- (m) Surface texture of tooth flanks and roots.
- (n) Minimum backlash.
- (o) Centre distance.
- (p) Basic rack tooth form.

- (q) Protuberance and final machining allowance.
- (r) Details of post hobbing processes, if any.
- (s) Details of tooth flank corrections, if adopted.
- (t) Case depth for surface-hardened teeth.
- (u) Shrinkage allowance for shrunk-on rims and hubs.
- (v) Type of coupling proposed for oil engine applications.

### 1.2 Material specifications

1.2.1 Specifications for materials of pinions, pinion sleeves, wheel rims, gear wheels, and quill shafts, giving chemical composition, heat treatment and mechanical properties, are to be submitted for approval with the plans of gearing.

1.2.2 Where the teeth of a pinion or gear wheel are to be surface hardened, i.e., carburised, nitrided, tufftrided or induction-hardened, the proposed specification and details of the procedure are to be submitted for approval.

## ■ Section 2 Materials

### 2.1 Material properties

2.1.1 In the selection of materials for pinions and wheels, consideration is to be given to their compatibility in operation. Except in the case of low reduction ratios, for gears of through-hardened steels, provision is also to be made for a hardness differential between pinion teeth and wheel teeth. For this purpose, the specified minimum tensile strength of the wheel rim material is not to be more than 85 per cent of that of the pinion.

2.1.2 Subject to 2.1.1, the specified minimum tensile strength is to be selected within the following limits:

Pinion and pinion sleeves	550 to 1050 N/mm <sup>2</sup> (56 to 107 kgf/mm <sup>2</sup> )
Gear wheels and rims	400 to 850 N/mm <sup>2</sup> (41 to 87 kgf/mm <sup>2</sup> )

A tensile strength range is also to be specified and is not to exceed 120 N/mm<sup>2</sup> (12 kgf/mm<sup>2</sup>) when the specified minimum tensile strength is 600 N/mm<sup>2</sup> (61 kgf/mm<sup>2</sup>) or less. For higher strength steels, the range is not to exceed 150 N/mm<sup>2</sup> (15 kgf/mm<sup>2</sup>).

2.1.3 Unless otherwise agreed, the full specified minimum tensile strength of the core is to be 800 N/mm<sup>2</sup> (82 kgf/mm<sup>2</sup>) for induction-hardened or nitrided gearing and 750 N/mm<sup>2</sup> (76 kgf/mm<sup>2</sup>) for carburised gearing.

2.1.4 For nitrided gearing, the full depth of the hardened zone is to be not less than 0,5 mm and the hardness is to be not less than 500 HV for a depth of 0,25 mm.

### 2.2 Non-destructive tests

2.2.1 An ultrasonic examination is to be carried out on all gear blanks where the finished diameter of the surfaces, where teeth will be cut, is in excess of 200 mm.

2.2.2 Magnetic particle or liquid penetrant examination is to be carried out on all surface-hardened teeth. This examination may also be requested on the finished machined teeth of through-hardened gears.

## Section 3 Design

### 3.1 Symbols

3.1.1 For the purposes of this Chapter the following symbols apply:

- $a$  = centre distance, in mm
- $b$  = face width, in mm
- $d$  = reference diameter, in mm
- $d_a$  = tip diameter, in mm
- $d_{an}$  = virtual tip diameter, in mm
- $d_b$  = base diameter, in mm
- $d_{bn}$  = virtual base diameter, in mm
- $d_{en}$  = virtual diameter to the highest point of single tooth pair contact, in mm
- $d_f$  = root diameter, in mm
- $d_{fn}$  = virtual root diameter, in mm
- $d_n$  = virtual reference diameter, in mm
- $d_s$  = shrink diameter, in mm
- $d_w$  = pitch circle diameter, in mm
- $f_{ma}$  = tooth flank misalignment due to manufacturing errors, in  $\mu\text{m}$
- $f_{pb}$  = maximum base pitch deviation of wheel, in  $\mu\text{m}$
- $f_{Sh}$  = tooth flank misalignment due to wheel and pinion deflections, in  $\mu\text{m}$
- $f_{Sho}$  = intermediary factor for the determination of  $f_{Sh}$
- $g_a$  = length of line of action for external gears, in mm:  

$$= 0,5\sqrt{(d_{a1}^2 - d_{b1}^2)} + 0,5\sqrt{(d_{a2}^2 - d_{b2}^2)} - a \sin \alpha_{tw}$$
 for internal gears:  

$$= 0,5\sqrt{(d_{a1}^2 - d_{b1}^2)} - 0,5\sqrt{(d_{a2}^2 - d_{b2}^2)} + a \sin \alpha_{tw}$$
- $h$  = total depth of tooth, in mm
- $h_{ao}$  = basic rack addendum of tool, in mm
- $h_F$  = bending moment arm for root stress, in mm
- $h_W$  = sum of actual tooth addenda of pinion and wheel, in mm
- $m_n$  = normal module, in mm
- $n$  = rev/min of pinion
- $q$  = machining allowances, in mm
- $q_s$  = notch parameter
- $q'$  = intermediary factor for the determination of  $C_\gamma$
- $u$  = gear ratio =  $\frac{\text{Number of teeth in wheel}}{\text{Number of teeth in pinion}} \geq 1$
- $v$  = linear speed at pitch circle, in m/s
- $x$  = addendum modification coefficient
- $y_\alpha$  = running in allowance, in  $\mu\text{m}$
- $y_\beta$  = running in allowance, in  $\mu\text{m}$
- $z$  = number of teeth
- $z_n$  = virtual number of teeth  

$$= \frac{z}{\cos^2 \beta_b \cos \beta}$$
- $C_\gamma$  = tooth mesh stiffness (mean total mesh stiffness per unit face width), in N/mm  $\mu\text{m}$

- $F_t$  = nominal tangential tooth load, in N  

$$= \frac{P}{nd} 19,098 \times 10^6$$
- $F_\beta$  = total tooth alignment deviation (maximum value specified), in  $\mu\text{m}$
- $F_{\beta x}$  = actual longitudinal tooth flank deviation before running in, in  $\mu\text{m}$
- $F_{\beta y}$  = actual longitudinal tooth flank deviation after running in, in  $\mu\text{m}$
- HV = Vickers hardness number
- $K_A$  = application factor
- $K_{F\alpha}$  = transverse load distribution factor
- $K_{F\beta}$  = longitudinal load distribution factor
- $K_{H\alpha}$  = transverse load distribution factor
- $K_{H\beta}$  = longitudinal load distribution factor
- $K_v$  = dynamic factor
- $K_{v\alpha}$  = dynamic factor for spur gears
- $K_{v\beta}$  = dynamic factor for helical gears
- $K_\gamma$  = load sharing factor
- $P$  = transmitted power, in kW
- $P_r$  = radial pressure at shrinkage surface, in N/mm<sup>2</sup>
- $P_{ro}$  = protuberance of tool, in mm
- $Q$  = accuracy grade derived from ISO 1328 – *Cylindrical gears – ISO system of accuracy*
- $R_a$  = surface roughness – arithmetical mean deviation (C.L.A.) as determined by an instrument having a minimum wavelength cut-off of 0,8 mm and for a sampling length of 2,5 mm, in  $\mu\text{m}$
- $S_{pr}$  = residual undercut left by protuberance in mm
- $S_{Fmin}$  = minimum factor of safety for bending stress
- $S_{Fn}$  = tooth root chord in the critical section, in mm
- $S_{Hmin}$  = minimum factor of safety for Hertzian contact stress
- $Y_D$  = design factor
- $Y_F$  = tooth form factor
- $Y_{RrelT}$  = relative surface finish factor
- $Y_S$  = stress concentration factor
- $Y_{ST}$  = stress correction factor
- $Y_x$  = size factor
- $Y_\beta$  = helix angle factor
- $Y_{\delta relT}$  = relative notch sensitivity factor
- $Z_E$  = material elasticity factor
- $Z_H$  = zone factor
- $Z_R$  = surface finish factor
- $Z_V$  = velocity factor
- $Z_X$  = size factor
- $Z_\beta$  = helix angle factor
- $Z_\epsilon$  = contact ratio factor
- $\alpha_{en}$  = pressure angle at the highest point of single tooth contact, in degrees
- $\alpha_n$  = normal pressure angle at reference diameter, in degrees
- $\alpha_t$  = transverse pressure angle at reference diameter, in degrees
- $\alpha_{tw}$  = transverse pressure angle at pitch circle diameter, in degrees
- $\alpha_{Fen}$  = angle for application of load at the highest point of single tooth contact, in degrees
- $\beta$  = helix angle at reference diameter, in degrees
- $\beta_b$  = helix angle at base diameter, in degrees
- $\gamma$  = intermediary factor for the determination of  $f_{Sh}$
- $\epsilon_\alpha$  = transverse contact ratio  

$$= \frac{g_\alpha \cos \beta}{\pi m_n \cos \alpha_t}$$

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$\varepsilon_{\alpha n}$  = virtual transverse contact ratio  
 $\varepsilon_{\beta}$  = overlap ratio  

$$= \frac{b \sin \beta}{\pi m_n}$$
  
 $\varepsilon_{\gamma}$  = total contact ratio  
 $\rho_{ao}$  = tip radius of tool, in mm  
 $\rho_c$  = relative radius of curvature at pitch point, in mm  

$$= \frac{a \sin \alpha_{tw} u}{\cos \beta_b (1 + u)^2}$$
  
 $\rho_F$  = tooth root fillet radius at the contact of the 30° tangent, in mm  
 $\sigma_y$  = yield or 0,2 per cent proof stress, in N/mm<sup>2</sup>  
 $\sigma_B$  = ultimate tensile strength, in N/mm<sup>2</sup>  
 $\sigma_F$  = bending stress at tooth root, in N/mm<sup>2</sup>  
 $\sigma_{Flim}$  = endurance limit for bending stress in N/mm<sup>2</sup>  
 $\sigma_{FP}$  = allowable bending stress at the tooth root, in N/mm<sup>2</sup>  
 $\sigma_H$  = Hertzian contact stress at the pitch circle, in N/mm<sup>2</sup>  
 $\sigma_{Hlim}$  = endurance limit for Hertzian contact stress, in N/mm<sup>2</sup>  
 $\sigma_{HP}$  = allowable Hertzian contact stress, in N/mm<sup>2</sup>  
 Subscript:  
     1 = pinion  
     2 = wheel  
     0 = tool.

## 3.2 Tooth form

3.2.1 The tooth profile in the transverse section is to be of involute shape, and the roots of the teeth are to be formed with smooth fillets of radii not less than  $0,25m_n$ .

3.2.2 All sharp edges left on the tips and ends of pinion and wheel teeth after hobbing and finishing are to be removed.

## 3.3 Tooth loading factors

3.3.1 For values of application factor,  $K_A$  see Table 5.3.1.

**Table 5.3.1 Values of  $K_A$**

Main and auxiliary gears	$K_A$
Main propulsion oil engine reduction gears:	
Hydraulic coupling or equivalent on input	1,10
High elastic coupling on input	1,30
Other coupling	1,50
Auxiliary gears:	
Electric and diesel engine drives with hydraulic coupling or equivalent on input	1,00
Diesel engine drives with high elastic coupling on input	1,20
Diesel engine drives with other couplings	1,40

3.3.2 Load sharing factor,  $K_{\gamma}$ . The value for  $K_{\gamma}$  is to be taken as 1,15 for multi-engine drives or split torque arrangements. Otherwise  $K_{\gamma}$  is to be taken as 1,0. Alternatively, where measured data exists, a derived value will be considered.

3.3.3 Dynamic factor,  $K_v$ :

For helical gears with  $\varepsilon_{\beta} \geq 1$ :

$$K_v = 1 + Q^2 v z_1 10^{-5} = K_{v\beta}$$

For helical gears with  $\varepsilon_{\beta} < 1$ :

$$K_v = K_{v\alpha} - \varepsilon_{\beta} (K_{v\alpha} - K_{v\beta})$$

For spur gears:

$$K_v = 1 + 1,8 Q^2 v z_1 10^{-5} = K_{v\alpha}$$

where  $\frac{v z_1}{100} > 14$  for helical gears, and

where  $\frac{v z_1}{100} > 10$  for spur gears the value of  $K_v$  will be specially considered.

3.3.4 Longitudinal load distribution factors,  $K_{H\beta}$  and  $K_{F\beta}$ :

$$K_{H\beta} = 1 + \frac{b F_{\beta y} C_{\gamma}}{2 F_t K_A K_{\gamma} K_v}$$

Calculated values of  $K_{H\beta} > 2$  are to be reduced by improved accuracy and helix correction as necessary:

where

$$F_{\beta y} = F_{\beta x} - y_{\beta} \text{ and}$$

$$F_{\beta x} = 1,33 f_{Sh} + f_{ma}$$

$$f_{ma} = \frac{2}{3} F_{\beta} \text{ at the design stage, or}$$

$$f_{ma} = \frac{1}{3} F_{\beta} \text{ where helix correction has been applied}$$

$$f_{Sh} = f_{Sho} \frac{F_t K_A K_{\gamma} K_v}{b} \text{ where}$$

$$f_{Sho} = 23 \gamma 10^{-3} \mu\text{m mm/N for gears without helix correction and without end relief, or}$$

$$= 16 \gamma 10^{-3} \mu\text{m mm/N for gears without helix correction but with end relief, where}$$

$$\gamma = \left( \frac{b}{d_1} \right)^2 \text{ for single helical and spur gears}$$

$$= 3 \left( \frac{b}{2d_1} \right)^2 \text{ for double helical gears}$$

The following minimum values are applicable, these also being the values where helix correction has been applied:

$$f_{Sho} = 10 \times 10^{-3} \mu\text{m mm/N for helical gears, or}$$

$$= 5 \times 10^{-3} \mu\text{m mm/N for spur gears}$$

For through-hardened steels and surface hardened steels running on through-hardened steels:

$$y_{\beta} = \frac{320}{\sigma_{Hlim}} F_{\beta x} \text{ when}$$

$$y_{\beta} \leq \frac{12800}{\sigma_{Hlim}} \mu\text{m, and}$$

For surface hardened steels, when

$$y_{\beta} = 0,15 F_{\beta x}$$

$$y_{\beta} \leq 6 \mu\text{m}$$

$$K_{F\beta} = K_{H\beta}^n$$

where

$$n = \frac{\left( \frac{b}{h} \right)^2}{1 + \frac{b}{h} + \left( \frac{b}{h} \right)^2}$$

NOTES

1.  $\frac{b}{h}$  is to be taken as the smaller of  $\frac{b_1}{h_1}$  or  $\frac{b_2}{h_2}$

2. For double helical gears  $\frac{b}{2}$  is to be substituted for  $b$  in the equation for  $n$ .

3.3.5 Transverse load distribution factors,  $K_{H\alpha}$  and  $K_{F\alpha}$

$$K_{H\alpha} = K_{F\alpha} \geq 1,00$$

where

$$\varepsilon_{\gamma} \leq 2$$

$$K_{H\alpha} = \frac{\varepsilon_{\gamma}}{2} \left\{ 0,9 + \frac{0,4C_{\gamma}(f_{pb} - y_{\alpha})b}{F_t K_A K_{\gamma} K_V K_{H\beta}} \right\}$$

where

$$\varepsilon_{\gamma} > 2$$

$$K_{H\alpha} = 0,9 + 0,4 \sqrt{\frac{2(\varepsilon_{\gamma} - 1)}{\varepsilon_{\gamma}}} \left\{ \frac{C_{\gamma}(f_{pb} - y_{\alpha})b}{F_t K_A K_{\gamma} K_V K_{H\beta}} \right\}, \text{ but}$$

$$K_{H\alpha} \leq \frac{\varepsilon_{\gamma}}{\varepsilon_{\alpha} Z_{\varepsilon}^2} \text{ and}$$

$$K_{F\alpha} \leq \frac{\varepsilon_{\gamma}}{0,25\varepsilon_{\gamma} + 0,75}$$

When tip relief is applied  $f_{pb}$  is to be half of the maximum specified value:

$$y_{\alpha} = \frac{160}{\sigma_{H \text{ lim}}} f_{pb} \text{ for through-hardened steels, when}$$

$$y_{\alpha} \leq \frac{6400}{\sigma_{H \text{ lim}}} \mu\text{m and}$$

$$y_{\alpha} = 0,075f_{pb} \text{ for surface hardened steels, when}$$

$$y_{\alpha} \leq 3 \mu\text{m}$$

When pinion and wheel are manufactured from different materials:

$$y_{\alpha} = \frac{y_{\alpha 1} + y_{\alpha 2}}{2}$$

3.3.6 Tooth mesh stiffness,  $C_{\gamma}$ :

$$C_{\gamma} = \frac{0,8}{q'} \cos \beta (0,75\varepsilon_{\alpha} + 0,25) \text{ N/mm } \mu\text{m}$$

where

$$q' = 0,04723 + \frac{0,1551}{Z_{n1}} + \frac{0,25791}{Z_{n2}} - 0,00635x_1 - \frac{0,11654x_1}{Z_{n1}} - 0,00193x_2 - \frac{0,24188x_2}{Z_{n2}} + 0,00529x_1^2 + 0,00182x_2^2$$

For internal gears  $Z_{n2} = \infty$

Other calculation methods for  $C_{\gamma}$  will be specially considered.

## 3.4 Tooth loading for surface stress

3.4.1 The Hertzian contact stress,  $\sigma_H$ , at the pitch circle is not to exceed the allowable Hertzian contact stress,  $\sigma_{HP}$ .

$$\sigma_H = Z_H Z_E Z_{\varepsilon} Z_{\beta} \sqrt{\frac{F_t(u+1)}{d_1 b u}} K_A K_{\gamma} K_V K_{H\beta} K_{H\alpha} \text{ and}$$

$$\sigma_{HP} = \frac{\sigma_{H \text{ lim}} Z_R Z_V Z_X}{S_{H \text{ min}}} \text{ for the pinion/wheel combination}$$

where

$$Z_H = \sqrt{\frac{2 \cos \beta_b \cos \alpha_{tw}}{\cos^2 \alpha_t \sin \alpha_{tw}}}$$

$$Z_E = 189,8 \text{ for steel}$$

$$Z_{\varepsilon} = \sqrt{\frac{4 - \varepsilon_{\alpha}}{3} (1 - \varepsilon_{\beta}) + \frac{\varepsilon_{\beta}}{\varepsilon_{\alpha}}} \text{ for } \varepsilon_{\beta} < 1 \text{ and}$$

$$Z_{\varepsilon} = \sqrt{\frac{1}{\varepsilon_{\alpha}}} \text{ for } \varepsilon_{\beta} \geq 1$$

$$Z_{\beta} = \sqrt{\cos \beta}$$

$$Z_R = \left( \frac{1}{R_a} \right)^{0,11} \text{ but } Z_R \leq 1,14$$

Where  $R_a$  is the surface roughness value of the tooth flanks. When pinion and wheel tooth flanks differ then the larger value of  $R_a$  is to be taken.

$$Z_V = 0,88 + 0,23 \left( 0,8 + \frac{32}{v} \right)^{-0,5}$$

For values of  $Z_X$ , see Table 5.3.2

$\sigma_{H \text{ lim}}$ , see Table 5.3.3

$S_{H \text{ lim}}$ , see Table 5.3.4.

**Table 5.3.2 Values of  $Z_X$**

Pinion heat treatment		$Z_X$
Carburised and induction-hardened	$m_n \leq 10$	1,00
	$10 < m_n < 30$	$1,05 - 0,005m_n$
	$30 \leq m_n$	0,9
Nitrided	$m_n < 7,5$	1,00
	$7,5 < m_n < 30$	$1,08 - 0,011m_n$
	$30 \leq m_n$	0,75
Through-hardened	All modules	1,00

**Table 5.3.3 Values of endurance limit for Hertzian contact stress,  $\sigma_{H \text{ lim}}$**

Heat treatment		$\sigma_{H \text{ lim}} \text{ N/mm}^2$
Pinion	Wheel	
Through-hardened	Through-hardened	$0,46\sigma_{B2} + 255$
Surface-hardened	Through-hardened	$0,42\sigma_{B2} + 415$
Carburised, nitrided or induction hardened	Soft bath nitrided (Tufftrided)	1000
Carburised, nitrided or induction-hardened	Induction-hardened	$0,88 \text{ HV}_2 + 675$
Carburised or nitrided	Nitrided	1300
Carburised	Carburised	1500

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**Table 5.3.4 Factors of safety**

	$S_H \text{ min}$	$S_F \text{ min}$
Main propulsion gears	1,4	1,8
Auxiliary gears	1,15	1,40

### 3.5 Tooth loading for bending stress

3.5.1 The bending stress at the tooth root,  $\sigma_F$  is not to exceed the allowable tooth root bending stress  $\sigma_{FP}$

$$\sigma_F = \frac{F_t}{b m_n} Y_F Y_S Y_\beta K_A K_V K_{F\beta} K_{F\alpha} \text{ N/mm}^2$$

$$\sigma_{FP} = \frac{\sigma_{F \text{ lim}} Y_{ST} Y_{\delta \text{ rel T}} Y_{R \text{ rel T}} Y_x}{S_{F \text{ min}} Y_D} \text{ N/mm}^2$$

For values of  $S_{F \text{ min}}$ , see Table 5.3.4

$\sigma_{F \text{ lim}}$ , see Table 5.3.5

Stress correction factor  $Y_{ST} = 2$ .

**Table 5.3.5 Values of endurance limit for bending stress,  $\sigma_{F \text{ lim}}$** 

Heat treatment	$\sigma_{F \text{ lim}} \text{ N/mm}^2$
Through-hardened carbon steel	$0,09\sigma_B + 150$
Through-hardened alloy steel	$0,1\sigma_B + 185$
Soft bath nitrided (Tufftrided)	330
Induction-hardened	$0,35 \text{ HV} + 125$
Gas nitrided	390
Carburised A	450
Carburised B	410
NOTES	
1. A is applicable for Cr Ni Mo carburising steels.	
2. B is applicable for other carburising steels.	

3.5.2 Tooth form factor,  $Y_F$ :

$$Y_F = \frac{6 \frac{h_F}{m_n} \cos \alpha_{F \text{ en}}}{\left(\frac{S_{Fn}}{m_n}\right)^2 \cos \alpha_n}$$

where

$h_F$ ,  $\alpha_{F \text{ en}}$  and  $S_{Fn}$  are shown in Fig. 5.3.1.

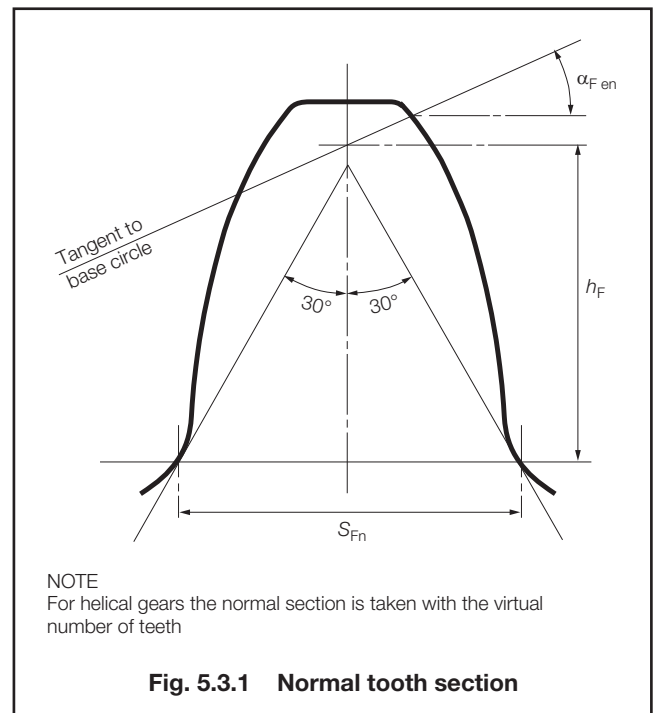
$$\frac{S_{Fn}}{m_n} = z_n \sin \left( \frac{\pi}{3} - v \right) + \sqrt{3} \left( \frac{G}{\cos v} - \frac{\rho_{ao}}{m_n} \right)$$

where

$$v = \frac{2G}{z_n} \tan v - H$$

$$G = \frac{\rho_{ao}}{m_n} - \frac{h_{ao}}{m_n} + x$$

$$H = \frac{2}{z_n} \left( \frac{\pi}{2} - \frac{E}{m_n} \right) - \frac{\pi}{3}$$


**Fig. 5.3.1 Normal tooth section**

$$E = \frac{\pi}{4} m_n - h_{ao} \tan \alpha_n + \frac{S_{pr}}{\cos \alpha_n} - (1 - \sin \alpha_n) \frac{\rho_{ao}}{\cos \alpha_n}$$

$E$ ,  $h_{ao}$ ,  $\alpha_n$ ,  $S_{pr}$  and  $\rho_{ao}$  are shown in Fig. 5.3.2

$$\frac{\rho_F}{m_n} = \frac{\rho_{ao}}{m_n} + \frac{2G^2}{\cos v (z_n \cos^2 v - 2G)}$$

$$d_{en} = \frac{2z}{|z|} \left\{ \left[ \sqrt{\left( \frac{d_{an}}{2} \right)^2 - \left( \frac{d_{bn}}{2} \right)^2} - \frac{\pi d \cos \beta \cos \alpha_n}{|z|} (\epsilon_{an} - 1) \right]^2 + \left( \frac{d_{bn}}{2} \right)^2 \right\}^{1/2}$$

where

$$d_{an} = d_n + d_a - d$$

$$d_n = \frac{d}{\cos^2 \beta_b}$$

$$d_{bn} = d_n \cos \alpha_n$$

$$\epsilon_{an} = \frac{\epsilon_a}{\cos^2 \beta_b}$$

$$\gamma_e = \frac{\frac{\pi}{2} + 2x \tan \alpha_n}{z_n} + \text{inv. } \alpha_n - \text{inv. } \alpha_{en}$$

where

$$\alpha_{en} = \arccos \frac{d_{bn}}{d_{en}}$$

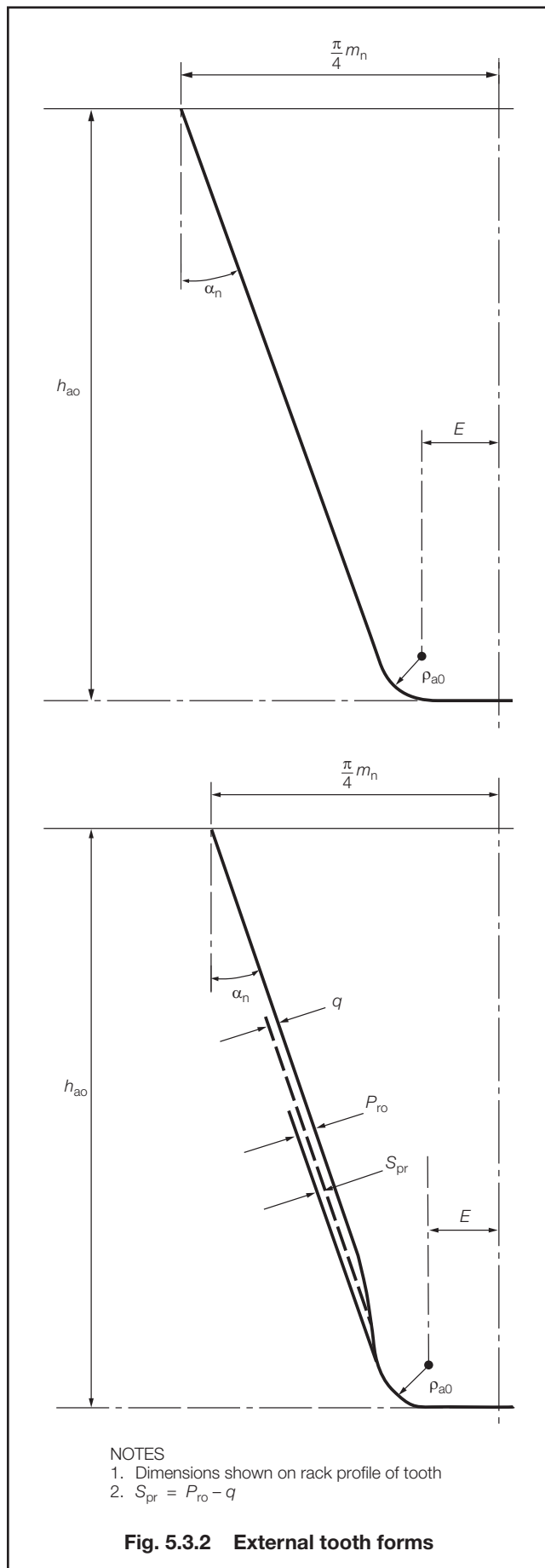
$$\frac{h_F}{m_n} = \frac{1}{2} \left[ (\cos \gamma_e - \sin \gamma_e \tan \alpha_{F \text{ en}}) \frac{d_{en}}{m_n} - \right.$$

$$\left. z_n \cos \left( \frac{\pi}{3} - v \right) - \frac{G}{\cos v} + \frac{\rho_{ao}}{m_n} \right]$$

where

$$\alpha_{F \text{ en}} = \alpha_{en} - \gamma_e.$$





3.5.3 For internal tooth forms the form factor is calculated, as an approximation, for a substitute gear rack with the form of the basic rack in the normal section, but having the same tooth depth as the internal gear:

$$\frac{S_{Fn2}}{m_n} = 2 \left[ \frac{\pi}{4} + \tan \alpha \left( \frac{h_{ao2} - p_{ao2}}{m_n} \right) + \left( \frac{p_{ao2} - S_{pr}}{m_n \cos \alpha_n} - \frac{p_{ao2}}{m_n} \cos \frac{\pi}{6} \right) \right], \text{ and}$$

$$\frac{h_{F2}}{m_n} = \frac{d_{en2} - d_{fn2}}{2m_n} - \left[ \frac{\pi}{4} + \left( \frac{h_{ao2}}{m_n} - \frac{d_{en2} - d_{fn2}}{2m_n} \right) \tan \alpha_n \right] \tan \alpha_n - \frac{p_{ao2}}{m_n} \left( 1 - \sin \frac{\pi}{6} \right)$$

where

$\alpha_{Fen}$  is taken as being equal to  $\alpha_n$

$$p_{F2} = \frac{p_{ao2}}{2}$$

$d_{en2}$  is calculated as  $d_{en}$  for external gears, and  
 $d_{fn} = d - d_f - d_n$ .

3.5.4 Stress concentration factor,  $Y_s$

$$Y_s = (1,2 + 0,13L) q_s \left( \frac{1}{1,21 + 2,3/L} \right)$$

where

$$L = \frac{S_{Fn}}{h_F}$$

$$q_s = \frac{S_{Fn}}{2p_F}$$

when  $q_s < 1$  the value of  $Y_s$  is to be specially considered.  
 The formula for  $Y_s$  is applicable to external gears with  $\alpha_n = 20^\circ$  but may be used as an approximation for other pressure angles and internal gears.

3.5.5 Helix angle factor  $Y_\beta$

$$Y_\beta = 1 - \left( \epsilon_\beta \frac{\beta}{120} \right), \text{ if } \epsilon_\beta > 1 \text{ let } \epsilon_\beta = 1$$

but  $Y_b \geq 1 - 0,25\epsilon_b \geq 0,75$ .

3.5.6 Relative notch sensitivity factor,  $Y_{\delta \text{ rel T}}$

$$Y_{\delta \text{ rel T}} = 1 + 0,036 (q_s - 2,5) \left( 1 - \frac{\sigma_y}{1200} \right) \text{ for through-hardened steels}$$

$$Y_{\delta \text{ rel T}} = 1 + 0,008 (q_s - 2,5) \text{ for carburised and induction-hardened steels, and}$$

$$Y_{\delta \text{ rel T}} = 1 + 0,04 (q_s - 2,5) \text{ for nitrided steels.}$$

3.5.7 Relative surface finish factor,  $Y_{R \text{ rel T}}$

$$Y_{R \text{ rel T}} = 1,674 - 0,529 (6R_a + 1)^{0,1} \text{ for through-hardened, carburised and induction hardened steels, and}$$

$$Y_{R \text{ rel T}} = 4,299 - 3,259 (6R_a + 1)^{0,005} \text{ for nitrided steels.}$$

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- 3.5.8 Size factor,  $Y_x$   
 $Y_x = 1,00$ , when  $m_n \leq 5$   
 $Y_x = 1,03 - 0,006m_n$  for through hardened steels  
 $Y_x = 0,85$ , when  $m_n \geq 30$   
 $Y_x = 1,05 - 0,01m_n$  for surface-hardened steels  
 $Y_x = 0,80$ , when  $m_n \geq 25$ .

- 3.5.9 Design factor,  $Y_D$   
 $Y_D = 0,83$  for gears treated with a controlled shot peening process  
 $Y_D = 1,5$  for idler gears  
 $Y_D = 1,25$  for shrunk on gears, or  
 $Y_D = 1 + \frac{0,2d_s^2 d P_r b}{F_t \sigma_{F \lim} (d_f^2 - d_s^2)}$ , otherwise  
 $Y_D = 1,00$ .

## 3.6 Factors of safety

- 3.6.1 Factors of safety are shown in Table 5.3.4.

## 3.7 Design of enclosed gear shafting

3.7.1 This sub-Section is applicable to shafting enclosed within the gearcase. Final gear wheel shafts and thrust shafts are to be in accordance with Ch 6,3.3 and Ch 6,3.4 respectively.

3.7.2 The diameter of the enclosed gear shafting adjacent to the pinion or wheel is to be not less than the greater of  $d_b$  or  $d_t$ , where:

$$d_b = 365 \left( \frac{P L}{R d_w S_b} \right)^{1/3} \left( 1 + \left( \frac{\tan \alpha_n}{\cos \beta} + \frac{\tan \beta d_w}{L} \right)^2 \right)^{1/6}$$

$$d_t = 365 \left( \frac{P}{R S_s} \right)^{1/3}$$

where

- $S_b = 45 + 0,24 (\sigma_u - 400)$  and  
 $S_s = 42 + 0,09 (\sigma_u - 400)$   
 $L$  = span between shaft bearing centres, in mm  
 $\alpha_n$  = normal pressure angle at the gear reference diameter, in degrees  
 $\beta$  = helix angle at the gear reference diameter, in degrees  
 $d_w$  = pitch circle diameter of the gear teeth, in mm  
 $\sigma_u$  = specified minimum tensile strength of the shaft material, in N/mm<sup>2</sup>.

NOTE

$P$  in kW and  $R$  in rpm are as defined in Ch 1,3.3.  
 Numerical value used for  $\sigma_u$  is not to exceed 800 N/mm<sup>2</sup> for gear and thrust shafts.

3.7.3 For the purposes of the above it is assumed that the pinion or wheel is mounted symmetrically spaced between bearings.

3.7.4 Outside a length equal to the required diameter at the pinion or wheel, the diameter may be reduced, if applicable, to that required for  $d_t$ .

3.7.5 For bevel gear shafts, where a bearing is located adjacent to the gear section, the diameter of the shaft is to be not less than  $d_t$ . Where a bearing is not located adjacent to the gear the diameter of the shaft will be specially considered.

## Section 4 Construction

### 4.1 Gear wheels and pinions

4.1.1 Where castings are used for wheel centres, any radial slots in the periphery are to be fitted with permanent chocks before shrinking-on the rim.

4.1.2 Where bolts are used to secure side plates to rim and hub, the bolts are to be a tight fit in the holes and the nuts are to be suitably locked by means other than welding.

4.1.3 Where welding is employed in the construction of wheels, the welding procedure is to be approved by the Surveyors before work is commenced. For this purpose, welding procedure approval tests are to be carried out with satisfactory results. Such tests are to be representative of the joint configuration and materials. Wheels are to be stress relieved after welding. All welds are to have a satisfactory surface finish and contour. Magnetic particle or liquid penetrant examination of all important welded joints is to be carried out to the satisfaction of the Surveyors.

4.1.4 In general, arrangements are to be made so that the interior structure of the wheel may be examined. Alternative proposals will be specially considered.

### 4.2 Accuracy of gear cutting and alignment

4.2.1 The machining accuracy (Q grade) of pinions and wheels is to be demonstrated to the satisfaction of the Surveyors. For this purpose records of measurements should be available for review by Surveyors on request.

4.2.2 Where allowance has been given for end relief or helix correction the normal shop meshing tests are to be supplemented by tooth alignment traces or other approved means to demonstrate the effectiveness of such modifications.

### 4.3 Gearcases

4.3.1 Gearcases and their supports are to be designed sufficiently stiff such that misalignment at the mesh due to movements of the external foundations and the thermal effects under all conditions of service do not disturb the overall tooth contact.

4.3.2 For gearcases fabricated by fusion welding the carbon content of steels should generally not exceed 0,23 per cent. Steels with higher carbon content may be approved subject to satisfactory results from weld procedure tests.

# Gearing

## Part 5, Chapter 5

Sections 4 & 5

4.3.3 Gearcases are to be stress relief heat treated on completion of all welding.

4.3.4 Inspection openings are to be provided at the peripheries of gearcases to enable the teeth of pinions and wheels to be readily examined. Where the construction of gearcases is such that sections of the structure cannot readily be moved for inspection purposes, access openings of adequate size are also to be provided at the ends of the gearcases to permit examination of the structure of the wheels. Their attachment to the shafts is to be capable of being examined by removal of bearing caps or by equivalent means.

### Section 5 Tests

#### 5.1 Balance of gear pinions and wheels

5.1.1 All rotating elements, (e.g. pinion and wheel shaft assemblies and coupling parts), are to be appropriately balanced.

5.1.2 The permissible residual unbalance,  $U$ , is defined as follows:

$$U = \frac{60m}{N} \times 10^3 \text{ g mm for } N \leq 3000$$

$$U = \frac{24m}{N} \times 10^3 \text{ g mm for } N > 3000$$

where

$m$  = mass of rotating element, kg

$N$  = maximum service rev/min of the rotating element.

5.1.3 Where the size or geometry of a rotating element precludes measurement of the residual unbalance, a full speed running test of the assembled gear unit at the manufacturer's works will normally be required to demonstrate satisfactory operation.

#### 5.2 Meshing tests

5.2.1 Initially, meshing gears are to be carefully matched on the basis of the accuracy measurements taken. The alignment is to be demonstrated in the workshop by meshing in the gearbox without oil clearance in the bearings. Meshing is to be carried out with the gears locating in their light load positions and a load sufficient to overcome pinion weight and axial movement is to be imposed.

5.2.2 The gears are to be suitably coated to demonstrate the contact marking. The marking is to reflect the accuracy grade specified and end relief of helix correction, where these have been applied.

5.2.3 For gears without helix correction the marking is to be not less than shown in Table 5.5.1.

**Table 5.5.1 No load tooth contact marking**

ISO accuracy grade	Contact marking area
$Q \leq 5$	40% $h_w$ for 50% $b$ and 20% $h_w$ for a further 40% $b$
$Q \geq 6$	40% $h_w$ for 35% $b$ and 20% $h_w$ for a further 35% $b$
<b>NOTES</b> 1. Where $b$ is face width and $h_w$ is working tooth depth. 2. For spur gears the values of $h_w$ should be increased by a further 10%.	

5.2.4 For gears with end relief of helix correction the marking is to correspond to the designed no load contact pattern.

5.2.5 A permanent record is to be made of the meshing contact for purpose of checking the alignment when installed on board ship.

5.2.6 The full load tooth contact marking is to be not less than shown in Table 5.5.2.

**Table 5.5.2 Full load tooth contact marking**

ISO accuracy grade	Contact marking area
$Q \leq 5$	70% $h_w$ for 60% $b$ and 50% $h_w$ for a further 30% $b$
$Q \geq 6$	60% $h_w$ for 45% $b$ and 40% $h_w$ for a further 35% $b$
<b>NOTES</b> 1. Where $b$ is face width and $h_w$ is working tooth depth. 2. For spur gears the values of $h_w$ should be increased by a further 10%.	

#### 5.3 Backlash

5.3.1 The normal backlash between any pair of gears should not be less than:

$$\frac{a\alpha_n}{90\,000} = +0,1 \text{ mm}$$

5.3.2 The normal backlash is not to exceed three times the value calculated in 5.3.1.

#### 5.4 Alignment

5.4.1 Reduction gears with sleeve bearings, for main and auxiliary purposes are to be provided with means for checking the internal alignment of the various elements in the gearcases.

5.4.2 In the case of separately mounted reduction gearing for main propulsion, means are to be provided by the gear manufacturer to enable the Surveyors to verify that no distortion of the gearcase has taken place, when chocked and secured to its seating on board ship.

5.4.3 Further requirements are given in Ch 8,5.

### ■ *Cross-reference*

For lubricating oil systems, see Chapter 14.

## ■ *Section 6* **Control and monitoring**

### **6.1 General**

6.1.1 Control engineering systems are to be in accordance with Pt 6, Ch 1.

6.1.2 All main and auxiliary gear units intended for essential services are to be provided with means of indicating the lubricating oil pressure supply to them. Audible and visual alarms are to be fitted to give warning of an appreciable reduction in pressure of the lubricating oil supply. Further, these alarms are to be actuated from the outlet side of any restrictions, such as filters, coolers, etc.

### **6.2 Unattended machinery**

6.2.1 Where machinery is fitted with automatic or remote controls so that under normal operating conditions it does not require any manual intervention by the operators, it is to be provided with the alarms and safety arrangements required by 6.2, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

6.2.2 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

6.2.3 Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm.

6.2.4 Alarms and safeguards are indicated in Table 5.6.1.

**Table 5.6.1 Main and auxiliary gear units: Alarms and safeguards**

Item	Alarm	Note
Lubricating oil sump level	Low	—
Lubricating oil inlet pressure*	1st stage low	Slow-down
Lubricating oil inlet pressure*	2nd stage low	Automatic shut-down
Lubricating oil inlet temperature*	High	—
Thrust bearing temperature*	High	Slow-down
NOTE For transmitted powers of 1500 kW or less, only the items marked * are required.		



# Main Propulsion Shafting

# Part 5, Chapter 6

Sections 1 & 2

## Section

### 1 Plans and particulars

### 2 Materials

### 3 Design

## ■ Scope

The requirements of this Chapter relate, in particular, to formulae for determining the diameters of shafting for main propulsion installations, but requirements for couplings, coupling bolts, keys, keyways, sternbushes and other associated components are also included. The diameters may require to be modified as a result of alignment considerations and vibration characteristics, see Chapter 8, or the inclusion of stress raisers, other than those contained in this Chapter.

Alternative calculation methods for determining the diameters of shafting for main propulsion and their permissible torsional stresses will be considered by LR. Any alternative calculation method is to include all relevant loads on the complete dynamic shafting system under all permissible operating conditions. Consideration is to be given to the dimensions and arrangements of all shaft connections. Moreover, an alternative calculation method is to take into account design criteria for continuous and transient operating loads (dimensioning for fatigue strength) and for peak operating loads (dimensioning for yield strength). The fatigue strength analysis may be carried out separately for different load assumptions, for example as given below.

Shafts complying with the applicable Rules in Chapter 6 and Chapter 8 satisfy the following:

- (a) Low cycle fatigue criterion (typically  $<10^4$ ), i.e. the primary cycles represented by zero to full load and back to zero, including reversing torque if applicable. This is addressed by the formulas in Ch 6,3.1, 3.5 and 3.6.
- (b) High cycle fatigue criterion (typically  $>>10^7$ ), i.e. torsional vibration stresses permitted for continuous operation as well as reverse bending stresses and the accumulated fatigue due to torsional vibration when passing through a barred speed range or any other transient condition with associated stresses beyond those permitted for continuous operation. This is addressed by the formulas in Ch 8,2.5. The influence of reverse bending stresses is addressed by the safety margins inherent in the formulas from Ch 6,3.1, 3.5 and 3.6.

## ■ Section 1 Plans and particulars

### 1.1 Shafting plans

1.1.1 The following plans, together with the necessary particulars of the machinery, including the maximum power and revolutions per minute, are to be submitted for consideration before the work is commenced:

- Final gear shaft.
- Thrust shaft.
- Intermediate shafting.
- Tube shaft, where applicable.
- Screwshaft.
- Screwshaft oil gland.
- Sternbush.

1.1.2 The specified minimum tensile strength of each shaft is to be stated.

1.1.3 In addition, a shafting arrangement plan indicating the relative positions of the main engines, flywheel, flexible coupling, gearing, thrust block, line shafting and bearings, sterntube, 'A' bracket and propeller, as applicable, is to be submitted for information.

## ■ Section 2 Materials

### 2.1 Materials for shafts

2.1.1 The specified minimum tensile strength of forgings for shafts is to be selected within the following general limits:

- (a) Carbon and carbon-manganese steel – 400 to 760 N/mm<sup>2</sup> (41 to 77,5 kgf/mm<sup>2</sup>). See also 3.5.1.
- (b) Alloy steel – not exceeding 800 N/mm<sup>2</sup> (82 kgf/mm<sup>2</sup>).

2.1.2 Where it is proposed to use alloy steel, details of the chemical composition, heat treatment and mechanical properties are to be submitted for approval.

2.1.3 Where shafts may experience vibratory stresses close to the permissible stresses for transient operation, the materials are to have a specified minimum tensile strength of 500 N/mm<sup>2</sup> (51 kgf/mm<sup>2</sup>).

2.1.4 Where materials with greater specified or actual tensile strengths than the limitations given above are used, reduced shaft dimensions or higher permissible vibration stresses are not acceptable when derived from the formulae used in Section 3.1, 3.5, 3.6 and Ch 8,2.5.

### 2.2 Ultrasonic tests

2.2.1 Ultrasonic tests are required on shaft forgings where the diameter is 250 mm or greater.

# Main Propulsion Shafting

# Part 5, Chapter 6

Section 3

## Section 3 Design

### 3.1 Intermediate shafts

3.1.1 The diameter,  $d$ , of the intermediate shaft is to be not less than determined by the following formula:

$$d = Fk \sqrt[3]{\frac{P}{R} \left( \frac{560}{\sigma_u + 160} \right)} \text{ mm}$$

$$\left( d = Fk \sqrt[3]{\frac{H}{R} \left( \frac{57}{\sigma_u + 16} \right)} \text{ mm} \right)$$

where

$k$  = 1,0 for shafts with integral coupling flanges complying with 3.7 or with shrink fit couplings, see 3.1.4

= 1,10 for shafts with keyways in tapered or cylindrical connections, where the fillet radii in the transverse section of the bottom of the keyway are to be not less than  $0,0125d$

= 1,10 for shafts with transverse or radial holes where the diameter of the hole ( $d_h$ ) is not greater than  $0,3d$

= 1,20 for shafts with longitudinal slots, see 3.1.6

$F$  = 95(86) for turbine installations, electric propulsion installations and oil engine installations with slip type couplings

= 100 (90,5) for other oil engine installations

$P$  ( $H$ ) and  $R$  are defined in Ch 1,3.3 (losses in gearboxes and bearings are to be disregarded)

$\sigma_u$  = specified minimum tensile strength of the shaft material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>), see 2.1.3

After a length of  $0,2d$  from the end of a keyway, transverse hole or radial hole and  $0,3d$  from the end of a longitudinal slot, the diameter of the shaft may be gradually reduced to that determined with  $k = 1,0$ .

3.1.2 For shafts with design features other than stated in 3.1.1, the value of  $k$  will be specially considered.

3.1.3 The Rule diameter of the intermediate shaft for oil engines, turbines and electric propelling motors may be reduced by 3,5 per cent for ships classed exclusively for smooth water service, and by 1,75 per cent for ships classed exclusively for service on the Great Lakes.

3.1.4 For shrink fit couplings  $k$  refers to the plain shaft section only. Where shafts may experience vibratory stresses close to the permissible stresses for continuous operation, an increase in diameter to the shrink fit diameter is to be provided, e.g. a diameter increase of 1 to 2 per cent and a blending radius as described in 3.8.

3.1.5 Keyways are in general not to be used in installations with a barred speed range.

3.1.6 The application of  $k = 1,20$  is limited to shafts with longitudinal slots having a length of not more than  $0,8d$  and a width of not more than  $0,1d$  and a diameter of central hole  $d_i$  of not more than  $0,8d$ , see 3.7. The end rounding of the slot is not to be less than half the width. An edge rounding should preferably be avoided as this increases the stress concentration slightly. The values of  $c_K$ , see Table 8.2.1 in Pt 5, Ch 8, are valid for 1, 2 and 3 slots, i.e. with slots at 360, 180 and 120 degrees apart respectively.

### 3.2 Gear quill shafts

3.2.1 The diameter of the quill shaft is to be not less than given by the following formula:

$$\text{Diameter of quill shaft} = 101 \sqrt[3]{\frac{P \cdot 400}{R \sigma_u}} \text{ mm}$$

$$\left( 91 \sqrt[3]{\frac{H \cdot 41}{R \sigma_u}} \text{ mm} \right)$$

where

$P$  ( $H$ ) and  $R$  are as defined in Ch 1,3.3

$\sigma_u$  = specified minimum tensile strength of the material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>) but is not to exceed 1100 N/mm<sup>2</sup> (112 kgf/mm<sup>2</sup>).

### 3.3 Final gear wheel shafts

3.3.1 Where there is only one pinion geared into the final wheel, or where there are two pinions which are set to subtend an angle at the centre of the shaft of less than 120 degrees, the diameter of the shaft at the final wheel and the adjacent journals is to be not less than 1,15 times that required for the intermediate shaft.

3.3.2 Where there are two pinions geared into the final wheel opposite, or nearly opposite, to each other, the diameter of the shaft at the final wheel and the adjacent journals is to be not less than 1,1 times that required for the intermediate shaft.

3.3.3 In both 3.3.1 and 3.3.2, abaft the journals, the shaft may be gradually tapered down to the diameter required for an intermediate shaft determined according to 3.1, where  $\sigma_u$  is to be taken as the specified minimum tensile strength of the final wheel shaft material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>).

### 3.4 Thrust shafts

3.4.1 The diameter at the collars of the thrust shaft transmitting torque, or in way of the axial bearing where a roller bearing is used as a thrust bearing, is to be not less than that required for the intermediate shaft in accordance with 3.1 with a  $k$  value of 1,10. Outside a length equal to the thrust shaft diameter from the collars, the diameter may be tapered down to that required for the intermediate shaft with a  $k$  value of 1,0. For the purpose of the foregoing calculations,  $\sigma_u$  is to be taken as the minimum tensile strength of the thrust shaft material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>).



# Main Propulsion Shafting

# Part 5, Chapter 6

Section 3

## 3.5 Screwshafts and tube shafts

3.5.1 The diameter,  $d_p$  of the screwshaft immediately forward of the forward face of the propeller boss or, if applicable, the forward face of the screwshaft flange, is to be not less than determined by the following formula:

$$d_p = 100k \sqrt[3]{\frac{P}{R} \left( \frac{560}{\sigma_u + 160} \right)} \text{ mm}$$

$$\left( d_p = 90,5k \sqrt[3]{\frac{P}{R} \left( \frac{57}{\sigma_u + 16} \right)} \text{ mm} \right)$$

where

$k = 1,22$  for a shaft carrying a keyless propeller fitted on a taper, or where the propeller is attached to an integral flange, and where the shaft is fitted with a continuous liner or is oil lubricated and provided with an approved type of oil sealing gland

$= 1,26$  for a shaft carrying a keyed propeller and where the shaft is fitted with a continuous liner or is oil lubricated and provided with an approved type of oil sealing gland

$P$  (H) and  $R$  are defined in Ch 1,3.3, (losses in gearboxes and bearings are to be disregarded)

$\sigma_u$  = specified minimum tensile strength of the shaft material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>) but is not to be taken as greater than 600 N/mm<sup>2</sup> (61 kgf/mm<sup>2</sup>). See 2.1.3.

3.5.2 The diameter,  $d_p$  of the screwshaft determined in accordance with the formula in 3.5.1 is to extend over a length not less than that to the forward edge of the bearing immediately forward of the propeller or  $2,5d_p$  whichever is the greater.

3.5.3 The diameter of the portion of the screwshaft and tube shaft, forward of the length required by 3.5.2 to the forward end of the forward stern tube seal, is to be determined in accordance with the formula in 3.5.1 with a  $k$  value of 1,15. The change of diameter from that determined with  $k = 1,22$  or 1,26 to that determined with  $k = 1,15$  should be gradual, see 3.7.

3.5.4 Screwshafts which run in sterntubes and tube shafts may have the diameter forward of the forward stern tube seal gradually reduced to the diameter of the intermediate shaft. Abrupt changes in shaft section at the screwshaft/tube shaft to intermediate shaft couplings are to be avoided, see 3.7.

3.5.5 Unprotected screwshafts and tube shafts of corrosion-resistant material will be specially considered.

3.5.6 For shafts of non-corrosion-resistant materials which are exposed to sea-water, the diameter of the shaft is to be determined in accordance with the formula in 3.5.1 with a  $k$  value of 1,26 and  $\sigma_u$  taken as 400 N/mm<sup>2</sup> (41 kgf/mm<sup>2</sup>).

## 3.6 Hollow shafts

3.6.1 Where the thrust, intermediate and tube shafts and screwshafts have central holes, the outside diameters of the shafts are to be not less than given by the following formula:

$$d_o = d \sqrt[3]{\frac{1}{\left[ 1 - \left( \frac{d_i}{d_o} \right)^4 \right]}}$$

where

$d_o$  = outside diameter, in mm

$d$  = Rule size diameter of solid shaft, in mm

$d_i$  = diameter of central hole, in mm.

However, where the diameter of the central hole does not exceed 0,4 times the outside diameter, no increase over Rule size need be provided.

## 3.7 Couplings and transitions of diameters

3.7.1 The minimum thicknesses of the coupling flanges are to be equal to the diameters of the coupling bolts at the face of the couplings as required by 3.8 and, for this purpose, the minimum tensile strength of the bolts is to be taken as equivalent to that of the shafts. For intermediate shafts, thrust shafts and the inboard end of the screwshaft, the thickness of the coupling flange is in no case to be less than 0,20 of the diameter of the intermediate shaft as required by 3.1.

3.7.2 The fillet radius at the base of the coupling flange is to be not less than 0,08 of the diameter of the shaft at the coupling but, in the case of crankshafts, the fillet radius at the centre coupling flanges may be 0,05 of the diameter of the shaft at the coupling. The fillets are to have a smooth finish and are not to be recessed in way of nut and bolt heads.

3.7.3 Where the propeller is attached by means of a flange, the thickness of the flange is to be not less than 0,25 of the actual diameter of the adjacent part of the screwshaft. The fillet radius at the base of the coupling flange is to be not less than 0,125 of the diameter of the shaft at the coupling.

3.7.4 All couplings which are attached to shafts are to be of approved dimensions.

3.7.5 Where couplings are separate from the shafts, provision is to be made to resist the astern pull.

3.7.6 Where a coupling is shrunk on to the parallel portion of a shaft or is mounted on a slight taper, e.g. by means of the oil pressure injection method, full particulars of the coupling including the interference fit are to be submitted for special consideration.

3.7.7 Transitions of diameters are to be designed with either a smooth taper or a blending radius. In general, a blending radius equal to the change in diameter is recommended.

# Main Propulsion Shafting

# Part 5, Chapter 6

Section 3

## 3.8 Coupling bolts

3.8.1 Close tolerance fitted bolts transmitting shear are to have a diameter, at the joining faces of the couplings not less than given by the following formula:

$$\text{Diameter of coupling bolts} = \sqrt{\frac{240}{nD} \frac{10^6}{\sigma_u} \frac{P}{R}} \text{ mm}$$

where

$n$  = number of bolts in the coupling

$D$  = pitch circle diameter of bolts, in mm

$\sigma_u$  = specified minimum tensile strength of bolts, in N/mm<sup>2</sup>

$P$  ( $H$ ) and  $R$  are as defined in Ch 1,3.3.

3.8.2 At the joining faces of couplings, other than within the crankshaft and at the thrust shaft/crankshaft coupling, the Rule diameter of the coupling bolts defined in 3.8.1 may be reduced by 5,2 per cent for ships classed exclusively for smooth water service, and 2,6 per cent for ships classed exclusively for service on the Great Lakes.

3.8.3 Where dowels or expansion bolts are fitted to transmit torque in shear they are to comply with the requirements of 3.8.1. The expansion bolts are to be installed, and the bolt holes in the flanges are to be correctly aligned, in accordance with manufacturer's instructions.

3.8.4 The minimum diameter of tap bolts or of bolts in clearance holes at the joining faces of coupling flanges, pretensioned to 70 per cent of the bolt material yield strength value, is not to be less than:

$$d_R = 1,348 \sqrt{\left( \frac{120 \cdot 10^6 \cdot F \cdot P \cdot (1 + C)}{R \cdot D} + Q \right) \frac{1}{n \cdot \sigma_y}}$$

where

$d_R$  is taken as the lesser of:

- Mean of effective (pitch) and minor diameters of the threads.
- Bolt shank diameter away from threads. (Not for waisted bolts which will be specially considered.)

$P$  ( $H$ ) and  $R$  are as defined in Ch 1,3.3.

$F$  = 2,5 where the flange connection is not accessible from within the ship

= 2,0 where the flange connection is accessible from within the ship

$C$  = ratio of vibratory/mean torque values at the rotational speed being considered

$D$  = pitch circle diameter of bolt holes, in mm

$Q$  = external load on bolt in N (+ve tensile load tending to separate flange, -ve)

$n$  = number of tap or clearance bolts

$\sigma_y$  = bolt material yield stress in N/mm<sup>2</sup>.

3.8.5 Consideration will be given to those arrangements where the bolts are pretensioned to loads other than 70 per cent of the material yield strength.

3.8.6 Where clamp bolts are fitted they are to comply with the requirements of 3.8.4 and are to be installed, and the bolt holes in the flanges correctly aligned, in accordance with manufacturer's instructions.

## 3.9 Bronze or gunmetal liners on shafts

3.9.1 The thickness,  $t$ , of liners fitted on screwshafts or on tube shafts, in way of the bushes, is to be not less, when new, than given by the following formula:

$$t = \frac{D + 230}{32} \text{ mm}$$

where

$t$  = thickness of the liner, in mm

$D$  = diameter of the screwshaft or tube shaft under the liner, in mm.

3.9.2 The thickness of a continuous liner between the bushes is to be not less than 0,75 $t$ .

3.9.3 Continuous liners should preferably be cast in one piece.

3.9.4 Where liners consist of two or more lengths, these are to be butt welded together. In general, the lead content of the gunmetal of each length forming a butt welded liner is not to exceed 0,5 per cent. The composition of the electrodes or filler rods is to be substantially lead-free.

3.9.5 The circumferential butt welds are to be of multi-run, full penetration type. Provision is to be made for contraction of the weld by arranging for a suitable length of the liner containing the weld, if possible about three times the shaft diameter, to be free of the shaft. To prevent damage to the surface of the shaft during welding, a strip of heat resisting material covered by a copper strip should be inserted between the shaft and the liner in way of the joint. Other methods for welding this joint may be accepted if approved. The welding is to be carried out by an approved method and to the Surveyor's satisfaction.

3.9.6 Each continuous liner or length of liner is to be tested by hydraulic pressure to 2,0 bar (2,0 kgf/cm<sup>2</sup>) after rough machining.

3.9.7 Liners are to be carefully shrunk on, or forced on, to the shafts by hydraulic pressure. Pins are not to be used to secure the liners.

3.9.8 Effective means are to be provided for preventing water from reaching the shaft at the part between the after end of the liner and the propeller boss.

## 3.10 Keys and keyways

3.10.1 Round ended or sled-runner ended keys are to be used, and the keyways in the propeller boss and cone of the screwshaft are to be provided with a smooth fillet at the bottom of the keyways. The radius of the fillet is to be at least 0,0125 of the diameter of the screwshaft at the top of the cone. The sharp edges at the top of the keyways are to be removed.

# Main Propulsion Shafting

# Part 5, Chapter 6

Section 3

3.10.2 Two screwed pins are to be provided for securing the key in the keyway, and the forward pin is to be placed at least one-third of the length of the key from the end. The depth of the tapped holes for the screwed pins is not to exceed the pin diameter, and the edges of the holes are to be slightly bevelled.

3.10.3 The distance between the top of the cone and the forward end of the keyway is to be not less than 0,2 of the diameter of the screwshaft at the top of the cone.

3.10.4 The effective sectional area of the key in shear, is to be not less than  $\frac{d^3}{2,6d_1}$  mm<sup>2</sup>

where

$d$  = diameter, in mm, required for the intermediate shaft determined in accordance with 3.1, based on material having a specified minimum tensile strength of 400 N/mm<sup>2</sup> (41 kgf/mm<sup>2</sup>) and  $k = 1$

$d_1$  = diameter of shaft at mid-length of the key, in mm.

## 3.11 Propellers

3.11.1 For keyed and keyless propellers, see Chapter 7.

## 3.12 Sternbushes

3.12.1 The length of the bearing in the sternbush next to and supporting the propeller is to be as follows:

- (a) For water lubricated bearings which are lined with lignum vitae, rubber composition or staves of approved plastics material, the length is to be not less than four times the diameter required for the screwshaft under the liner.
- (b) For water lubricated bearings lined with two or more circumferentially spaced sectors of an approved plastics material, in which it can be shown that the sectors operate on hydrodynamic principles, the length of the bearing is to be such that the nominal bearing pressure will not exceed 5,5 bar (5,6 kgf/cm<sup>2</sup>). The length of the bearing is to be not less than twice its diameter.
- (c) For oil lubricated bearings of synthetic material the flow of lubricant is to be such that overheating, under normal operating conditions, cannot occur. The acceptable nominal bearing pressure will be considered upon application and is to be supported by the results of an agreed test programme. In general, the length of the bearing is not to be less than 2,0 times the rule diameter of the shaft in way of the bearing.
- (d) For bearings which are white-metal lined, oil lubricated and provided with an approved type of oil sealing gland, the length of the bearing is to be approximately twice the diameter required for the screwshaft and is to be such that the nominal bearing pressure will not exceed 8,0 bar (8,1 kgf/cm<sup>2</sup>). The length of the bearing is to be not less than 1,5 times its diameter.
- (e) For bearings of cast iron and bronze which are oil lubricated and fitted with an approved oil sealing gland, the length of the bearing is, in general, to be not less than four times the diameter required for the screwshaft.
- (f) For bearings which are grease lubricated, the length of the bearing is to be not less than four times the diameter required for the screwshaft.

3.12.2 Forced water lubrication is to be provided for all bearings lined with rubber or plastics and for those bearings lined with lignum vitae where the shaft diameter is 380 mm or over. The supply of water may come from a circulating pump or other pressure source. Flow indicators are to be provided for the water service to plastics and rubber bearings. The water grooves in the bearings are to be of ample section and of a shape which will be little affected by wear down, particularly for bearings of the plastics type.

3.12.3 Bearings of synthetic material are to be supplied finished machined to design dimensions within a rigid bush. Means are to be provided to prevent rotation of the lining within the bush during operation.

3.12.4 All sternbushes are to be adequately secured in the sterntube/housings.

3.12.5 The shut-off valve or cock controlling the supply of water is to be fitted direct to the after peak bulkhead, or to the sterntube where the water supply enters the sterntube forward of the bulkhead.

3.12.6 Oil sealing glands fitted in ships classed for unrestricted service must be capable of accommodating the effects of differential expansion between hull and line of shafting in sea temperatures ranging from arctic to tropical. This requirement applies particularly to those glands which span the gap and maintain oiltightness between the sterntube and the propeller boss.

3.12.7 Where a tank supplying lubricating oil to the sternbush is fitted, it is to be located above the load waterline and is to be provided with a low level alarm device in the engine room.

3.12.8 Where sternbush bearings are oil lubricated, provision is to be made for cooling the oil by maintaining water in the after peak tank above the level of the sterntube or by other approved means.

3.12.9 Two temperature sensors or other approved arrangements that can, where practicable, be replaced without dry-docking or divers are to be provided to ascertain the sterntube aft end bearing temperature.

3.12.10 Where there is compliance with the terms of 3.12.1(c) and (d) to the Surveyor's satisfaction, a screwshaft will be assigned the notation **OG** in the *Supplement to the Register Book* for Periodical Survey purposes, see Pt 1, Ch 3.

3.12.11 Screwshafts which are grease lubricated are not eligible for the **OG** notation.

3.12.12 Where an **\*IWS** (In-water Survey) notation is to be assigned, see Pt 1, Ch 2,2.3.11, means are to be provided for ascertaining the clearance in the sternbush with the vessel afloat.

# Main Propulsion Shafting

## Part 5, Chapter 6

*Section 3*

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### **3.13      Vibration and alignment**

3.13.1      For the requirements for torsional, axial and lateral vibration, and for alignment of the shafting, see Chapter 8.

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## Section

- 1 Plans and particulars
- 2 Materials
- 3 Design
- 4 Fitting of propellers
- 5 Control and monitoring

## Section 1 Plans and particulars

### 1.1 Details to be submitted

1.1.1 A plan, in triplicate, of the propeller is to be submitted for approval, together with the following particulars using the symbols shown:

- (a) Maximum blade thickness of the expanded cylindrical section considered,  $T$ , in mm.
- (b) Maximum shaft power, see Ch 1,3.3,  $P$ , in kW ( $H$ , in shp).
- (c) Estimated ship speed at design loaded draught in the free running condition at maximum shaft power and corresponding revolutions per minute, see (b) and (d).
- (d) Revolutions per minute of the propeller at maximum power,  $R$ .
- (e) Propeller diameter,  $D$ , in metres.
- (f) Pitch at 25 per cent radius (for solid propellers only),  $P_{0,25}$ , in metres.
- (g) Pitch at 35 per cent radius (for controllable pitch propellers only),  $P_{0,35}$ , in metres.
- (h) Pitch at 60 per cent radius  $P_{0,6}$ , in metres.
- (i) Pitch at 70 per cent radius  $P_{0,7}$ , in metres.
- (k) Length of blade section of the expanded cylindrical section at 25 per cent radius (for solid propellers only),  $L_{0,25}$ , in mm.
- (l) Length of blade section of the expanded cylindrical section at 35 per cent radius (for controllable pitch propellers only)  $L_{0,35}$ , in mm.
- (m) Length of blade section of the expanded cylindrical section at 60 per cent radius,  $L_{0,6}$ , in mm.
- (n) Rake at blade tip measured at shaft axis (backward rake positive, forward rake negative),  $A$ , in mm.
- (o) Number of blades,  $N$ .
- (p) Developed area ratio,  $B$ .
- (q) Material: type and specified minimum tensile strength.
- (r)  $\theta_s$ , skew angle, in degrees, see Fig. 7.1.1.
- (s) Connection of propeller to shaft – details of fit, push-up, securing, etc.

1.1.2 For propellers having a skew angle equal to or greater than  $50^\circ$ , in addition to the particulars detailed in 1.1.1, details are to be submitted of:

- (a) Full blade section details at each radial station defined for manufacture.
- (b) A detailed blade stress computation supported by the following hydrodynamic data for the ahead mean wake condition and when absorbing full power:

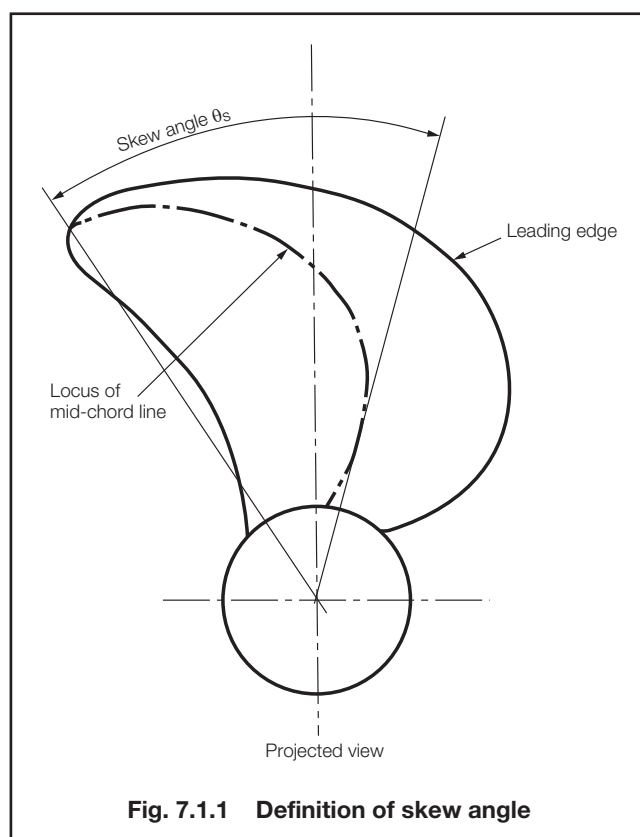


Fig. 7.1.1 Definition of skew angle

- (i) Radial distribution of lift and drag coefficients, section inflow velocities and hydrodynamic pitch angles.
- (ii) Section pressure distributions calculated by either an advised inviscid or viscous procedure.

1.1.3 For blades of fixed pitch propellers with skew angle of  $30^\circ$  or greater, the stresses in the propeller blade during astern operation are not to exceed 80 per cent of the propeller blade material proof stress. Consideration is to be given to failure conditions and a factor of safety of 1,5 is to be attained using an acceptable fatigue failure criteria. Documentary evidence confirming that these criteria are satisfied is to be submitted.

1.1.4 The maximum skew angle of a propeller blade is defined as the angle, in projected view of the blade, between a line drawn through the blade tip and the shaft centreline and a second line through the shaft centreline which acts as a tangent to the locus of the mid-points of the helical blade sections, see Fig. 7.1.1.

1.1.5 Where propellers and similar devices of unusual design are intended for more than one operating regime, such as towing or trawling, then a detailed blade stress calculation for each operating condition, indicating the rotational and ship speed, is to be submitted for consideration.

1.1.6 Where it is proposed to fit the propeller to the screwshaft without the use of a key, plans of the boss, tapered end of screwshaft, propeller nut and, where applicable, the sleeve, are to be submitted.

# Propellers

# Part 5, Chapter 7

Sections 1, 2 & 3

1.1.7 Where a sleeve is fitted, details of the proposed type of material and mechanical properties are also to be submitted.

1.1.8 In cases where the ship has been the subject of model wake field tests, a copy of the results is to be submitted.

## Section 2 Materials

### 2.1 Castings

2.1.1 Castings for propellers and propeller blades are to comply with the requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials). The specified minimum tensile strength is to be not less than stated in Table 7.2.1.

2.1.2 Where it is proposed to use materials which are not included in Table 7.2.1, details of the chemical composition, mechanical properties and density are to be submitted for approval.

2.1.3 Spheroidal cast iron load transmitting components of controllable pitch mechanisms, are to be manufactured, tested and certified in accordance with Chapter 7 of the Rules for Materials, and have an elongation of not less than 12 per cent.

## Section 3 Design

### 3.1 Minimum blade thickness

3.1.1 For propellers having a skew angle of 25° or less, as defined in 1.1.4, the minimum blade thickness,  $T$ , of the propeller blades at 25 per cent radius for solid propellers, 35 per cent radius for controllable pitch propellers, neglecting any increase due to fillets, and at 60 per cent radius, is to be not less than:

$$T = \frac{KCA}{EFULN} + 100 \sqrt{\frac{3150MP}{EFRULN}} \text{ mm}$$

$$\left( T = \frac{KCA}{9,81EFULN} + 27,4 \sqrt{\frac{3150MH}{EFRULN}} \text{ mm} \right)$$

where

$$L = L_{0,25}, L_{0,35}, \text{ or } L_{0,6}, \text{ as appropriate}$$

$$K = \frac{GBD^3R^2}{675}$$

$G$  = density, in g/cm<sup>3</sup>, see Table 7.2.1

$U$  = allowable stress, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>) see 3.1.2, 3.1.3, 3.1.4, and Table 7.2.1

$$E = \frac{\text{actual face modulus}}{0,09T^2L}$$

For aerofoil sections with and without trailing edge washback,  $E$  may be taken as 1,0 and 1,25 respectively

**Table 7.2.1 Materials for propellers**

Material	SI units			Metric units		
	Specified minimum tensile strength N/mm <sup>2</sup>	$G$ Density g/cm <sup>3</sup>	$U$ Allowable stress N/mm <sup>2</sup>	Specified minimum tensile strength kgf/mm <sup>2</sup>	$G$ Density g/cm <sup>3</sup>	$U$ Allowable stress kgf/mm <sup>2</sup>
Grey cast iron	250	7,2	17,2	25	7,2	1,75
Spheroidal or nodular graphite cast iron	400	7,3	20,6	41	7,3	2,1
Carbon steels	400	7,9	20,6	41	7,9	2,1
Low alloy steels	440	7,9	20,6	45	7,9	2,1
13% chromium stainless steels	540	7,7	41	55	7,7	4,2
Chromium-nickel austenitic stainless steel	450	7,9	41	46	7,9	4,2
Duplex stainless steels	590	7,8	41	60	7,8	4,2
Grade Cu 1 Manganese bronze (high tensile brass)	440	8,3	39	45	8,3	4,0
Grade Cu 2 Ni-Manganese bronze (high tensile brass)	440	8,3	39	45	8,3	4,0
Grade Cu 3 Ni-Aluminium bronze	590	7,6	56	60	7,6	5,7
Grade Cu 4 Mn-Aluminium bronze	630	7,5	46	64	7,5	4,7



# Propellers

# Part 5, Chapter 7

Section 3

$$\left. \begin{aligned} C &= 1,0 \\ F &= \frac{P_{0,25}}{D} + 0,8 \\ M &= 1,0 + \frac{3,75D}{P_{0,7}} + 2,8 \frac{P_{0,25}}{D} \end{aligned} \right\} \text{for solid propellers at 25 per cent radius}$$

$$\left. \begin{aligned} C &= 1,4 \\ F &= \frac{P_{0,35}}{D} + 1,6 \\ M &= 1,35 + \frac{5D}{P_{0,7}} + 2,6 \frac{P_{0,35}}{D} \end{aligned} \right\} \text{for controllable pitch propellers at 35 per cent radius}$$

$$\left. \begin{aligned} C &= 1,6 \\ F &= \frac{P_{0,6}}{D} + 4,5 \\ M &= 1,35 + \frac{5D}{P_{0,7}} + 1,35 \frac{P_{0,6}}{D} \end{aligned} \right\} \text{for all propellers at 60 per cent radius}$$

3.1.2 The fillet radius between the root of a blade and the boss of a propeller is to be not less than the Rule thickness of the blade or equivalent at this location. Composite radiused fillets or elliptical fillets which provide a greater effective radius to the blade are acceptable and are to be preferred. Where fillet radii of the required size cannot be provided, the value of  $U$  is to be multiplied by  $\left(\frac{r}{T}\right)^{0,2}$

where

$r$  = proposed fillet radius at the root, in mm

$T$  = Rule thickness of the blade at the root, in mm

Where a propeller has bolted-on blades, consideration is also to be given to the distribution of stress in the palms of the blades. In particular, the fillets of recessed bolt holes and the lands between bolt holes are not to induce stresses which exceed those permitted at the outer end of the fillet radius between the blade and the palm.

3.1.3 For propellers having skew angles of greater than 25°, but less than 50°, the mid-chord thickness,  $T_{sk0,6}$ , at the 60 per cent radius is to be not less than:

$$T_{sk0,6} = 0,54T_{0,6} \sqrt{1 + 0,1\theta_s} \quad \text{mm}$$

The mid-chord thickness,  $T_{sk root}$ , at 25 or 35 per cent radius, neglecting any increase due to fillets, is to be not less than:

$$T_{sk root} = 0,75T_{root} \sqrt[4]{1 + 0,1\theta_s} \quad \text{mm}$$

where

$\theta_s$  = proposed skew angle as defined in 1.1.4

$T_{0,6}$  = thickness at 60 per cent radius, calculated by 3.1.1, in mm

$T_{root}$  = thickness at 25 per cent radius or 35 per cent radius, calculated by 3.1.1, in mm

The thicknesses at the remaining radii are to be joined by a fair curve and the sections are to be of suitable aerofoil section.

3.1.4 Results of detailed calculations where carried out, are to be submitted.

3.1.5 For cases where the composition of the propeller material is not specified in Table 7.2.1, or where propellers of the cast irons and carbon and low alloy steels shown in this Table are provided with an approved method of cathodic protection, special consideration will be given to the value of  $U$ .

3.1.6 The value  $U$  may be increased by 10 per cent for twin screw and outboard propellers of triple screw ships.

3.1.7 Where the design of a propeller has been based on analysis of reliable wake survey data in conjunction with a detailed fatigue analysis and is deemed to permit scantlings less than required by 3.1.1 or 3.1.3, a detailed stress computation for the blades is to be submitted for consideration.

## 3.2 Keyless propellers

3.2.1 The symbols used in 3.2.2 (oil injection method of fitting) and 3.2.3 to 3.2.7 (dry fitting cast iron sleeve) are defined as follows:

$d_1$  = diameter of the screwshaft cone at the mid-length of the boss or sleeve, in mm

$d_2$  = outside diameter of the sleeve at its mid-length, in mm

$d_3$  = outside diameter of the boss at its mid-length, in mm

$d_i$  = bore diameter of screwshaft, in mm

$$h = \frac{2}{E_2} \left( \frac{1}{k_1^2 - 1} \right)$$

$$k_1 = \frac{d_2}{d_1}$$

$$k_2 = \frac{d_3}{d_2}$$

$$k_3 = \frac{d_3}{d_1}$$

$$l = \frac{d_i}{d_1}$$

$$p_1 = \frac{2M}{A_1\theta_1V_1} \left( -1 + \sqrt{1 + V_1 \left( \frac{F_1^2}{M^2} + 1 \right)} \right)$$

$$p_2 = \frac{2M}{A_2\theta_2V_2} \left( -1 + \sqrt{1 + V_2 \left( \frac{F_2^2}{M^2} + 1 \right)} \right)$$

$$p_{10} = \frac{2M}{A_1\theta_1V_1} \left( -1 + \sqrt{1 + V_1 \left( \frac{F_{10}^2}{M^2} + 1 \right)} \right)$$

$$p_{20} = \frac{2M}{A_2\theta_2V_2} \left( -1 + \sqrt{1 + V_2 \left( \frac{F_{20}^2}{M^2} + 1 \right)} \right)$$

$A_1$  = contact area of fitting at screwshaft, in mm<sup>2</sup>

$A_2$  = contact area of fitting at outside of sleeve, in mm<sup>2</sup>

$$B_1 = \frac{1}{E_2} \left( \frac{k_1^2 + 1}{k_1^2 - 1} + v_2 \right) + \frac{1}{E_1} \left( \frac{1 + l^2}{1 - l^2} - v_1 \right)$$



# Propellers

# Part 5, Chapter 7

Section 3

$$B_2 = \frac{1}{E_3} \left( \frac{k_2^2 + 1}{k_2^2 - 1} + \nu_3 \right) + \frac{1}{E_2} \left( \frac{k_1^2 + 1}{k_1^2 - 1} - \nu_2 \right)$$

$$B_3 = \frac{1}{E_3} \left( \frac{k_3^2 + 1}{k_3^2 - 1} + \nu_3 \right) + \frac{1}{E_1} \left( \frac{1 + l^2}{1 - l^2} - \nu_1 \right)$$

$C = 0$  for turbine installations

=  $\frac{\text{vibratory torque at the maximum service speed}}{\text{mean torque at the maximum service speed}}$

for oil engine installations

$E_1$  = modulus of elasticity of screwshaft material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>)

$E_2$  = modulus of elasticity of sleeve material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>)

$E_3$  = modulus of elasticity of propeller material, in N/mm<sup>2</sup> (kgf/mm<sup>2</sup>)

$$F_1 = \frac{2Q}{d_1} (1 + C)$$

$$F_2 = \frac{2Q}{d_2} (1 + C)$$

$$F_{10} = \frac{2Q}{d_1} \left( 1 + C + \frac{I_f}{100} \right)$$

$$F_{20} = \frac{2Q}{d_2} \left( 1 + C + \frac{I_f}{100} \right)$$

$I_f$  = percentage increase for Ice Class 1D and 1E, obtained from Table 2.5.1 in Pt 8, Ch 2,5

$M$  = propeller thrust, in N (kgf)

$Q$  = mean torque corresponding to  $P$  (H) and  $R$  as defined in Ch 1,3.3, in N mm (kgf mm)

$T_1$  = temperature at time of fitting propeller on shaft, in °C

$T_2$  = temperature at time of fitting sleeve into boss, in °C

$$V_1 = 0,51 \left( \frac{\mu_1}{\theta_1} \right)^2 - 1$$

$$V_2 = 0,51 \left( \frac{\mu_2}{\theta_2} \right)^2 - 1$$

$$Y = B_1 B_2 - h^2 k_1^2$$

$\alpha_1$  = coefficient of linear expansion of screwshaft material, in mm/mm/°C

$\alpha_2$  = coefficient of linear expansion of sleeve material, in mm/mm/°C

$\alpha_3$  = coefficient of linear expansion of propeller material, in mm/mm/°C

$\theta_1$  = taper of the screwshaft cone, but is not to exceed

$$\frac{1}{15} \text{ on the diameter, i.e. } \theta_1 \leq \frac{1}{15}$$

$\theta_2$  = taper of the outside of the sleeve

$\mu_1$  = coefficient of friction for fitting of boss assembly on shaft

= 0,13 for oil injection method of fitting

$\mu_2$  = coefficient of friction for fitting sleeve into the boss

$\nu_1$  = Poisson's ratio for screwshaft material

$\nu_2$  = Poisson's ratio for sleeve material

$\nu_3$  = Poisson's ratio for propeller material

Consistent sets of units are to be used in all formulae.

3.2.2 Where it is proposed to fit a keyless propeller by the oil shrink method, the pull-up,  $\delta$  on the screwshaft is to be not less than:

$$\delta_T = \frac{d_1}{\theta_1} (\rho_1 B_3 + (\alpha_3 - \alpha_1)(35 - T_1)) \text{ mm}$$

or, where Ice Class notation is required, the greater of  $\delta_T$  or  $\delta_O$ , where

$$\delta_O = \frac{d_1}{\theta_1} (\rho_{10} B_3 - (\alpha_3 - \alpha_1) T_1) \text{ mm}$$

The yield stress or 0,2 per cent proof stress,  $\sigma_o$  of the propeller material is to be not less than:

$$\sigma_o = \frac{1,4}{B_3} \left( \frac{\theta_1 \delta_p}{d_1} + T_1 (\alpha_3 - \alpha_1) \right) \frac{\sqrt{3k_3^4 + 1}}{k_3^2 - 1} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

where

$\delta_p$  = proposed pull-up at the fitting temperature

The start point load,  $W$ , to determine the actual pull-up is to be not less than:

$$W = A_1 \left( 0,002 + \frac{\theta_1}{20} \right) \left( \rho_1 + \frac{18}{B_3} (\alpha_3 - \alpha_1) \right) \text{ N (kgf)}$$

3.2.3 Where a cast iron sleeve is first fitted to the bore of the propeller boss by an interference fit, the push-up load of the sleeve into the boss,  $W_2$ , is to be not less than:

$$W_{2T} = \frac{A_2}{B_2} \left( \mu_2 + \frac{\theta_2}{2} \right) (B_2 \rho_2 - h \rho_1 + (\alpha_3 - \alpha_2)(35 - T_2)) \text{ N (kgf)}$$

or, where Ice Class notation is required, the greater of  $W_{2T}$  or  $W_{20}$  where

$$W_{20} = \frac{A_2}{B_2} \left( \mu_2 + \frac{\theta_2}{2} \right) (B_2 \rho_{20} - h \rho_{10} - (\alpha_3 - \alpha_2) T_2) \text{ N (kgf)}$$

The pull-up of the sleeve in the boss at the fitting temperature is to be in accordance with the following formula:

$$\delta_2 = \frac{W_2 B_2 d_2}{A_2 \left( \mu_2 + \frac{\theta_2}{2} \right) \theta_2} \text{ mm}$$

The push-up load,  $W_1$ , of the combined boss and sleeve on a steel screwshaft is to be not less than:

$$W_{1T} = A_1 \left( \mu_1 + \frac{\theta_1}{2} \right) \left( \rho_1 + \frac{h k_1^2}{Y} (\alpha_3 - \alpha_2)(35 - T_1) \right) \text{ N (kgf)}$$

or where Ice Class notation is required, the greater of  $W_{1T}$  or  $W_{10}$  where

$$W_{10} = A_1 \left( \mu_1 + \frac{\theta_1}{2} \right) \left( \rho_{10} - \frac{h k_1^2}{Y} (\alpha_3 - \alpha_2) T_1 \right) \text{ N (kgf)}$$

The push-up distance of the combined boss and sleeve on a steel screwshaft is to be in accordance with the following formula:

$$\delta_1 = \frac{W_1 d_1 Y}{A_1 B_2 \theta_1 \left( \mu_1 + \frac{\theta_1}{2} \right)} \text{ mm}$$

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3.2.4 Where a cast iron sleeve is fitted into the boss by means of Araldite, the conditions are to satisfy those of 3.2.3 except that the value of  $W_2$  is to be taken as equivalent to:

$$W_2 = A_2 \left( 0,25 + \frac{\theta_2}{2} \right) \left( \rho_A + \frac{(\alpha_3 - \alpha_2)(18 - T_2)}{B_2} \right) \text{ N (kgf)}$$

where

$$\begin{aligned} \rho_A &= 3,5 \text{ N/mm}^2 \\ (\rho_A &= 0,35 \text{ kgf/mm}^2) \end{aligned}$$

3.2.5 For the triple element keyless propeller, the yield stress or 0,2 per cent proof stress of the propeller material,  $\sigma_o$  is to be not less than:

$$\sigma_o = 1,4\rho_3 \sqrt{\frac{3k_2^4 + 1}{k_2^2 - 1}} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

where

$$\begin{aligned} \rho_3 &= \frac{W_1 h}{A_1 B_2 \left( \mu_1 + \frac{\theta_1}{2} \right)} + \frac{W_2}{A_2 \left( \mu_2 + \frac{\theta_2}{2} \right)} + \\ &\quad \frac{\alpha_3 - \alpha_2}{B_2} \left( T_2 + \frac{h^2 k_1^2}{Y} T_1 \right) \end{aligned}$$

3.2.6 Where the sleeve is manufactured of material having an elongation in excess of five per cent, the yield point or 0,2 per cent proof stress of the sleeve material,  $\sigma_o$  is to be not less than:

$$\sigma_o = \frac{1,6}{k_1^2 - 1} \sqrt{3k_1^4 (\rho_3 - \rho_5)^2 + (\rho_3 k_1^2 - \rho_5)^2} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

or

$$\sigma_o = \frac{1,6}{k_1^2 - 1} \sqrt{3k_1^4 (\rho_4 - \rho_6)^2 + (\rho_4 k_1^2 - \rho_6)^2} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

where

$$\rho_4 = \rho_3 - \frac{35B_1}{Y} (\alpha_3 - \alpha_2)$$

$$\rho_5 = \frac{W_1}{A_1 \left( \mu_1 + \frac{\theta_1}{2} \right)} + \frac{h k_1^2}{Y} (\alpha_3 - \alpha_2) T_1$$

$$\rho_6 = \rho_5 - \frac{35h k_1^2}{Y} (\alpha_3 - \alpha_2)$$

3.2.7 Where the sleeve is manufactured of material having an elongation not more than five per cent, the minimum specified ultimate tensile strength  $\sigma_u$ , based on the ruling section, is to be not less than:

$$\sigma_u = \frac{2,4}{k_1^2 - 1} \left( \rho_5 \left( \frac{5k_1^2 + 3}{4} \right) - 2\rho_3 k_1^2 \right) \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

or

$$\sigma_u = \frac{2,4}{k_1^2 - 1} \left( \rho_6 \left( \frac{5k_1^2 + 3}{4} \right) - 2\rho_4 k_1^2 \right) \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

3.2.8 Where it is proposed to use a sleeve manufactured from a material other than cast iron, full details are to be submitted for consideration.

## Section 4 Fitting of propellers

### 4.1 Propeller boss

4.1.1 The propeller boss is to be a good fit on the screw-shaft cone. The forward edge of the bore of the propeller boss is to be rounded to about a 6 mm radius. In the case of keyed propellers, the length of the forward fitting surface is to be about one diameter and where the fitting is by means of a hydraulic nut, the requirements of 4.2 and 4.3, where appropriate, are applicable.

### 4.2 Shop tests of keyless propellers

4.2.1 The bedding of the propeller, or the sleeve where applicable with the shaft, is to be demonstrated in the shop to the satisfaction of the Surveyors. Sufficient time is to be allowed for the temperature of the components to equalise before bedding. Alternative means for demonstrating the bedding of the propeller will be considered.

4.2.2 Means are to be provided to indicate the relative axial position of the propeller boss on the shaft taper.

### 4.3 Final fitting of keyless propellers

4.3.1 After verifying that the propeller and shaft are at the same temperature and the mating surfaces are clean and free from oil or grease, the propeller is to be fitted on the shaft to the satisfaction of the Surveyors. The propeller nut is to be securely locked to the shaft.

4.3.2 Permanent reference marks are to be made on the propeller boss, nut and shaft to indicate angular and axial positioning of the propeller. Care is to be taken in marking the inboard end of the shaft taper to minimise stress raising effects.

4.3.3 The outside of the propeller boss is to be hard stamped with the following details:

- For the oil injection method of fitting, the start point load and the axial pull-up at 0°C and 35°C.
- For the dry fitting method, the push-up load at 0°C and 35°C.

4.3.4 A copy of the fitting curve relative to temperature and means for determining any subsequent movement are to be placed on board.

## ■ Section 5

### **Control and monitoring**

#### **5.1 General**

5.1.1 Control engineering systems are to be in accordance with the requirements of Pt 6, Ch 1.

#### **5.2 Unattended machinery**

5.2.1 Where controllable pitch propellers are fitted with automatic or remote controls so that under normal operating conditions they do not require any manual intervention by the operators, they are to be provided with the alarms and safety arrangements required by 5.2 to 5.3, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

5.2.2 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

#### **5.3 Controllable pitch propellers and transverse thrust units**

5.3.1 Alarms and safeguards are indicated in 5.3.2 to 5.3.5 and Table 7.5.1. For azimuth thrusters, see also Chapter 20.

5.3.2 For controllable pitch propellers for main propulsion, a standby or alternative power source of actuating medium for controlling the pitch of the propelling blades is to be provided. Automatic start of the standby pump supplying hydraulic power for pitch control is to be provided.

5.3.3 Controllable pitch propellers for main propulsion are to be provided with indications of shaft speed, direction and magnitude of thrust and propeller pitch as a measure of the propeller blade or actuator movement at each station from which it is possible to control shaft speed or propeller pitch.

5.3.4 Where transverse thrust units are remotely controlled, means are to be provided at the remote control station to stop the propulsion unit.

5.3.5 Transverse thrust units are to be provided with indications of direction and magnitude of thrust and propeller pitch at each station from which it is possible to control the propeller pitch.

**Table 7.5.1 Controllable pitch propellers and transverse thrust units: Alarms and safeguards**

Item	Alarm	Note
Hydraulic system pressure	Low	—
Hydraulic oil supply tank level	Low	—
Hydraulic oil temperature	High	Where an oil cooler is fitted
Power supply to the control system between the remote control station and hydraulic actuator	Failure	See Pt 6, Ch 1,2.5.3

# Shaft Vibration and Alignment

## Part 5, Chapter 8

Sections 1 & 2

### Section

- 1 **General**
- 2 **Torsional vibration**
- 3 **Axial vibration**
- 4 **Lateral vibration**
- 5 **Shaft alignment**

### 1.2 Resilient mountings

- 1.2.1 For resilient mountings, see Ch 1,4.3.

### 1.3 Flexible couplings

- 1.3.1 Where the shafting system incorporates flexible couplings, the effects of such couplings on the various modes of vibration are to be considered, see Sections 2, 3 and 4.

## ■ Scope

The requirements of this Chapter are applicable to the following systems:

- (a) Main propulsion systems formed by oil engines, turbines or electric motors, directly driven or geared to the shafting.
- (b) Machinery driven at constant speed by oil engines, developing 110 kW and over, for essential auxiliary services including generator sets which are the source of power for main electric propulsion motors.

Unless otherwise advised, it is the responsibility of the Shipbuilder as main contractor to ensure, in co-operation with the Enginebuilders, that the information required by this Chapter is prepared and submitted.

## ■ Section 2 Torsional vibration

### 2.1 General

- 2.1.1 In addition to the shafting complying with the requirements of Chapters 1 to 7 and 20 (where applicable), approval is also dependent on the torsional vibration characteristics of the complete shafting system(s) being found satisfactory.

- 2.1.2 Further to the Scope of this Chapter, the requirements of this Section are not applicable to ships that are not:

- (a) required to comply with the *International Convention for the Safety at Sea, 1974*, as amended, (SOLAS); or
- (b) where a main engine does not have a power output exceeding 500 kW.

### 2.2 Particulars to be submitted

- 2.2.1 Torsional vibration calculations, showing the mass elastic values, associated natural frequencies and an analysis of the vibratory torques and stresses for the full dynamic system.

- 2.2.2 Particulars of the division of power and utilisation, throughout the speed range, for turbines, multi-engine or other combined power installations, and those with power take-off systems. For multi-engined installations, special considerations associated with the possible variations in the mode of operation and phasing of engines.

- 2.2.3 Enginebuilder's harmonic torque data used in the torsional vibration calculations, see 2.3.3.

- 2.2.4 Details of operating conditions encountered in service for prolonged periods, e.g. idling speed, range of trawling revolutions per minute, combinator characteristics for installations equipped with controllable pitch propellers.

- 2.2.5 Details, obtained from the manufacturers, of the principal characteristics of machinery components such as dampers and couplings, confirming their capability to withstand the effects of vibratory loading including, where appropriate, heat dissipation. Evidence that the data which is used to represent the characteristics of components, which has been quoted from other sources, is supported by a programme of physical measurement and control.

## ■ Section 1 General

### 1.1 Basic requirements

- 1.1.1 The systems are to be free from excessive torsional, axial, lateral and linear vibration, and are to be aligned in accordance with accepted tolerances and taking into account the requirements of 5.5.

- 1.1.2 System designs are to take account of the potential effects of engine and component malfunction and variability in characteristic values such as stiffness and damping of flexible couplings and dampers or engine misfire conditions.

- 1.1.3 Where torques, stresses or amplitudes are found to exceed the limits for continuous operation, restrictions in speed and/or power will be imposed.

- 1.1.4 Where significant changes are subsequently made to a dynamic system which has been approved, (e.g. by changing the original design parameters of the prime movers and/or propulsion shafting system or by fitting a propeller or flexible coupling of different design from the previous), revised calculations may require to be submitted for consideration. Details of all such changes are to be submitted.

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## Section 2

2.2.6 Where installations include electric motors, generators or non-integral pumps, drawings showing the principal dimensions of the shaft, together with manufacturer's estimates of mass moment of inertia for the rotating parts.

2.2.7 Details of vibration or performance monitoring proposals where required.

## 2.3 Scope of calculations

2.3.1 Calculations are to be carried out, by recognised techniques, for the full dynamic system formed by the oil engines, turbines, motors, generators, flexible couplings, gearing, shafting and propeller, where applicable, including all branches.

2.3.2 Calculations are to give due consideration to the potential deviation in values used to represent component characteristics due to manufacturing/service variability.

2.3.3 The calculations carried out on oil engine systems are to be based on the Enginebuilders' harmonic torque data. The calculations are to take account of the effects of engine malfunctions commonly experienced in service, such as a cylinder not firing (i.e. no injection but with compression) giving rise to the highest torsional vibration stresses in the shafting. Calculations are also to take account of a degree of imbalance between cylinders, which is characteristic of the normal operation of an engine under service conditions.

2.3.4 Whilst limits for torsional vibration stress in crankshafts are no longer stated explicitly, calculations are to include estimates of crankshaft stress at all designated operating/service speeds, as well as at any major critical speed.

2.3.5 Calculations are to take into account the possible effects of excitation from propeller rotation. Where the system shows some sensitivity to this phenomenon, propeller excitation data for the installation should be used as a basis for calculation, and submitted.

2.3.6 Where the torsional stiffness of flexible couplings varies with torque, frequency or speed, calculations should be representative of the appropriate range of effective dynamic stiffness.

## 2.4 Symbols and definitions

2.4.1 The symbols used in this Section are defined as follows:

- $d$  = minimum diameter of shaft considered, in mm
- $d_i$  = diameter of internal bore, in mm
- $k$  = the factor used in determining minimum shaft diameter, defined in Ch 6,3.1.1 and 3.5.1
- $r$  = ratio  $N/N_s$  or  $N_c/N_s$  whichever is applicable
- $C_d$  = a size factor defined as  $0,35 + 0,93d^{-0,2}$
- $C_k$  = a factor for different shaft design features, see Table 8.2.1
- $N$  = engine speed, in rev/min
- $N_c$  = critical speed, in rev/min

**Table 8.2.1  $C_k$  factors**

<b>Intermediate shafts with</b>	
Integral coupling flange and straight sections	1,0
Shrink fit coupling	1,0
Keyway, tapered connection	0,60
Keyway, cylindrical connection	0,45
Radial hole	0,50
Longitudinal slot	0,30 (see 2.4.4)
<b>Thrust shafts external to engines</b>	
On both sides of thrust collar	0,85
In way of axial bearing where a roller bearing is used as a thrust bearing	0,85
<b>Propeller shafts</b>	
Flange mounted or keyless taper fitted propellers	0,55
Key fitted propellers	0,55
Between forward end of aft most bearing and forward stern tube seal	0,80
<b>NOTE</b>	
The determination of $C_k$ – factors for shafts other than shown in this Table will be specially considered by LR.	

- $N_s$  = maximum continuous engine speed, in rev/min, or, in the case of constant speed generating sets, the full load speed, in rev/min
- $Q_s$  = rated full load mean torque
- $\sigma_u$  = specified minimum tensile strength of the shaft material, in N/mm<sup>2</sup>
- $\tau_c$  = permissible stress due to torsional vibrations for continuous operation, in N/mm<sup>2</sup>
- $\tau_t$  = permissible stress due to torsional vibrations for transient operation, in N/mm<sup>2</sup>
- $e$  = slot width, in mm
- $l$  = slot length, in mm.

2.4.2 Alternating torsional vibration stresses are to be based on half-range amplitudes of stress resulting from the alternating torque (which is superimposed on the mean torque) representing the synthesis of all harmonic orders present.

2.4.3 All vibration stress limits relate to the synthesis or measurement of total nominal torsional stress and are to be based on the plain section of the shafting neglecting stress raisers.

2.4.4 For a longitudinal slot  $C_k = 0,3$  is applicable within the dimension limitations given in Pt 5 Ch 6,3.1.6. If the slot dimensions are outside these limitations, or if the use of another  $C_k$  is desired, the actual stress concentration factor ( $scf$ ) is to be documented or determined from 2.4.5, in which case:

$$C_k = \frac{1,45}{scf}$$

Note that the  $scf$  is defined as the ratio between the maximum local principal stress and  $\sqrt{3}$  times the nominal torsional stress (determined for the bored shaft without slots).

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**2.4.5 Stress concentration factor of slots.** The stress concentration factor (*scf*) at the ends of slots can be determined by means of the following empirical formulae:

$$scf = \alpha_{t(hole)} + 0,8 \frac{\frac{(l-e)}{d}}{\sqrt{\left(1 - \frac{d_i}{d}\right) \frac{e}{d}}}$$

This formula applies to:

- Slots at 120 or 180 or 360 degrees apart.
- Slots with semicircular ends. A multi-radii slot end can reduce the local stresses, but this is not included in this empirical formula.
- Slots with no edge rounding (except chamfering), as any edge rounding increases the *scf* slightly.

$\alpha_{t(hole)}$  represents the stress concentration of radial holes and can be determined as :

$$\alpha_{t(hole)} = 2,3 - 3 \frac{e}{d} + 15 \left(\frac{e}{d}\right)^2 + 10 \left(\frac{e}{d}\right)^2 \left(\frac{d_i}{d}\right)^2$$

where

$e$  = hole diameter, in mm  
or simplified to  $\alpha_{t(hole)} = 2,3$ .

## 2.5 Limiting stress in propulsion shafting

**2.5.1** The following stress limits apply to intermediate shafts, thrust shafts and to screwshafts fully protected from seawater. For screwshafts, the limits apply to the minimum sections of the portions of the screwshaft as defined in Ch 6,3.5.

**2.5.2** In the case of unprotected screwshafts, special consideration will be given.

**2.5.3** In no part of the propulsion shafting system may the alternating torsional vibration stresses exceed the values of  $\tau_c$  for continuous operation, and  $\tau_t$  for transient running, given by the following formulae:

$$\tau_c = \frac{\sigma_u + 160}{18} C_k C_d (3 - 2r^2) \text{ for } r < 0,9 \text{ N/mm}^2$$

$$\tau_c = \frac{\sigma_u + 160}{18} C_k C_d 1,38 \text{ for } 0,9 \leq r \leq 1,05 \text{ N/mm}^2$$

$$\tau_t = \pm 1,7 \tau_c \frac{1}{\sqrt{C_k}} \text{ for } r \leq 0,8 \text{ N/mm}^2$$

**2.5.4** In general, the tensile strength of the steel used is to comply with the requirements of Ch 6,2. For the calculation of the permissible limits of stresses due to torsional vibration,  $\sigma_u$  is not to be taken as more than 800 N/mm<sup>2</sup> in the case of alloy steel intermediate shafts, or 600 N/mm<sup>2</sup> in the case of carbon and carbon-manganese steel intermediate thrust and propeller shafts.

**2.5.5** Where the scantlings of coupling bolts and straight shafting differ from the minimum required by the Rules, special consideration will be given.

## 2.6 Generator sets

**2.6.1** Natural frequencies of the complete set are to be sufficiently removed from the firing impulse frequency at the full load speed, particularly where flexible couplings are interposed between the engine and generator.

**2.6.2** Within the speed limits of 0,95 $N_s$  and 1,05 $N_s$  the vibration stresses in the transmission shafting are not to exceed the values given by the following formula:

$$\tau_c = \pm (21 - 0,014d) \text{ N/mm}^2.$$

**2.6.3** Vibration stresses in the transmission shafting due to critical speeds which have to be passed through in starting and stopping, are not to exceed the values given by the following formula:

$$\tau_t = 5,5 \tau_c.$$

**2.6.4** The amplitudes of the total vibratory inertia torques imposed on the generator rotors are to be limited to  $\pm 2,0Q_s$  in general, or to  $\pm 2,5Q_s$  for close-coupled revolving field alternating current generators, over the speed range from 0,95 $N_s$  to 1,05 $N_s$ . Below 0,95 $N_s$  the amplitudes are to be limited to  $\pm 6,0Q_s$ . Where two or more generators are driven from one engine, each generator is to be considered separately in relation to its own rated torque.

**2.6.5** The rotor shaft and structure are to be designed to withstand these magnitudes of vibratory torque. Where it can be shown that they are capable of withstanding a higher vibratory torque, special consideration will be given.

**2.6.6** In addition to withstanding the vibratory conditions over the speed range from 0,95 $N_s$  to 1,05 $N_s$ , flexible couplings, if fitted, are to be capable of withstanding the vibratory torques and twists arising from transient criticals and short-circuit currents.

**2.6.7** In the case of alternating current generators, resultant vibratory amplitudes at the rotor are not to exceed  $\pm 3,5$  electrical degrees under both full load working conditions and the malfunction condition mentioned in 2.3.3.

## 2.7 Other auxiliary machinery systems

**2.7.1** The relevant requirements of 2.6.1, 2.6.2 and 2.6.3 are also applicable to other machinery installations such as pumps or compressors with the speed limits being taken as 0,95 $N_s$  to 1,10 $N_s$ .

## 2.8 Other machinery components

**2.8.1 Torsional vibration dampers.** The use of dampers or detuners to limit vibratory stress due to resonances which occur within the range between 0,85 $N_s$  and 1,05 $N_s$  are to be considered. If fitted, these should be of a type which makes adequate provision for dissipation of heat. Where necessary, performance monitoring may be required.

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## 2.8.2 Flexible couplings:

- (a) Flexible couplings included in an installation are to be capable of transmitting the mean and vibratory loads without exceeding the makers' recommended limits for angular amplitude or heat dissipation.
- (b) Where calculations indicate that the limits recommended by the manufacturer may be exceeded under misfiring conditions, a suitable means is to be provided for detecting and indicating misfiring. Under these circumstances power and/or speed restrictions may be required. Where machinery is non-essential, disconnection of the branch containing the coupling would be an acceptable action in the event of misfiring.

## 2.8.3 Gearing:

- (a) The torsional vibration characteristics are to comply with the requirements of 2.3. The sum of the mean and of the vibratory torque should not exceed four-thirds of the full transmission torque, at MCR, throughout the speed range. In cases where the proposed transmission torque loading on the gear teeth is less than the maximum allowable, special consideration will be given to the acceptance of additional vibratory loading on the gears.
- (b) Where calculations indicate the possibility of torque reversal, the operating speed range is to be determined on the basis of observations during sea trials.

## 2.9 Measurements

2.9.1 Where calculations indicate that the limits for torsional vibration within the range of working speeds are exceeded, measurements, using an appropriate technique, may be taken from the machinery installation for the purpose of approval of torsional vibration characteristics, or determining the need for restricted speed ranges, and the confirmation of their limits.

2.9.2 Where differences between calculated and measured levels of stress, torque or angular amplitude arise, the stress limits are to be applied to the stresses measured on the completed installation.

2.9.3 The method of measurement is to be appropriate to the machinery components and the parameters which are of concern. Where shaft stresses have been estimated from angular amplitude measurements, and are found to be close to limiting stresses as defined in 2.5, strain gauge techniques may be required. When measurements are required, detailed proposals are to be submitted.

## 2.10 Vibration monitoring

2.10.1 Where calculations and/or measurements have indicated the possibility of excessive vibratory stresses, torques or angular amplitudes in the event of a malfunction, vibration or performance monitoring, directly or indirectly, may be required.

## 2.11 Restricted speed and/or power ranges

2.11.1 Restricted speed and/or power ranges will be imposed to cover all speeds where the stresses exceed the limiting values,  $\tau_c$ , for continuous running, including one-cylinder misfiring conditions if intended to be continuously operated under such conditions. For controllable pitch propellers with the possibility of individual pitch and speed control, both full and zero pitch conditions are to be considered. Similar restrictions will be imposed, or other protective measures required to be taken, where vibratory torques or amplitudes are considered to be excessive for particular machinery items. At each end of the restricted speed range the engine is to be stable in operation.

2.11.2 The restricted speed range is to take account of the tachometer speed tolerances at the barred speeds.

2.11.3 Critical responses which give rise to speed restrictions are to be arranged sufficiently removed from the maximum revolutions per minute to ensure that, in general, at  $r = 0,8$  the stress due to the upper flank does not exceed  $\tau_c$ .

2.11.4 Provided that the stress amplitudes due to a torsional critical response at the borders of the barred speed range are less than  $\tau_c$  under normal and stable operating conditions the speed restriction derived from the following formula may be applied:

$$\frac{16}{18-r} N_c \text{ to } \frac{18-r}{16} N_c \text{ inclusive.}$$

2.11.5 Where calculated vibration stresses due to criticals below  $0,8N_s$  marginally exceed  $\tau_c$  or where the critical speeds are sharply tuned, the range of revolutions restricted for continuous operation may be reduced.

2.11.6 In cases where the resonance curve of a critical speed has been derived from measurements, the range of revolutions to be avoided for continuous running may be taken as that over which the measured vibration stresses are in excess of  $\tau_c$ , having regard to the tachometer accuracy.

2.11.7 Where restricted speed ranges under normal operating conditions are imposed, notice boards are to be fitted at the control stations stating that the engine is not to be run continuously between the speed limits obtained as above, and the engine tachometers are to be marked accordingly.

2.11.8 Where vibration stresses approach the limiting value,  $\tau_t$ , the range of revolutions restricted for continuous operation may be extended. The notice boards are to indicate that this range must be passed through rapidly.

2.11.9 For excessive vibratory torque, stress or amplitude in other components, based on 2.8.1 to 2.8.3, the limits of any speed/power restriction are to be such as to maintain acceptable levels during continuous operation.

2.11.10 Where the restrictions are imposed for the contingency of an engine malfunction or component failure, the limits are to be entered in the machinery Operating Manual.



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**2.11.11** Restricted speed ranges in one-cylinder misfiring conditions on ships with single engine propulsion are to enable safe navigation whereby sufficient propulsion power is available to maintain control of the ship.

**2.11.12** There are to be no restricted speed ranges imposed above a speed ratio of  $r = 0,8$  under normal operating conditions.

## 2.12 Tachometer accuracy

**2.12.1** Where restricted speed ranges are imposed as a condition of approval, the tachometer accuracy is to be checked against the counter readings, or by equivalent means, in the presence of the Surveyors to verify that it reads correctly within  $\pm 2$  per cent in way of the restricted range of revolutions.

## 2.13 Governor control

**2.13.1** Where there is a significant critical response above and close to the maximum service speed, consideration is to be given to the effect of temporary overspeed.

## Section 3 Axial vibration

### 3.1 General

**3.1.1** For all main propulsion shafting systems, the Shipbuilders are to ensure that axial vibration amplitudes are satisfactory throughout the speed range. Where natural frequency calculations indicate significant axial vibration responses, sufficiently wide restricted speed ranges will be imposed. Alternatively, measurements may be used to determine the speed ranges at which amplitudes are excessive for continuous running.

### 3.2 Particulars to be submitted

**3.2.1** The results of calculations, together with recommendations for any speed restrictions found necessary.

**3.2.2** Enginebuilder's recommendation for axial vibration amplitude limits at the non-driving end of the crankshaft or at the thrust collar.

**3.2.3** Estimate of flexibility of the thrust bearing and its supporting structure.

**3.2.4** The requirement for calculations to be submitted may be waived upon request provided evidence of satisfactory service experience of similar dynamic installations is submitted.

## 3.3 Calculations

**3.3.1** Calculations of axial vibration natural frequency are to be carried out using appropriate techniques, taking into account the effects of flexibility of the thrust bearing, for shaft systems where the propeller is:

- (a) Driven directly by a reciprocating internal combustion engine.
- (b) Driven via gears, or directly by an electric motor, and where the total length of shaft between propeller and thrust bearing is in excess of 60 times the intermediate shaft diameter.

**3.3.2** Where an axial vibration damper is fitted, the calculations are to consider the effect of a malfunction of the damper.

**3.3.3** For those systems as defined in 3.3.1(b) the propeller speed at which the critical frequency occurs may be estimated using the following formula:

$$\frac{0,98}{N} \left( \frac{ab}{a+b} \right)^{1/2} \text{ rev/min}$$

where

$$a = \frac{E}{G l^2} (66,2 + 97,5A - 8,88A^2)^2 \text{ (c/min)}^2$$

$$b = 91,2 \frac{k}{M_e} \text{ (c/min)}^2$$

$d$  = internal diameter of shaft, in mm

$k$  = estimated stiffness at thrust block bearing, in N/m

$l$  = length of shaft line between propeller and thrust bearing, in mm

$m$  = mass of shaft line considered, in kg  
 $= 0,785 (D^2 - d^2) G l$

$$A = \frac{m}{M}$$

$D$  = outside diameter of shaft, taken as an average over length  $l$ , in mm

$E$  = modulus of elasticity of shaft material, in N/mm<sup>2</sup>

$G$  = density of shaft material, in kg/mm<sup>3</sup>

$M$  = dry mass of propeller, in kg

$M_e = M (A + 2)$

$N$  = number of propeller blades

Where the results of this method indicate the possibility of an axial vibration resonance in the vicinity of the maximum service speed, calculations using a more accurate method will be required.

## 3.4 Measurements

**3.4.1** Where calculations indicate the possibility of excessive axial vibration amplitudes within the range of working speeds under normal or malfunction conditions, measurements are required to be taken from the shafting system for the purpose of determining the need for restricted speed ranges.

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## 3.5 Restricted speed ranges

3.5.1 The limits of any speed restriction are to be such as to maintain axial amplitudes within recommended levels during continuous operation.

3.5.2 Limits of a speed restriction, where required, may be determined by calculation or on the basis of measurement.

3.5.3 Where a speed restriction is imposed for the contingency of a damper malfunction, the speed limits are to be entered in the machinery Operating Manual and regular monitoring of the axial vibration amplitude is required. Details of proposals for monitoring are to be submitted.

## 3.6 Vibration monitoring

3.6.1 Where a vibration monitoring system is to be specified, details of proposals are to be submitted.

## Section 4 Lateral vibration

### 4.1 General

4.1.1 For all main propulsion shafting systems, the Shipbuilders are to ensure that lateral vibration characteristics are satisfactory throughout the speed range.

### 4.2 Particulars to be submitted

4.2.1 Calculations of the lateral vibration characteristics of shafting systems having supports outboard of the hull or incorporating cardan shafts are to be submitted.

### 4.3 Calculations

4.3.1 The calculations in 4.2.1, taking account of bearing, oil-film (where applicable) and structural dynamic stiffnesses, are to investigate the excitation frequencies giving rise to all critical speeds which may result in significant amplitudes within the speed range, and are to indicate relative deflections and bending moments throughout the shafting system.

4.3.2 The calculated natural frequencies of the system are to be compared to both the shaft rotational orders and propeller blade passing frequencies. Where cardan shafts are fitted, the shaft second rotational orders are also to be considered.

4.3.3 Requirements for calculations may be waived upon request provided evidence of satisfactory service experience of similar dynamic installations is submitted.

## 4.4 Measurements

4.4.1 Where calculations indicate the possibility of significant lateral vibration responses within the range of  $\pm 20$  per cent of the M.C.R. speed, measurements using an appropriate recognised technique may be required to be taken from the shafting system for the purpose of determining the need for restricted speed ranges.

4.4.2 The method of measurement is to be appropriate to the machinery arrangement and the modes of vibration which are of concern. When measurements are required, detailed proposals are to be submitted in advance.

## Section 5 Shaft alignment

### 5.1 General

5.1.1 Shaft alignment calculations are to be carried out for main propulsion shafting rotating at propeller speed, including the crankshaft of direct drive systems or the final reduction gear wheel on geared installations. The Builder is to make available shaft alignment procedures detailing the proposed alignment method and checks for these arrangements.

### 5.2 Particulars to be submitted for approval – Shaft alignment calculations

5.2.1 Shaft alignment calculations are to be submitted to LR for approval for the following shafting systems:

- All geared installations, where the screwshaft has a diameter of 300 mm or greater in way of the aftmost bearing, except for multiple input/single output geared installations, in which case all such installations will be submitted for approval.
- All direct drive installations which incorporate 3 or fewer bearings supporting the intermediate and screwshaft aft of the prime mover.
- Where prime movers in a direct drive installation or shaftline bearings are installed on resilient mountings.
- All systems where the screwshaft has a diameter of 800 mm or greater in way of the aftmost bearing.

5.2.2 The shaft alignment calculations are to take into account the:

- thermal displacements of the bearings between cold static and hot dynamic machinery conditions;
- buoyancy effect of the propeller immersion due to the ship's operating draughts;
- effect of predicted hull deformations over the range of the ship's operating draughts, where known;
- effect of filling the aft peak ballast tank upon the bearing loads, where known;
- gear forces, where appropriate, due to prime-mover engagement on multiple input/single output installations. For multiple input systems, consideration is to be given to each possible combination of inputs;
- propeller offset thrust effects;

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- (g) maximum allowed bearing wear, for water or grease-lubricated stern-tube bearings, and its effect on the bearing loads.

5.2.3 The shaft alignment calculations are to state the:

- (a) expected bearing loads at light and normal ballast, fully loaded and any other draughts deemed to be part of the ship's operating profile, for the machinery in cold and hot, static and dynamic conditions;
- (b) bearing influence coefficients and the deflection, slope, bending moment and shear force along the shaftline;
- (c) details of propeller offset thrust;
- (d) details of proposed slope-bore of the aftermost stern-tube bearing, where applicable;
- (e) manufacturer's specified limits for bending moment and shear force at the shaft couplings of the gearbox/prime movers;
- (f) estimated bearing wear rates for water or grease-lubricated stern-tube bearings;
- (g) expected hull deformation effects and their origin, viz. whether finite element calculations or measured results from sister or similar ships have been used;
- (h) anticipated thermal rise of prime movers and gearing units between cold static and hot running conditions; and
- (j) manufacturer's allowable bearing loads.

## 5.3 Shaft alignment procedures

5.3.1 A shaft alignment procedure is to be made available for review and for the information of the attending surveyors for all main propulsion installations detailing, as a minimum,

- (a) expected bearing loads at light and normal ballast, fully loaded and any other draughts deemed to be part of the ship's operating profile, for the machinery in cold and hot, static and dynamic conditions;
- (b) maximum permissible loads for the proposed bearing designs;
- (c) design bearing offsets from the straight line;
- (d) design gaps and sags;
- (e) location and loads for the temporary shaft supports;
- (f) expected relative slope of the shaft and the bearing in the aftermost stern-tube bearing;
- (g) details of slope-bore of the aftermost stern-tube bearing, where applied;
- (h) proposed bearing load measurement technique and its estimated accuracy;
- (j) jack correction factors for each bearing where the bearing load is measured using a specified jacking technique;
- (k) proposed shaft alignment acceptance criteria, including the tolerances; and
- (l) flexible coupling alignment criteria.

## 5.4 Design and installation criteria

5.4.1 For main propulsion installations, the shafting is to be aligned to give, in all conditions of ship loading and machinery operation, bearing load distribution satisfying the requirements of 5.4.2.

5.4.2 Design and installation of the shafting is to satisfy the following criteria:

- (a) The Builder is to position the bearings and construct the bearing seatings to minimise the effects of hull deflections under any of the ship's operating conditions with the aim of optimising the bearing load distribution.
- (b) Relative slope between the propeller shaft and the aftermost stern-tube bearing is, in general, not to exceed  $3 \times 10^{-4}$  rad in the static condition.
- (c) Stern-tube bearing loads are to satisfy the requirements of Ch 6,3.12.
- (d) Evidence is to be provided to LR demonstrating that bearings of synthetic material have been verified as being within the tolerance stated by the bearing manufacturer for diameter, ovality, and straightness after installation.
- (e) Bearings of synthetic material are to be verified as being within tolerance for ovality and straightness, circumferentially and longitudinally, after installation.
- (f) The stern-tube forward bearing static load is to be sufficient to prevent unloading in all static and dynamic operating conditions, including the transient conditions experienced during manoeuvring turns and during operation in heavy weather.
- (g) Intermediate shaft bearings' loads are not to exceed 80 per cent of the bearing manufacturer's allowable maximum load, for plain journal bearings, based on the bearing projected area.
- (h) Equipment manufacturer's bearing loads are to be within the manufacturer's specified limits, i.e. prime movers, gearing.
- (j) Resulting shear forces and bending moments are to meet the equipment manufacturer's specified coupling conditions.
- (k) The manufacturer's radial, axial and angular alignment limits for the flexible couplings are to be maintained.

## 5.5 Measurements

5.5.1 The system bearing load measurements are to be carried out to verify that the design loads have been achieved. In general the measurements will be carried out by the jack-up measurement technique using calibrated equipment.

5.5.2 For the first vessel of a new design an agreed programme of static shaft alignment measurements is to be carried out in order to verify that the shafting has been installed in accordance with the design assumptions and to verify the design assumptions in respect of the hull deflections and the effects of machinery temperature changes. The programme is to include static bearing load measurements in a number of selected conditions. Depending on the ship type and the operational loading conditions that are achievable prior to and during sea trials these should include, where practicable, combinations of light ballast cold, full ballast cold, full ballast hot and full draught hot with aft peak tank empty and full.

## Shaft Vibration and Alignment

## Part 5, Chapter 8

### Section 5

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5.5.3 For vessels of an existing design or similar to an existing design where evidence of satisfactory service experience is submitted for consideration and for subsequent ships in a series a reduced set of measurements may be accepted. In such cases the minimum set of measurements is to be sufficient to verify that the shafting has been installed in accordance with the design assumptions and are to include at least one cold and one hot representative condition.

5.5.4 Where calculations indicate that the system is sensitive to changes in alignment under different service conditions, the shaft alignment is to be verified by measurements during sea trials using an approved strain gauge technique.

### 5.6 Flexible couplings

5.6.1 Where the shafting system incorporates flexible couplings, the effects of such couplings on the various modes of vibration are to be considered, see Sections 2, 3 and 4.

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# Podded Propulsion Units

## Part 5, Chapter 9

Section 1

## Section

- 1 **Scope**
- 2 **General requirements**
- 3 **Functional capability**
- 4 **Materials**
- 5 **Structure design and construction requirements**
- 6 **Machinery design and construction requirements**
- 7 **Electrical equipment**
- 8 **Control engineering arrangements**
- 9 **Testing and trials**
- 10 **Installation, maintenance and replacement procedures**

### Section 1 Scope

#### 1.1 General

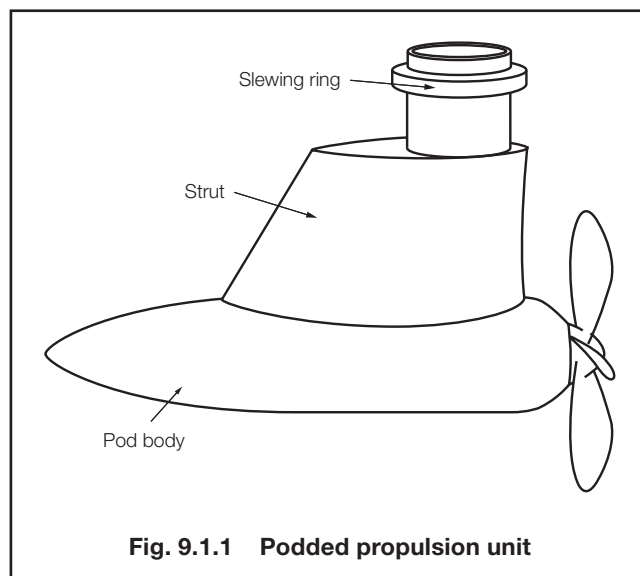
1.1.1 This Chapter applies to podded propulsion units where used for propulsion, dynamic positioning duty or as the sole means of steering.

1.1.2 For the purposes of these Rules, a podded propulsion unit is any propulsion or manoeuvring device that is external to the normal form of the ship's hull and houses a propeller powering device.

1.1.3 The requirements of this Chapter relate to podded propulsion units powered by electric propulsion motors, (and are in addition to the requirements for Electric Propulsion in Pt 6, Ch 2,16 and other relevant Sections). Podded propulsion units with other drive arrangements will be subject to individual consideration.

1.1.4 The structural requirements stated in 5.1, 5.2 and 5.3 relate to podded propulsion units having a pod body with single supporting strut with or without an integral slewing ring arrangement, see Fig. 9.1.1. Novel and unconventional arrangements will be subject to individual consideration. In such cases, the designers are advised to contact LR in the early stages of the design for advice on the manner and content of design information required for formal classification appraisal.

1.1.5 The aft end structures associated with podded installations are to be examined with respect to potential slamming, see Pt 4, Ch 2.



**Fig. 9.1.1 Podded propulsion unit**

1.1.6 It is the shipbuilder's responsibility to ensure that all installed equipment is suitable for operation in the location and under all anticipated environmental conditions associated with the design of the ship which is to include temperature, humidity, vibration and impulsive accelerations.

1.1.7 The design of a podded propulsor system is to take into account a range of operating conditions which are to include the following:

- All ahead seagoing conditions up to and including the maximum rated output of the podded propulsor while maintaining a steady course under foreseeable sea and wind conditions.
- The ability of the ship to change direction rapidly at the declared steering angles with the ship running at maximum ahead service speed.
- Executing a steady turning manoeuvre with a tactical diameter not greater than  $5L$  and advance not greater than  $4,5L$  whilst maintaining a power corresponding to the test speed, where  $L$  is the length measured between the aft and forward perpendiculars. Test speed is defined as a speed of at least 90 per cent of the ship's speed corresponding to 85 per cent of the maximum rated power of the podded propulsor.
- Changing heading, manoeuvring in and out of harbour both ahead and astern, at slow speeds, stationary and starting from rest in foreseeable current and wind conditions.
- Berthing manoeuvres in the case of azimuthing podded propulsion units.
- Rapid acceleration and deceleration manoeuvres where the ship's operating profile demands this capability.
- Holding stationary positions over-ground under different conditions.
- Stopping manoeuvre as required by Ch 1,5.2.
- Manoeuvring in ice where ice class is required.

# Podded Propulsion Units

## Part 5, Chapter 9

Section 2

### Section 2

#### General requirements

##### 2.1 Pod arrangement

2.1.1 In general, for a ship to be assigned an unrestricted service notation, a minimum of two podded propulsion units are to be provided where these form the sole means of propulsion. For vessels where a single podded propulsion unit is the sole means of propulsion, an evaluation of a detailed engineering and safety justification will be conducted by LR, see 2.2.2. This evaluation process will include the appraisal of a Failure Modes and Effects Analysis (FMEA) to verify that sufficient levels of redundancy and monitoring are incorporated in the podded propulsion unit's essential support systems and operating equipment.

##### 2.2 Plans and information to be submitted

2.2.1 In addition to the plans required by Chapters 5, 6, 7, 8, 14 and 19, and Pt 6, Ch 1 and Ch 2, the following plans and information are required to be submitted for appraisal:

- (a) Description of the ship's purpose/capabilities together with the pod's intended operational modes in support of these capabilities.
- (b) Power transmitted at MCR condition (shaft power and rpm) and other maximum torque conditions, e.g. bollard pull.
- (c) Maximum transient thrust, torque and other forces and moments experienced during all envisaged operating modes as permitted by the steering and propulsor drive control systems.
- (d) Details of the electric propulsion motor short-circuit torque and motor air gap tolerance.
- (e) Sectional assembly in the Z-X plane, see Fig. 9.2.1.
- (f) Specifications of materials and NDE procedures for components essential for propulsion and steering operation to include propulsion shaft and slewing ring bearings, gearing and couplings, see 4.1.
- (g) Details of intended manoeuvring capability of the ship in each operating condition. (To be declared by the shipyard, see also 3.1.1).
- (h) Design loads for both the pod structure and propeller together with podded propulsion unit design operating modes, see 2.4.1, 6.3.7, 6.6.6 and 6.6.7.
- (i) Supporting data and direct calculation reports. This is to include, where applicable, an assessment of anticipated global accelerations acting on the ship's machinery and equipment which may potentially affect the reliable operation of the propulsion system for all foreseeable seagoing and operating conditions. Typically, this may include response to slamming, extreme ship motions and pod interaction. See also 1.1.5.
- (k) Structural component details including: strut, pod body, bearing supports, bearing end caps, ship's structure in way of podded propulsion unit integration and a welding Table showing a key to weld symbols used on the plans specifying weld size, type, preparation and heat treatment. The information should include the following:
  - Detailed drawings showing the structural arrangement, dimensions and scantlings.
  - Welding and structural details.

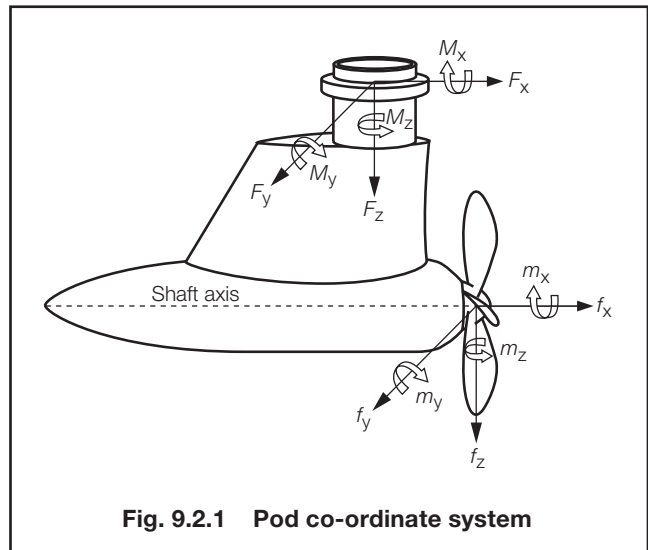


Fig. 9.2.1 Pod co-ordinate system

- Connections between structural components (bolting).
  - Casting's chemical and mechanical properties.
  - Forging's chemical and mechanical properties.
  - Material grades for plate and sections.
- (l) Nozzle structure, its support arrangements, together with related calculations for all permitted operating conditions where the propeller operates in a nozzle (duct), see Pt 3, Ch 13.3.
  - (m) Propeller shaft bearing mounting and housing arrangement details, see also 6.3.6.
  - (n) Details of propeller shaft and steering bearings, where roller bearings are used supporting calculations are to be submitted, see 6.3.7 and 6.6.7.
  - (o) Propeller shaft seal details.
  - (p) Details of propeller shaft and pod steering securing/locking and means of aligning the securing/locking arrangements.
  - (q) Cooling systems piping system schematic.
  - (r) Details of any lubricating oil conditioning systems (filtering/cooling/heating) and control arrangements necessary to ensure the continuous availability of the required lubricating oil quality to the propeller shaft bearings.
  - (s) Details of installed condition monitoring equipment.
  - (t) Details of the derivation of any duty factor used in the design of the steering gears.
  - (u) Identification of any potentially hazardous atmospheric conditions together with details of how the hazard will be countered, this should include a statement of the maximum anticipated air temperature within the pod during full power steady state operation, see 2.3.
  - (v) Where provided, access and closing arrangements for pod unit inspection and maintenance.
  - (w) Heat balance calculations for pods having an electric propulsion motor but no active cooling system, see 6.7.4.
  - (x) Details of proposed testing and trials required by Section 9.
  - (y) Details of emergency steering and pod securing arrangements. See 6.3.11.
  - (z) Quality plan for electronic control systems and electrical actuating systems.

## Podded Propulsion Units

## Part 5, Chapter 9

### Section 2

2.2.2 Where an engineering and safety justification report is required, the following supporting information is to be submitted:

- A Failure Mode and Effects Analysis (FMEA), see 2.5.
- Design standards and assumptions.
- Limiting operating parameters.
- A statement and evidence in respect of the anticipated reliability of any non-duplicated components.

2.2.3 Recommended installation, inspection, maintenance and component replacement procedures (see also 5.1.2). This is to include any in-water/underwater engineering procedures where recommended by the pod manufacturer. See also 6.5.7 and Section 10.

### 2.3 Pod internal atmospheric conditions

2.3.1 Machinery and electrical equipment installed within the pod unit are to be suitable for operation, without degraded performance, at the maximum anticipated air temperature and humidity conditions within the pod unit with the pod operating at its maximum continuous rating in sea water of not less than 32°C after steady state operating conditions have been achieved.

2.3.2 Precautions are to be taken to prevent as far as reasonably practicable the possibility of danger to personnel and damage to equipment arising from the development of hazardous atmospheric conditions within the pod unit. Circumstances that may give rise to these conditions are to be identified and the counter measures taken are to be defined.

### 2.4 Global loads

2.4.1 The overall strength of the podded propulsion unit structure is to be based upon the maximum anticipated in-service loads, including the effects of ship manoeuvring and of ship motion (see Table 14.8.1 in Pt 3, Ch 14). This is to include the effects of any pod to pod and/or pod to ship hydrodynamic interference effects. The designer is to supply the following maximum load and moment values to which the unit may be subjected with a description of the operating condition at which they occur.

- $F_x$ , Force in the longitudinal direction;
- $F_y$ , Force in the transverse direction;
- $F_z$ , self weight, in water, augmented by the ship's pitch and heave motion and flooded volume where applicable, see Pt 3, Ch 14;
- $M_x$ , moment at the slewing ring about the pod unit's global longitudinal axis;
- $M_y$ , moment at the slewing ring about the pod unit's global transverse axis;
- $M_z$ , moment at the slewing ring about the pod unit's vertical axis (maximum dynamic duty steering torque on steerable pods).

The directions of the X, Y and Z axes, with the origin at the centre of the slewing ring, are shown in Fig. 9.2.1.

2.4.2 Where the maximum forces and moments defined in 2.4.1 cannot be accurately calculated, then, an estimate of these loadings is to be stated together with an assessment of the associated error tolerances for the sequences of permitted design manoeuvres, see 1.1.7. Typically this will include emergency astern manoeuvres, zig zag manoeuvres and pod interaction. Such estimates are to be defined on a load versus pod angle basis. In the case of pod to pod and/or pod to ship hydrodynamic interaction effects these, must be defined for the most severely affected propulsor.

2.4.3 Where control systems are installed to limit the operation of the podded drive to defined angles at defined ship speeds, this information may be taken into consideration when determining the pod unit loading.

2.4.4 Where pod units are fixed about their Z axis, then maximum global loads, to be used as the basis of the structural appraisal, are to be determined for inflows in 5 degree increments between the extremes of anticipated inflow angle during manoeuvring with ship at full speed and maximum propeller thrust.

2.4.5 The podded propulsor is to be capable of withstanding a blade root failure due to fatigue occurring at the maximum rated output of the podded propulsor without initiating a failure in other parts of the propulsor system.

### 2.5 Failure Modes and Effects Analysis (FMEA)

2.5.1 An FMEA is to be carried out where a single podded propulsion unit is the vessel's sole means of propulsion, see 2.1.1. The FMEA is to identify components where a single failure could cause loss of all propulsion and/or steering capability and the proposed arrangements for preventing and mitigating the effects of such a failure. The assessment required by Pt 6, Ch 2, 16.2.2 may be considered for demonstrating the acceptability of the proposed design for propulsion power purposes.

2.5.2 The FMEA is to be carried out using the format presented in Table 22.2.1 in Chapter 22 or an equivalent format that addresses the same reliability issues. Analyses in accordance with IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*, or IMO MSC Resolution 36(63) Annex 4 – *Procedures for Failure Mode and Effects Analysis*, would be acceptable.

2.5.3 The FMEA is to be organised in terms of equipment and function. The effects of item failures at a stated level and at higher levels are to be analysed to determine the effects on the system as a whole. Actions for mitigation of the effects of failure are to be determined, see 2.5.1.



# Podded Propulsion Units

# Part 5, Chapter 9

Sections 2, 3 & 4

2.5.4 The FMEA is to:

- (a) identify the equipment or sub-system and mode of operation;
- (b) identify potential failure modes and their causes;
- (c) evaluate the effects on the system of each failure mode;
- (d) identify measures for reducing the risks associated with each failure mode;
- (e) identify measures for preventing failure; and
- (f) identify trials and testing necessary to prove conclusions.

2.5.5 At sub-system level it is acceptable, for the purpose of these Rules, to consider failure of equipment items and their functions, e.g. failure of a pump to produce flow or pressure head. It is not required that the failure of components within that pump be analysed. In addition, their failure need only be dealt with as a cause of failure of the pump.

2.5.6 Where FMEA is used for consideration of systems that depend on software-based functions for control or co-ordination, the analysis is to investigate failure of the functions rather than a specific analysis of the software code itself.

## 2.6 Ice Class requirements

2.6.1 Where an ice class notation is included in the class of a ship, additional requirements as detailed in Part 8 are to be complied with as applicable.

## Section 3 Functional capability

### 3.1 General

3.1.1 The arrangement of podded propulsion units is to be such that the ship can be satisfactorily manoeuvred to a declared performance capability. The operating conditions covered are to include the following:

- (a) Maximum continuous shaft power/speed to the propeller in the ahead condition at the declared steering angles and sea conditions.
- (b) Manoeuvring speeds of the propeller shaft in the ahead and astern direction at the declared steering angles and sea conditions.
- (c) The stopping manoeuvre described in Ch 1,5.2.2(b).
- (d) All astern running conditions for the ship.
- (e) Manoeuvring in ice where ice class is required.

3.1.2 The main steering arrangements are to be capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,4 rev/min with the ship initially operating at its maximum ahead service speed.

3.1.3 The steering mechanism for podded units used for Dynamic Positioning applications with an associated class notation, is to be capable of a rotational speed of not less than 1,5 rev/min.

3.1.4 The auxiliary steering arrangements are to be:

- (a) Capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,083 rev/min, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.
- (b) For all ships, operated by power where necessary to meet the requirements of (a) and in any ship having power more than 2,500 kW propulsion power per thruster unit.

## Section 4 Materials

### 4.1 General

4.1.1 The materials used for major structural and machinery components are to be manufactured and tested in accordance with the requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials). These components include hull support structure, pod body, pod strut, shafting and propellers.

4.1.2 Components of novel design or components manufactured from materials not covered by the Rules for Materials are to be subject to evaluation and approval by Lloyd's Register (hereinafter referred to as 'LR') prior to manufacture.

4.1.3 Material specifications, see 2.2.1(f), for propulsion shaft and slewing ring bearings, gearing and couplings are to be approved by LR prior to manufacture. The specification is to include details of the grade of material, including the target range of chemical composition that is to be reported on the certificate, the required mechanical properties, heat treatment details including temperatures and hold times, details of necessary non-destructive examinations including acceptance levels. Additionally, any steel cleanliness or microstructure requirements are to be included. These components are to be manufactured under survey.

4.1.4 For propulsion shaft rolling element bearings, the amount of retained austenite is to be determined and is not to exceed 4 per cent for nominally bainitic structures.

4.1.5 Where load carrying threaded fasteners screw directly into structural castings, the integrity of the casting is to be such that there is no porosity or shrinkage in the area of the connection.

## Section 5 Structure design and construction requirements

### 5.1 Pod structure

5.1.1 Podded unit struts and pod bodies may be of cast, forged or fabricated construction or a combination of these construction methods.

5.1.2 Means are to be provided to enable the shaft, bearings and seal arrangements to be examined in accordance with LR's requirements and the manufacturer's recommendations.

5.1.3 When high tensile steel fasteners are used as part of the structural arrangement and there is a risk that these fasteners may come into contact with sea-water, carbon-manganese and low alloy steels with a specified tensile strength of greater than 950 N/mm<sup>2</sup> are not to be used due to the risk of hydrogen embrittlement.

5.1.4 For steerable pod units, an integral slewing ring is to be arranged at the upper extremity of the strut to provide support for the slewing bearing.

5.1.5 The strut is to have a smooth transition from the upper mounting to the lower hydrodynamic sections.

5.1.6 For fabricated structures, vertical and horizontal plate diaphragms are to be arranged within the strut and, where necessary, secondary stiffening members are to be arranged.

5.1.7 Pod unit structure scantling requirements are shown in Table 9.5.1. Where the scantling requirements in Table 9.5.1 cannot be satisfied, direct calculations carried out in accordance with 5.3 may be considered.

5.1.8 The connection between the strut and the pod body should generally be effected through large radiused fillets in cast pod units or curved plates in fabricated pod units.

5.1.9 The structural response under the most onerous combination of loads is not to exceed the normal operational requirements of the propulsion or steering system components.

5.1.10 For cast pod structures, the elongation of the material on a gauge length of  $5,65 \sqrt{S_0}$  is to be not less than 12 per cent where  $S_0$  is the actual cross sectional area of the test piece.

5.1.11 In castings, sudden changes of section or possible constriction to the flow of metal during casting are to be avoided. All fillets are to have adequate radii, which should, in general, be not less than 75 mm.

**Table 9.5.1 Podded propulsion unit – Fabricated structure requirements**

Location	Requirement	Notes
Strut external shell plating	Thickness, in mm, is to be not less than: $t = 0,0063s f (h_7 k)^{0,5}$	The minimum thickness of plating diaphragms and primary webs within the strut is to be not less than the Rule requirement for the strut external plating. For internal diaphragms, panel stiffening is to be provided where the ratio of spacing to plate thickness ( $s/t$ ) exceeds 100. Where there are no secondary members, $s$ is to be replaced by $S$ .
Strut primary framing	The section modulus in cm <sup>3</sup> is to be not less than: $z = 7,75h_7 l_e^2 S k$	This does not apply to full breadth plate diaphragms.
Strut secondary stiffening	The section in cm <sup>3</sup> is to be not less than: $z = 0,0056h_7 l_e^2 s k$	This does not apply to full breadth plate diaphragms.
Cylindrical pod body external shell plating	Thickness, in mm, is to be not less than: $t = 3,0R_g (h_7 k)^{0,5}$	Not to be less than the Rule basic shell end thickness from Table 3.2.1 in Pt 3, Ch 3,2
Symbols		
$f$ = panel aspect ratio correction factor = $[1,1 - s/(2500S)]$ $h_7$ = $(T + C_w + 0,014V^2)$ $k$ = local higher tensile steel factor, as in Pt 3, Ch 2 $l_e$ = effective span of the member under consideration, in metres $s$ = the frame spacing of secondary members, in mm $C_w$ = design wave amplitude, in metres, as in Pt 4, Ch 1,1.5 $R_g$ = mean radius of pod body tube, in metres $S$ = the spacing of primary members, in metres $T$ = the vessel scantling draft, in metres, as in Pt 3, Ch 1,6.1 $V$ = ship service speed, in knots, as in Pt 3, Ch 1,6.1.		

5.1.12 Castings are to comply with the requirements of Chapters 4 or 7 of the Rules for Materials.

5.2 Hull support structure

5.2.1 For supporting the main slewing bearing outer races, a system of primary structural members is to be provided in order to transfer the maximum design loads and moments from the podded propulsion unit into the ship's hull without undue deflection. Due account is also to be taken of the loads induced by the maximum ship's motions in the vertical direction resulting from combined heave and pitch motion of the ship. Account is also to be taken of any manoeuvring conditions that are likely to give rise to high mean or vibratory loadings induced by the podded propulsion unit. See 2.2.1(c).

5.2.2 The hull support structure in way of the slewing bearing should be sufficiently stiff that the bearing manufacturer's limits on seating flatness are not exceeded due to hull flexure as a consequence of the loads defined under 5.2.1.

5.2.3 Generally, the system of primary members is to comprise a pedestal girder directly supporting the slewing ring and bearing. The pedestal girder is to be integrated with the ship's structure by means of radial girders and transverses aligned at their outer ends with the ship's bottom girders and transverses, see Fig. 9.5.1. Proposals to use alternative arrangements that provide an equivalent degree of strength and rigidity may be submitted for appraisal.

5.2.4 The ship's support structure in way of the podded unit may be of double or single bottom construction. Generally, podded drives should be supported where practical within a double bottom structure; however final acceptance of the supporting arrangements will be dependent upon satisfying the stress criteria set out in Table 9.5.2, see also 5.3.5.

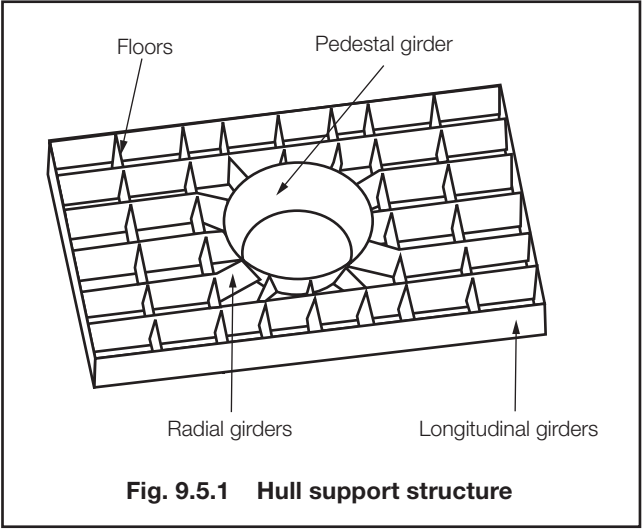


Fig. 9.5.1 Hull support structure

5.2.5 The shell envelope plating and tank top plating in way of the aperture for the podded drive (i.e. over the extent of the radial girders shown in Fig. 9.5.1) are to be increased by 50 per cent over the Rule minimum thickness to provide additional local stiffness and robustness. However the thickness of this plating is not to be less than the actual fitted thickness of the surrounding shell or tank top plating.

5.2.6 The scantlings of the primary support structure in way of the podded drive are to be based upon the limiting design stress criteria specified in Table 9.5.2, see also 5.3.5. Primary member scantlings are, however, not to be less than those required by Pt 3, Ch 6,5.

5.2.7 The pedestal girder is to have a thickness not less than the required shell envelope minimum Rule thickness in way. Where abutting plates are of dissimilar thickness then the taper requirements of Pt 3, Ch 10,2 are to be complied with.

Table 9.5.2 Direct calculation maximum permissible stresses for steel fabricated structures

Permissible stress values		
Location	Podded drive structure	Podded drive/hull interface
X-Y shear stress	$0,26\sigma_0$	$0,35\sigma_0$
Direct stress due to bending	$0,33\sigma_0$	$0,63\sigma_0$
Von Mises stress	$0,40\sigma_0$	$0,75\sigma_0$
Localised Von Mises peak stresses	$\sigma_0$	$\sigma_0$
Symbols		
$\sigma_0$ = minimum yield strength of the material		
NOTES		
1. The values stated above are intended to give an indication of the levels of stress in the pod and ship structure for the maximum loads which could be experienced during normal service.		
2. If design is based on extreme or statistically low probability loads, then proposals to use alternative acceptance stress criteria may be considered.		

# Podded Propulsion Units

## Part 5, Chapter 9

Sections 5 &amp; 6

5.2.8 In general, full penetration welds are to be applied at the pedestal girder boundaries and in way of the end connections between the radial girders and the pedestal girder. Elsewhere, for primary members, double continuous fillet welding is to be applied using a minimum weld factor of 0,34.

### 5.3 Direct calculations

5.3.1 Finite element or other direct calculation techniques may be employed in the verification of the structural design. The mesh density used is to be sufficient to accurately demonstrate the response characteristics of the structure and to provide adequate stress and deflection information. A refined mesh density is to be applied to geometry transition areas and those locations where high localised stress or stress gradients are anticipated.

5.3.2 Model boundary constraints are generally to be applied in way of the slewing ring/ship attachment only.

5.3.3 The loads applied to the mathematical model, see 2.4.1, are to include the self weight, dynamic acceleration due to ship motion, hydrodynamic loads, hydrostatic pressure, propeller forces and shaft bearing support forces. In situations where a pod can operate in the flooded conditions or where flooding of a pod adds significant mass to the pod, details are to be included.

5.3.4 Based on the most onerous combination of normal service loading conditions, the stress criteria shown in Table 9.5.2 are not to be exceeded. See also 2.2.1(c).

5.3.5 Where the structural design is based on a fatigue assessment and the stress criteria shown in Table 9.5.2 are not applicable, details of cumulative load history and stress range together with the proposed acceptance criteria are to be submitted for consideration.

5.3.6 For cast structures, the localised von Mises stress should not exceed 0,6 times the nominal 0,2 per cent proof or yield stress of the material for the most onerous design condition.

6.1.2 Means are to be provided whereby normal operation of the podded propulsion system can be sustained or readily restored if one of the supporting auxiliaries becomes inoperative, see also 2.1.1. Consideration shall be given to the malfunctioning of:

- sources of lubricating oil pressure,
- sources of cooling,
- hydraulic, pneumatic or electrical means for control of the podded propulsor.

### 6.2 Gearing

6.2.1 If gearing is used in the propulsion system then the requirements of Chapter 5 are applicable.

### 6.3 Propulsion shafting

6.3.1 In addition to meeting the requirements of Chapters 6 and 8, the pod propulsion shafting supporting an electric motor is to be sufficiently stiff that both static and dynamic shaft flexure are within the motor manufacturer's limits for all envisaged operating conditions.

6.3.2 There is to be no significant lateral vibration response that may cause damage to the shaft seals within  $\pm 20$  per cent of the running speed range. For vibration analysis computations the influence of the slewing ring and shaft bearing stiffnesses together with the contribution from the seating stiffnesses are to be included in the calculation procedures.

6.3.3 As an alternative to the requirements of Chapter 6, a fatigue strength analysis of shafting components indicating a factor of safety of 1,5 at the design loads based on a suitable fatigue failure criterion may be submitted for consideration. The effects of stress concentrations, material properties and operating environment are to be taken into account.

6.3.4 With the exception of the propeller connection (requirements stated in Chapter 7) couplings relying on friction are to have a factor of safety of 2,5 against slippage at the maximum rated torque. In order to reduce the possibility of fretting, a grip stress of not less than 20 N/mm<sup>2</sup> is to be attained.

6.3.5 The effects of motor short-circuit torque on the shafting system should not prevent continued operation once the fault has been rectified.

6.3.6 The arrangement of shaft bearings is to take account of shaft thermal expansion, misalignment of bearings, shaft slope through the bearings and manufacturing tolerances. Additionally, the influence of the pod deflection on the shaft bearing alignment is to be considered under the most onerous mechanical and hydrodynamic loading conditions.

## Section 6

### Machinery design and construction requirements

#### 6.1 General

6.1.1 The requirements detailed in Chapter 1 are applicable.

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6.3.7 Propeller shaft roller bearing life calculations are to take account of the following loadings:

- Shaft, motor, propeller and other shaft appendages' weights;
- Forces due to ship's motion;
- The propeller-generated forces and moments about the three Cartesian axes related to the shaft;  $f_x$ ,  $f_y$ ,  $f_z$ ,  $m_x$ ,  $m_y$ ,  $m_z$ , see Fig. 9.2.1;
- Variance of propeller-generated forces and moments with pod azimuth angle. This load variance should take account of the motor control characteristics;
- Forces due to pod rotation, including gyroscopic forces;
- A predicted azimuth service profile for the pod indicating the proportion of time spent at various azimuth angles;
- Loads due to hydrodynamic interaction between pods;
- Any additional loads experienced during operation in ice conditions (for Ice Class notations);
- Where validation of the above loadings is available, detailed calculations must demonstrate that the bearing life when operating at the normal duty profile will comfortably exceed the time between 5-yearly surveys. Parameters used to justify the bearing life, i.e. those related to oil cleanliness, viscosity limits and material quality are to be quoted.

6.3.8 Where detailed validation of the loadings identified in 6.3.7. is not available, the calculations for roller bearings are to indicate a bearing life greater than 65,000 hours at the maximum continuous rating of the podded drive taking into account the azimuth angle duty cycle. Any parameters used to justify this life, i.e. those related to oil cleanliness, water contamination and viscosity limits are to be quoted. Proposals for the use of a shaft bearing of life less than 65,000 hours will be considered on application with details of alleviating factors and supporting documentation; however, this bearing life must exceed the time between surveys.

6.3.9 The design of the shaft line bearings is to take account of the maximum and minimum operating temperatures likely to be encountered during both a voyage cycle and, more widely, during the ship's operational life. Furthermore, any anticipated temperature distributions through the bearing components and structures are to be included in the design calculations.

6.3.10 Means are to be provided for detecting shaft bearing deterioration. Where rolling element shaft bearings are used in single pod applications or in pods where the motor power exceeds 6 MW, vibration monitoring of the shaft bearings is to be provided. The bearing monitoring system is to be suitable for the local bearing conditions and is to be able to differentiate from other vibration sources such as propeller cavitation or ship motions.

6.3.11 In multi-podded propulsor systems or ships having at least one pod in association with other propulsion devices and where the individual pod installed power is greater than 5 MW, means are to be provided to hold the propeller for an inoperable unit stationary whilst the other pod(s) propel the vessel at a manoeuvring speed of not less than 7 knots. Operating instructions displayed at the holding mechanism's operating position are to include a direction to inform the bridge of any limitation in ship's speed required as a result of the holding mechanism being activated.

6.3.12 Shaft seals for maintaining the watertight integrity of the pod are to be Type Approved to a standard acceptable to LR. The seals are to be designed to withstand the extremes of operation for which they are intended and this is to include extremes of temperature, vibration, pressure and shaft movement.

6.3.13 In single pod installations, the integrity of shaft seals is to be evaluated on the basis of a double failure. In such installations, seal duplication is to be used with indication of failure of one seal being provided.

## 6.4 Propeller

6.4.1 The requirements of Chapter 7 are to be complied with.

6.4.2 Where propeller scantlings have been determined by a detailed fatigue analysis, based on reliable wake survey data as described in Ch 7,3.1.7, a factor of safety of 1,5 against suitable fatigue failure criteria is to be demonstrated. The effects of fillet stress concentrations, residual stress, fluctuating loads and material properties are to be taken into account.

## 6.5 Bearing lubrication system

6.5.1 The bearing lubrication system is to be arranged to provide a sufficient quantity of lubricant of a quality, viscosity and temperature acceptable to the bearing manufacturer under all ship operating conditions.

6.5.2 In addition to the requirements detailed in this Section, the requirements of Chapter 14, sub-Sections 8.1, 8.5, 8.7 and 8.9 are to be complied with.

6.5.3 For systems employing forced lubrication, the sampling points required by Ch 14,8.13.6 are to be located such that the sample taken is representative of the oil present at the bearing.

6.5.4 For lubricating oil systems employing gravity feed, the arrangements are to be such as to permit oil sampling and oil changes in accordance with the manufacturer's instructions for the safe and reliable operation of the propulsion system.

6.5.5 Where continuous operation of the lubricating oil system is essential for the pod to operate at its maximum continuous rating, a standby pump in accordance with Ch 14,8.2.2 is to be provided. In such systems, provision is to be made for the efficient filtration of the oil. The filters are to be capable of being cleaned without stopping the pod.

6.5.6 Where bearings are grease lubricated, means are to be provided for collecting waste grease to enable analysis for particulates and water. The arrangements for collecting waste grease are to be in accordance with the pod manufacturer's recommendations. Alternative arrangements which demonstrate that bearings are satisfactorily lubricated will be considered.



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Section 6

6.5.7 Pipework conveying lubricating oil is to be sited such that any possible leakage from joints will not impinge on electrical equipment, hot surfaces or other sources of ignition, see also Ch 13,2.9.3.

6.5.8 The procedures for flushing the lubrication system are to be defined. This procedure is to embrace the following conditions:

- (a) Initial installation.
- (b) Post maintenance situations.
- (c) Major dry-docking refits.

See Section 10.

### 6.6 Steering system

6.6.1 The requirements of Chapter 19, Sections 1, 2, 3, 6, 7 and 8 are to be complied with where applicable. See also 3.1.

6.6.2 For vessels where a single podded propulsion unit is the sole means of propulsion, the requirement for auxiliary steering arrangements in Ch 19,2 is to be achieved by means of two or more identical power units.

6.6.3 For vessels with more than one steerable podded propulsion unit, the requirement for auxiliary steering arrangements in Ch 19,2 is to be achieved by equipping each of the pod units with its own dedicated and independent steering gear control system and power actuating system. Consideration will be given to alternative arrangements providing equivalence can be demonstrated.

6.6.4 Steering arrangements, other than of the hydraulic type, may be accepted provided that there are means of limiting the maximum torque to which the steering arrangement may be subjected.

6.6.5 The steering mechanism is to be provided with power that is sufficient for the maximum steering torques present during the declared functional capability identified in 3.1 and is to be demonstrated for the most onerous specified manoeuvring trial, see Section 9.

6.6.6 Geared arrangements employed for steering are to consider the following conditions:

- A design maximum dynamic duty steering torque,  $M_z$ , see 2.4.1;
- A static duty ( $\leq 10^3$  load cycles) steering torque. The static duty steering torque should not be less than  $M_v$ , the maximum torque which can be generated by the steering gear mechanism.

The minimum factors of safety, as derived using ISO 6336 Calculation of load capacity of spur and helical gears, or a recognised National Standard, are to be 1.5 on bending stress and 1.0 on Hertzian contact stress. The use of a duty factor in the dynamic duty strength calculations is acceptable but the derivation of such a factor, based on percentage of time spent at a percentage of the maximum working torque, should be submitted to LR for consideration and acceptance.

6.6.7 Slewing ring bearing capacity calculations are to take account of:

- Pod weight in water;
- Gyroscopic forces from the propeller and motor;
- Hydrodynamic loads on pod; and
- Forces due to ship's motions.

The calculations are to demonstrate that the factor of safety against the maximum combination of the above forces is not less than 2. The calculations are to be carried out in accordance with a suitable declared standard.

6.6.8 Means of allowing the condition of the slewing gears and bearings to be assessed are to be provided.

6.6.9 On multi podded ships, means are to be provided to secure each pod unit's slewing mechanism in its mid position in the event of a steering system failure. These arrangements are to be of sufficient strength to hold the pod in position at the ship's manoeuvring speed to be taken as not less than 7 knots, see also 6.3.9. Operating instructions displayed at the securing mechanism's operating position are to include a direction to inform the bridge of any limitation in ship's speed required as a result of the securing mechanism being activated.

### 6.7 Ventilation and cooling systems

6.7.1 Means are to be provided to ensure that air used for motor cooling purposes is of a suitable temperature and humidity as well as being free from harmful particles.

6.7.2 Cooling water supplies are to comply with Ch 14,7. See also Pt 6, Ch 2,9.6.

6.7.3 On single podded installations, a standby cooling arrangement of the same capacity as the main cooling system, is to be provided and available for immediate use.

6.7.4 For pods having an electric propulsion motor but no active cooling system, heat balance calculations as required by 2.2.1(w) are to demonstrate that the pod unit and associated systems are able to function satisfactorily over all operating conditions, see Ch 1,3.5.

### 6.8 Pod drainage requirements

6.8.1 Unless the electrical installation is suitable for operation in a flooded space, means are to be provided to ensure that leakage from shaft bearings or the propeller seal do not reach the motor windings, or other electrical components. Account is to be taken of cooling air flow circulating within the pod unit.

6.8.2 Where the design of a pod space has a requirement to be maintained in a dry condition, two independent means of drainage are to be provided so that liquid leakage may be removed from the pod unit at all design angles of heel and trim, see Ch 1,3.6.

6.8.3 Pipework conveying leakage from the pod is to be sited such that any leakage from joints will not impinge on electrical equipment, see also Ch 13,2.9.3.

# Podded Propulsion Units

## Part 5, Chapter 9

Sections 6, 7 &amp; 8

### 6.9 Hydraulic actuating systems

6.9.1 Hydraulic actuating systems are to comply with Ch 14,9 and Ch 19,3 as applicable.

### Section 7 Electrical equipment

#### 7.1 General

7.1.1 The electrical installation is to be designed, constructed and installed in accordance with the requirements of Pt 6, Ch 2.

7.1.2 Means are to be provided to prevent electrical currents flowing across shaft bearings, which may cause their premature failure.

7.1.3 Steering gear electrical systems are to comply with Ch 19,5.

7.1.4 Details are to be submitted to demonstrate the suitability of cables and busbars intended to operate at temperatures exceeding 95°C, see Pt 6, Ch 2,7.2.2 and 11.4.3.

#### 7.2 Slip rings

7.2.1 Where slip rings are incorporated in the design, the details of the following are to be submitted for consideration:

- (a) temperature rise test reports;
- (b) maximum permitted temperature ratings and design operating temperatures for materials;
- (c) where applicable, arrangements for forced air or liquid cooling;
- (d) for data communication link slip rings, evidence to demonstrate compliance with Pt 6, Ch 1,2.11.3;
- (e) suitability for use under the conditions of vibration expected to arise in normal operation;
- (f) evidence of satisfactory operation under the normal angles of inclination given in Pt 6, Ch 2,1.10;
- (g) cable securing arrangements; and
- (h) evidence of electromagnetic compatibility of control, alarm and safety systems with power circuits.

7.2.2 Where forced cooling is used on slip rings, an alarm is to be initiated to indicate the failure of the forced cooling and it is to be possible to operate the slip ring at a reduced power level defined by the Manufacturer in the event of failure of the forced cooling.

### Section 8 Control engineering systems

#### 8.1 General

8.1.1 Control engineering arrangements are to be in accordance with Pt 6, Ch 1.

8.1.2 Steering gear control, monitoring and alarm systems are to comply with Ch 19,4 and Ch 19,5.

8.1.3 Steering control is to be provided for podded drives from the navigating bridge and locally.

8.1.4 An indication of the angular position of the podded propulsion unit(s) and the magnitude of the thrust is to be provided at each station from which it is possible to control the direction of thrust. This indication is to be independent of the steering control system.

8.1.5 Emergency Stop Functions are to be provided at the remote control station(s), independent of the podded drive control system, to stop each podded drive in an emergency. See also Pt 6, Ch 2,16.4.7.

8.1.6 Where programmable electronic equipment is used to prevent loads exceeding those for which the system has been designed (see 2.4.3), then either:

- (a) A fully independent hard wired backup is to be provided; or
- (b) The software is to be certified in accordance with LR's Software Conformity Assessment System – Assessment Module GEN1 (1994) and have an independent solution showing redundancy with design diversity, etc., see Pt 6, Ch 1,2.13 of the Rules.

8.1.7 Where a propulsion system which includes a podded propulsor unit is controlled by a series of interactive and integrated programmable electronic systems, then these are to comply with the requirements of Pt 6, Ch 1,2.13 of the Rules.

8.1.8 For electronic control systems and electrical actuating systems, an overall quality plan for sourcing, design, installation and testing is to address the following issues:

- (a) Standard(s) applied.
- (b) Details of the quality control system applied during manufacture and testing.
- (c) Details of type approval, type testing or approved type status assigned to the equipment.
- (d) Details of installation and testing recommendations for the equipment.
- (e) Details of any local and/or remote diagnostic arrangements where assessment and alteration of control parameters can be made which can affect the operation of the podded propulsor unit.
- (f) Software lifecycle activities, including configuration management and arrangements for software upgrades.



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8.1.9 The quality plan referred to in 8.1.8 to identify the process for verification of the functional outputs from the electronic control systems with particular reference to system integrity, consistency, security against unauthorised changes to software and maintaining the outputs within acceptable tolerances of stated performance for safe and reliable operation of the podded propulsor unit.

8.1.10 For the permitted range of operating conditions, the control system is to be capable of protecting the podded propulsor from experiencing mechanical loads that may initiate damage while permitting the desired manoeuvres to take place.

## 8.2 Monitoring and alarms

8.2.1 The requirements for alarms and monitoring arrangements are to be in accordance with Ch 19,5.3 and Table 9.8.1. These alarms are in addition to the requirements of Pt 6, Ch 2,16.

8.2.2 Alarms specified in Table 9.8.1 are to be in accordance with the alarm system specified by Pt 6, Ch 1,2,3.

8.2.3 Sensors for control, monitoring and alarm systems required by the Rules and located within the pod are to be duplicated in order that a single sensor failure does not inhibit system functionality.

8.2.4 Pod unit dry space pumping arrangements are to function automatically in the event of a high liquid level being detected in the pod unit.

8.2.5 Spaces intended to be dry are to be provided with arrangements to indicate water ingress in accordance with 8.2.6 and Table 9.8.1.

8.2.6 The number and location of dry space level detectors are to be such that accumulation of liquids will be detected at all design angles of heel and trim.

8.2.7 Condition monitoring arrangements are not to interface with the operation of safety systems which may cause slow-down or shut-down of the propulsion system. See also Pt 6, Ch 1,2.6.9.

**Table 9.8.1 Additional alarms and safeguards for podded propulsion units**

Item	Alarm	Note
Podded drive azimuth angle	—	Indicator, see 8.1.4
Propulsion motors	Power supply failure	To be indicated on the navigating bridge
Propulsion motor power limitation or automatic reduction	Activated	See also Pt 6, Ch 2,16.4.9
Hydraulic oil system pressure	Low	To be indicated on the navigating bridge
Bearing temperature	High	For grease lubricated bearings
Motor temperature	High	See Pt 6, Ch 2,16.1.3
Lubricating oil supply pressure	Low	If separate forced lubrication for shaft bearings; to be indicated on the navigating bridge
Lubricating oil temperature	High	See also Pt 6, Ch 2,15.5.9
Lubricating oil tank level for motor bearings	Low	
Water in lubricating oil for motor bearings	High	Required for single podded propulsion units only
Motor cooling air inlet temperature	High	
Motor cooling air outlet temperature	High	
Motor cooling air flow	Low	
Shaft bearing vibration monitoring	High	See 6.3.10. Monitoring is to allow bearing condition to be gauged using trend analysis
Shaft sealing	Failure	See 6.3.13
Dry space water pump operation	Abnormal	Alarm set to indicate a frequency or duration exceeding that which would normally be expected
Dry space water level	1st stage high 2nd stage high	— Propulsion motor is to shut down automatically, See Note
Slip ring forced cooling	Failure	See 7.2.2

**NOTE**

The second stage dry space water level high alarm is not needed where the electrical equipment installed within the pod is suitable for operation in flooded spaces, see 6.8.1.

## ■ Section 9 Testing and trials

### 9.1 General

9.1.1 The following requirements are to be complied with:

- Ch 1,5.2 for sea trials.
- Ch 19,7.2 for steering trials.

In addition, the functional capability specified in 3.1.1 is to be demonstrated to the Surveyor's satisfaction.

9.1.2 The actual values of steering torque are to be verified during sea trials to confirm that the design maximum dynamic duty torque has not been exceeded.

9.1.3 Electric motor cooling systems are to be verified, as far as possible, to ensure that they are capable of limiting the extremes of ambient temperature to those specified in 2.3.1.

9.1.4 Any trials and testing identified from the FMEA report, see 2.5.4(f), are also to be carried out.

## ■ Section 10 Installation, maintenance and replacement procedures

### 10.1 General

10.1.1 All podded propulsion units are to be supplied with a copy of the manufacturer's installation and maintenance manual that is pertinent to the actual equipment.

10.1.2 The manual required by 10.1.1 is to be placed on board and is to contain the following information:

- (a) Description of the podded propulsion unit with details of function and design operating limits. This is also to include details of support systems such as lubrication, cooling and condition monitoring arrangements.
- (b) Identification of all components together with details of any that have a defined maximum operating life.
- (c) Instructions for installation of unit(s) on board ship with details of any required specialised equipment.
- (d) Instructions for commissioning at initial installation and following maintenance.
- (e) Maintenance and service instructions to include inspection/renewal of bearings, seals, motors, slip rings and other major components. This is also to include component fitting procedures, special environmental arrangements, clearance and push-up measurements and lubricating oil treatment where applicable.
- (f) Actions required in the event of fault/failure conditions being detected.
- (g) Precautions to be taken by personnel working during installation and maintenance.

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

Section 1

## Section

- 1 **General requirements**
- 2 **Cylindrical shells and drums subject to internal pressure**
- 3 **Spherical shells subject to internal pressure**
- 4 **Dished ends subject to internal pressure**
- 5 **Conical ends subject to internal pressure**
- 6 **Standpipes and branches**
- 7 **Boiler tubes subject to internal pressure**
- 8 **Headers**
- 9 **Flat surfaces and flat tube plates**
- 10 **Flat plates and ends of vertical boilers**
- 11 **Furnaces subject to external pressure**
- 12 **Boiler tubes subject to external pressure**
- 13 **Tubes welded at both ends and bar stays for cylindrical boilers**
- 14 **Construction**
- 15 **Mountings and fittings for cylindrical and vertical boilers, steam generators, pressurised thermal liquid and pressurised hot water heaters**
- 16 **Mountings and fittings for water tube boilers**
- 17 **Hydraulic tests**
- 18 **Control and monitoring**

1.1.2 The scantlings of coil type heaters with pumped circulation, which are fired or heated by exhaust gas, are to comply with the appropriate requirements of this Chapter.

1.1.3 Where exhaust gas emissions abatement equipment is fitted to steam raising plant, it is to meet the requirements of Chapter 24.

### 1.2 Definition of symbols

1.2.1 The symbols used in the various formulae in Sections 2 to 8, unless otherwise stated, are defined as follows and are applicable to the specific part of the pressure vessel under consideration:

- $d$  = diameter of hole or opening, in mm
- $p$  = design pressure, see 1.3, in bar
- $r_i$  = inside knuckle radius, in mm
- $r_o$  = outside knuckle radius, in mm
- $s$  = pitch, in mm
- $t$  = minimum thickness, in mm
- $D_i$  = inside diameter, in mm
- $D_o$  = outside diameter, in mm
- $J$  = joint factor applicable to welded seams, see 1.9, or ligament efficiency between tube holes (expressed as a fraction, see 2.2)
- $R_i$  = inside radius, in mm
- $R_o$  = outside radius, in mm
- $T$  = design temperature, in °C
- $\sigma$  = allowable stress, see 1.8, in N/mm<sup>2</sup>.

1.2.2 Where reference is made to calculated or actual plate thickness for the derivation of other values, these thicknesses are to be minus the standard Rule corrosion allowance of 0,75 mm, if not so stated.

### 1.3 Design pressure

1.3.1 The design pressure is the maximum permissible working pressure and is to be not less than the highest set pressure of any safety valve.

1.3.2 The calculations made to determine the scantlings of the pressure parts are to be based on the design pressure, adjusted where necessary to take account of pressure variations corresponding to the most severe operational conditions.

1.3.3 It is desirable that there should be a margin between the normal pressure at which the boiler or pressure vessel operates and the lowest pressure at which any safety valve is set to lift, to prevent unnecessary lifting of the safety valve.

### 1.4 Metal temperature

1.4.1 The metal temperature,  $T$ , used to evaluate the allowable stress,  $\sigma$ , is to be taken as the actual mean wall metal temperature expected under operating conditions for the pressure part concerned, and is to be stated by the manufacturer when plans of the pressure parts are submitted for consideration.

## Section 1 General requirements

### 1.1 Application

1.1.1 The requirements of this Chapter are applicable to fusion welded pressure vessels and their mountings and fittings, for the following uses:

- (a) Production or storage of steam.
- (b) Heating of pressurised hot water above 120°C.
- (c) Heating of pressurised thermal liquid.

The formulae in this Chapter may be used for determining the thickness of seamless pressure vessels using a joint factor of 1,0. Seamless pressure vessels are to be manufactured and tested in accordance with the requirements of Chapter 5 of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

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Section 1

1.4.2 The following values are to be regarded as the minimum:

- (a) For fired steam boilers,  $T$ , is to be taken as not less than 250°C.
- (b) For steam heated generators, secondary drums of double evaporation boilers, steam receivers and pressure parts of fired pressure vessels, not heated by hot gases and adequately protected by insulation,  $T$ , is to be taken as the maximum temperature of the internal fluid.
- (c) For pressure parts heated by hot gases,  $T$ , is to be taken as not less than 25°C in excess of the maximum temperature of the internal fluid.
- (d) For boiler, superheater, reheater and economiser tubes,  $T$ , is to be taken as indicated in 7.1.2.
- (e) For combustion chambers of the type used in horizontal wet-back boilers,  $T$ , is to be taken as not less than 50°C in excess of the maximum temperature of the internal fluid.
- (f) For furnaces, fireboxes, rear tube plates of dry-back boilers and pressure parts subject to similar rates of heat transfer,  $T$ , is to be taken as not less than 90°C in excess of the maximum temperature of the internal fluid.

1.4.3 In general any parts of boiler drums or headers not protected by tubes, and exposed to radiation from the fire or to the impact of hot gases, are to be protected by a shield of good refractory material or by other approved means.

1.4.4 Drums and headers of thickness greater than 35 mm are not to be exposed to combustion gases having an anticipated temperature in excess of 650°C unless they are efficiently cooled by closely arranged tubes.

### 1.5 Classification of fusion welded pressure vessels

1.5.1 For Rule purposes, pressure vessels with fusion welded seams are graded as Class 1 if they comply with the following conditions:

- (a) For pressure parts of fired steam boilers, fired thermal liquid heaters and exhaust gas heated shell type steam boilers where the design pressure exceeds 3,4 bar.
- (b) For pressure parts of steam heated steam generators and separate steam receivers where the design pressure exceeds 11,3 bar, or where the pressure, in bar, multiplied by the internal diameter of the shell, in mm, exceeds 14 420.

1.5.2 For Rule purposes, pressure vessels with fusion welded seams, used for the production or storage of steam, the heating of pressurised hot water above 120°C or the heating of pressurised thermal liquid not included in Class 1 are graded as Class 2/1 and 2/2.

1.5.3 Pressure vessels which are constructed in accordance with Class 2/1 or Class 2/2 standards (as indicated above) will, if manufactured in accordance with requirements of a superior class, be approved with the scantlings appropriate to that class.

1.5.4 Pressure vessels which have only circumferential fusion welded seams, will be considered as seamless with no class being assigned. Preliminary weld procedure tests and non-destructive examination for the circumferential seam welds should be carried out for the equivalent class as determined by 1.5.1 and 1.5.2.

1.5.5 In special circumstances relating to service conditions, materials, operating temperature, the carriage of dangerous gases and liquids, etc., it may be required that certain pressure vessels be manufactured in accordance with the requirements of a superior class.

1.5.6 Details of heat treatment, non-destructive examination and routine tests (where required) are given in Chapter 13 of the Rules for Materials.

1.5.7 Hydraulic testing is required for pressure vessels of Class 1, 2/1 and 2/2.

### 1.6 Plans

1.6.1 Plans of boilers, superheaters and economisers are to be submitted in triplicate for consideration. When plans of water tube boilers are submitted for approval, particulars of the safety valves and their disposition on boilers and superheaters, together with the estimated pressure drop through the superheaters, are to be stated. The pressures proposed for the settings of boiler and superheater safety valves are to be indicated on the boiler plan.

1.6.2 Plans, in triplicate, showing full constructional features of fusion welded pressure vessels and dimensional details of the weld preparation for longitudinal and circumferential seams and attachments, together with particulars of the welding consumables and of the mechanical properties of the materials, are to be submitted before construction is commenced.

1.6.3 Plans, in triplicate, showing details of the air flow through the combustion chamber, boiler furnace and boiler uptake spaces, including measures taken to assure effective purging in all of the spaces, are to be submitted for consideration. See also Pt 5, Ch 10, 18.3 and Ch 14, 2.2.

1.6.4 Plans, in triplicate, showing all areas of refractory material in the combustion chamber and boiler furnace spaces, are to be submitted for consideration. See 1.12.1.

1.6.5 Calculations, in triplicate, showing that a minimum of 4 air changes of the combustion chamber, boiler furnace and boiler uptake spaces will be achieved during automatic purging operations, with details of the forced draft fans and arrangements of air flow from fan intake to flue outlet, are to be submitted for consideration, see 1.12.1.

1.6.6 Calculations, in triplicate, are to be submitted showing that the ventilation of machinery spaces containing boilers is adequate for the air consumers within the space with an unimpaired air supply, in accordance with the equipment manufacturer's recommendations, under operating conditions as defined in Ch 1, 4.4.2.

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### 1.7 Materials

1.7.1 Materials used in the construction are to be manufactured and tested in accordance with the requirements of the Rules for Materials.

1.7.2 The specified minimum tensile strength of carbon and carbon-manganese steel plates, pipes, forgings and castings is to be within the following general limits:

- (a) For seamless, Class 1, Class 2/1 and Class 2/2 fusion welded pressure vessels:  
340 to 520 N/mm<sup>2</sup>.
- (b) For boiler furnaces, combustion chambers and flanged plates:  
400 to 520 N/mm<sup>2</sup>.

1.7.3 The specified minimum tensile strength of low alloy steel plates, pipes, forgings and castings is to be within the general limits of 400 to 500 N/mm<sup>2</sup> and pressure vessels made in these steels are to be either seamless or Class 1 fusion welded.

1.7.4 The specified minimum tensile strength of boiler and superheater tubes is to be within the following general limits:

- (a) Carbon and carbon-manganese steels:  
320 to 460 N/mm<sup>2</sup>.
- (b) Low alloy steels:  
400 to 500 N/mm<sup>2</sup>.

1.7.5 Where it is proposed to use materials other than those specified in the Rules for Materials, details of the chemical compositions, heat treatment and mechanical properties are to be submitted for approval. In such cases the values of the mechanical properties used for deriving the allowable stress are to be subject to agreement by Lloyd's Register (hereinafter referred to as 'LR').

1.7.6 Where a fusion welded pressure vessel is to be made of alloy steel, and approval of the scantlings is required on the basis of the high temperature properties of the material, particulars of the welding consumables to be used, including typical mechanical properties and chemical composition of the deposited weld metal, are to be submitted for approval.

### 1.8 Allowable stress

1.8.1 The term 'allowable stress',  $\sigma$ , is the stress to be used in the formulae for the calculation of scantlings of pressure parts.

1.8.2 The allowable stress,  $\sigma$ , is to be the lowest of the following values:

$$\sigma = \frac{E_t}{1,5} \quad \sigma = \frac{R_{20}}{2,7} \quad \sigma = \frac{S_R}{1,5}$$

where

$E_t$  = specified minimum lower yield stress or 0,2 per cent proof stress at temperature,  $T$

$R_{20}$  = specified minimum tensile strength at room temperature

$S_R$  = average stress to produce rupture in 100 000 hours at temperature,  $T$

$T$  = metal temperature, see 1.4.

1.8.3 The allowable stress for steel castings is to be taken as 80 per cent of the value determined by the method indicated in 1.8.2, using the appropriate values for cast steel.

1.8.4 Where steel castings, which have been tested in accordance with the Rules for Materials, are also subjected to non-destructive tests, consideration will be given to increasing the allowable stress using a factor up to 90 per cent in lieu of the 80 per cent referred to in 1.8.3. Particulars of the non-destructive test proposals are to be submitted for consideration.

### 1.9 Joint factors

1.9.1 The following joint factors are to be used in the equations in Sections 2 to 8, where applicable. Fusion welded pressure parts are to be made in accordance with Chapter 17.

Class of pressure vessel	Joint factor
Class 1	1,0
Class 2/1	0,85
Class 2/2	0,75

1.9.2 The longitudinal and circumferential joints for all classes of pressure vessels for the purposes of this Chapter are to be butt joints. For typical acceptable methods of attaching dished ends, see Fig. 10.14.1.

### 1.10 Pressure parts of irregular shape

1.10.1 Where pressure parts are of such irregular shape that it is impracticable to design their scantlings by the application of formulae in Sections 2 to 8, the suitability of their construction is to be determined by hydraulic proof test of a prototype or by agreed alternative method.

### 1.11 Adverse working conditions

1.11.1 Where working conditions are adverse, special consideration may be required to be given to increasing the scantlings derived from the formulae. In this connection, where necessary, account should also be taken of any excess of loading resulting from:

- (a) impact loads, including rapidly fluctuating pressures,
- (b) weight of the vessel and normal contents under operating and test conditions,
- (c) superimposed loads such as other pressure vessels, operating equipment, insulation, corrosion-resistant or erosion-resistant linings and piping,
- (d) reactions of supporting lugs, rings, saddles or other types of supports, or
- (e) the effect of temperature gradients on maximum stress.

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

Sections 1 & 2

### 1.12 Furnace explosion prevention

1.12.1 The design of combustion chamber and furnace arrangements is to incorporate measures to minimise the risk of explosion as far as practicable. Measures are to be taken to prevent the accumulation of flammable gases in spaces which may not effectively be reached by purging air. Measures are to be taken to minimise heat retaining surfaces e.g., refractory which can become sources of ignition in the furnace and uptakes.

### 1.13 Exhaust gas economiser/boiler arrangements

1.13.1 The design of exhaust gas economisers/boilers of the plain or extended surface fin tube types is to be compatible with the installed engine design parameters. The parameters which influence the build up of soot deposits and overheating such as fuel, exhaust gas temperature and efflux velocity are to be considered in the design of the exhaust gas economiser/boiler for use with the installed engine, in order to minimise the risk of fire and breakdown during operation.

1.13.2 A design statement demonstrating compliance with the requirements of 1.13.1 or alternative means of preventing the accumulation of soot or overheating, such as the use of exhaust gas bypass ducting with automatic flap valve arrangements and/or effective soot prevention and cleaning systems, is to be submitted for approval.

### 2.2 Efficiency of ligaments between tube holes

2.2.1 Where tube holes are drilled in a cylindrical shell in a line or lines parallel to its axis, the efficiency,  $J$ , of the ligaments is to be determined as in 2.2.2, 2.2.3 and 2.2.4.

2.2.2 **Regular drilling.** Where the distance between adjacent tube holes is constant, see Fig. 10.2.1,

$$J = \frac{s - d}{s}$$

where

$d$  = the mean effective diameter of the tube holes, in mm, after allowing for any serrations, counter-boring or recessing, or the compensating effect of the tube stub. See 2.3 and 2.4.

$s$  = pitch of tube holes, in mm.

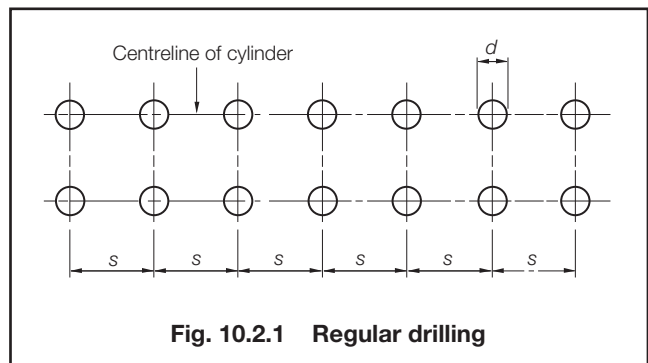


Fig. 10.2.1 Regular drilling

2.2.3 **Irregular drilling.** Where the distance between centres of adjacent tube holes is not constant, see Fig. 10.2.2:

$$J = \frac{s_1 + s_2 - 2d}{s_1 + s_2}$$

where  $d$  is as defined in 2.2.2

$s_1$  = the shorter of any two adjacent pitches, in mm

$s_2$  = the longer of any two adjacent pitches, in mm.

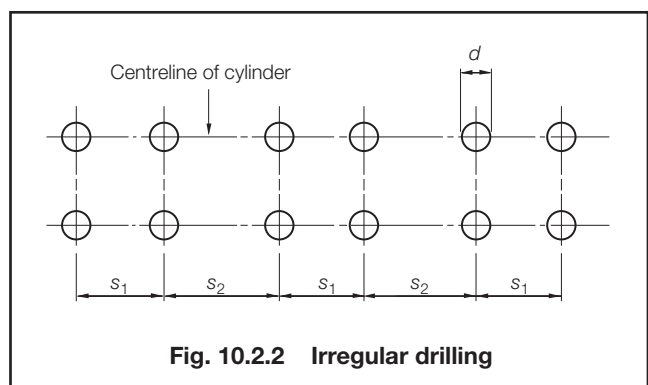


Fig. 10.2.2 Irregular drilling

2.2.4 When applying the formula in 2.2.3, the double pitch ( $s_1 + s_2$ ) chosen is to be that which makes  $J$ , a minimum, and in no case is  $s_2$  to be taken as greater than twice  $s_1$ .

## Section 2 Cylindrical shells and drums subject to internal pressure

### 2.1 Minimum thickness

2.1.1 Minimum thickness,  $t$ , of a cylindrical shell is to be determined by the following formula:

$$t = \frac{p R_i}{10\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $R_i$  and  $\sigma$  are defined in 1.2,

$J$  = efficiency of ligaments between tube holes or other openings in the shell or the joint factor of the longitudinal joints (expressed as a fraction). See 1.9 or 2.2, whichever applies. In the case of seamless shells clear of tube holes or other openings,  $J = 1,0$ .

2.1.2 The formula in 2.1.1 is applicable only where the resulting thickness does not exceed half the internal radius, i.e. where  $R_o$  is not greater than  $1,5R_i$ .

2.1.3 Irrespective of the thickness determined by the above formula,  $t$  is to be not less than:

- 6,0 mm for cylindrical shell plates.
- For tube plates, such thickness as will give a minimum parallel seat of 9,5 mm, or such greater width as may be necessary to ensure tube tightness, see 14.6.



# Steam Raising Plant and Associated Pressure Vessels

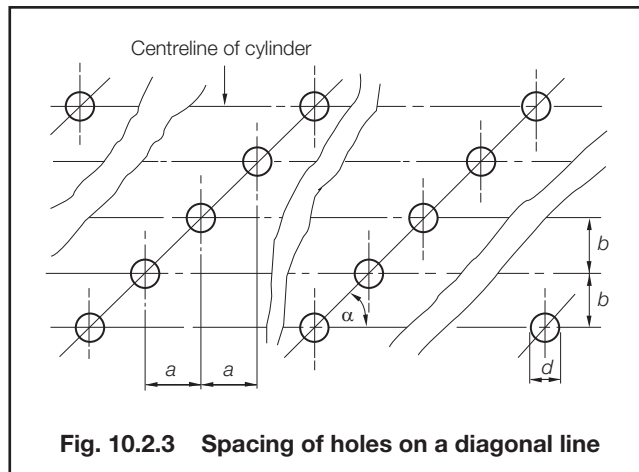
## Part 5, Chapter 10

Section 2

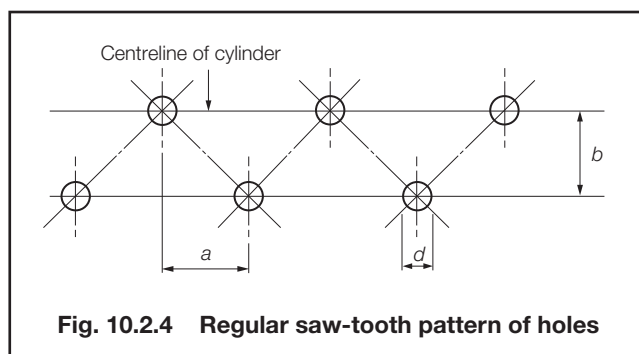
2.2.5 Where the circumferential pitch between tube holes measured on the mean of the external and internal drum or header diameters is such that the circumferential ligament efficiency determined by the formulae in 2.2.2 and 2.2.3 is less than one-half of the ligament efficiency on the longitudinal axis,  $J$  in 2.1 is to be taken as twice the circumferential efficiency.

2.2.6 Where tube holes are drilled in a cylindrical shell along a diagonal line with respect to the longitudinal axis, the efficiency,  $J$ , of the ligaments is to be determined as in 2.2.7 to 2.2.10.

2.2.7 For spacing of tube holes on a diagonal line as shown in Fig. 10.2.3, or in a regular saw-tooth pattern as shown in Fig. 10.2.4,  $J$  is to be determined from the formula in 2.2.8, where  $a$  and  $b$ , as shown in Figs. 10.2.3 and 10.2.4, are measured, in mm, on the median line of the plate, and  $d$ , is as defined in 2.2.2.



**Fig. 10.2.3 Spacing of holes on a diagonal line**



**Fig. 10.2.4 Regular saw-tooth pattern of holes**

2.2.8 For tube holes on a diagonal line:

$$J = \frac{2}{A + B + \sqrt{(A - B)^2 + 4C^2}}$$

where

$$A = \frac{\cos^2 \alpha + 1}{2 \left( 1 - \frac{d \cos \alpha}{a} \right)}$$

$$B = 0,5 \left( 1 - \frac{d \cos \alpha}{a} \right) (\sin^2 \alpha + 1)$$

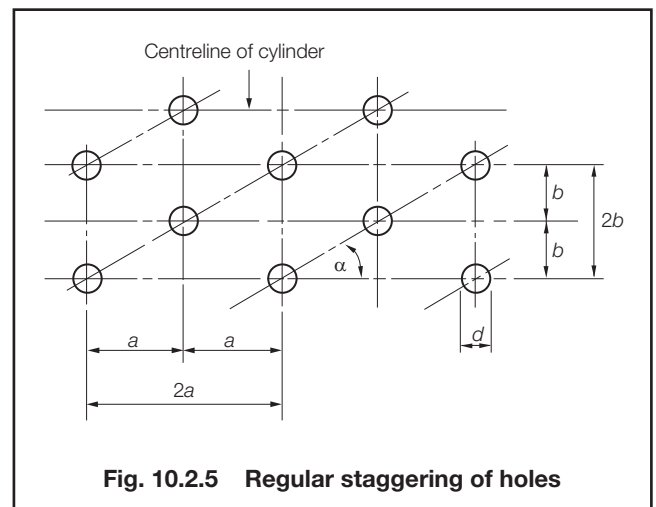
$$C = \frac{\sin \alpha \cos \alpha}{2 \left( 1 - \frac{d \cos \alpha}{a} \right)}$$

$$\cos \alpha = \frac{1}{\sqrt{1 + \frac{b^2}{a^2}}}$$

$$\sin \alpha = \frac{1}{\sqrt{1 + \frac{a^2}{b^2}}}$$

$\alpha$  = angle between centreline of cylinder and centreline of diagonal holes.

2.2.9 For regularly staggered spacing of tube holes as shown in Fig. 10.2.5, the smallest value of the efficiency,  $J$ , of all ligaments (longitudinal, circumferential and diagonal) is obtained from Fig. 10.2.6, where  $a$  and  $b$  as shown in Fig. 10.2.5 are measured, in mm, on the median line of the plate, and  $d$  is as defined in 2.2.2.



**Fig. 10.2.5 Regular staggering of holes**

2.2.10 For irregularly spaced tube holes whose centres do not lie on a straight line, the formula in 2.2.3 is to apply, except that an equivalent longitudinal width of the diagonal ligament is to be used. An equivalent longitudinal width is that width which gives, using the formula in 2.2.2, the same efficiency as would be obtained using the formula in 2.2.8 for the diagonal ligament in question.



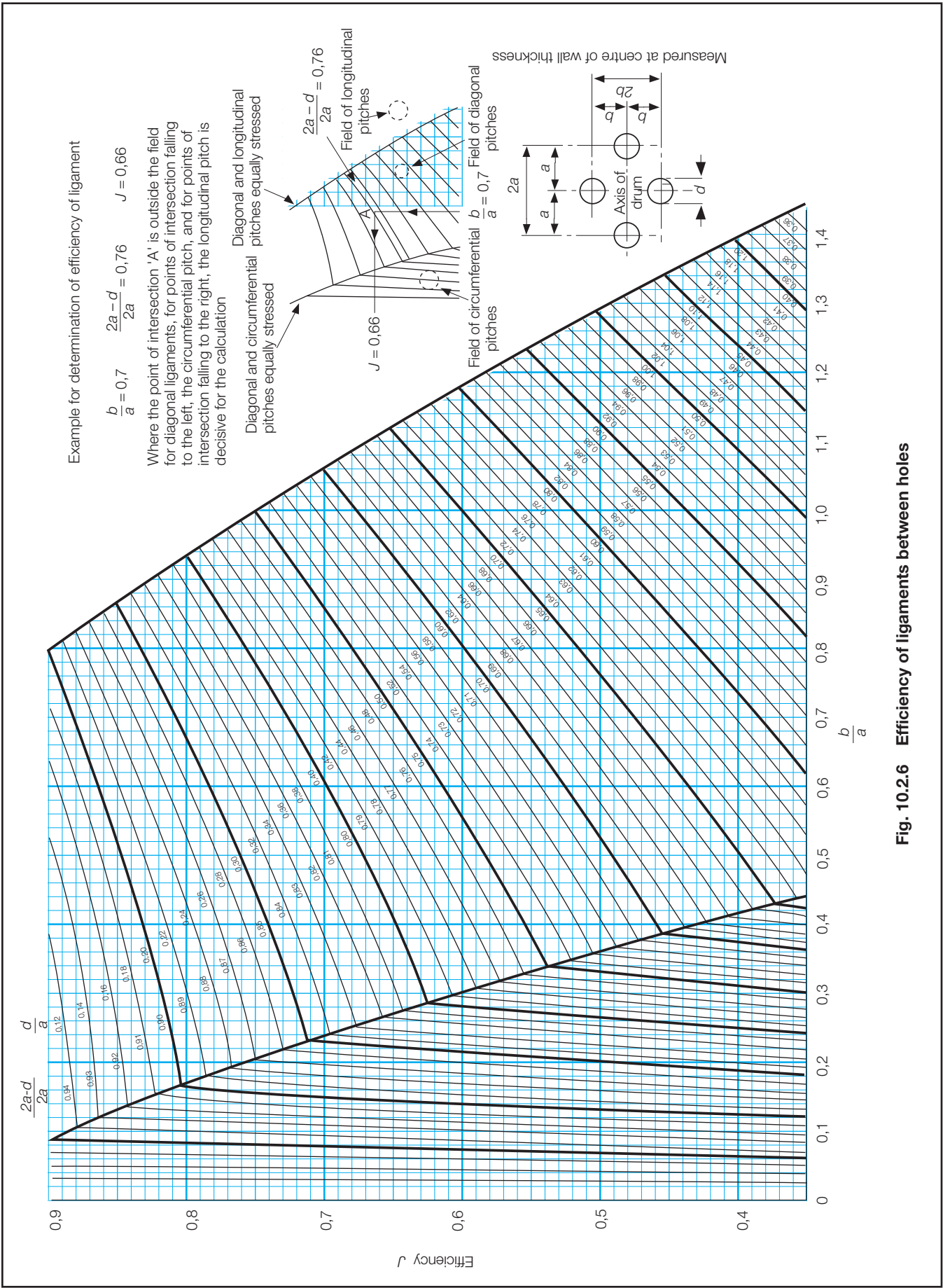


Fig. 10.2.6 Efficiency of ligaments between holes

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

Section 2

### 2.3 Compensating effect of tube stubs

2.3.1 Where a drum or header is drilled for tube stubs fitted by strength welding, either in line or in staggered formation, the effective diameter of holes is to be taken as:

$$d_e = d_a - \frac{A}{t}$$

where

- $d_e$  = the equivalent diameter of the hole, in mm
- $d_a$  = the actual diameter of the hole, in mm
- $t$  = the thickness of the shell, in mm
- $A$  = the compensating area provided by each tube stub and its welding fillets, in mm<sup>2</sup>.

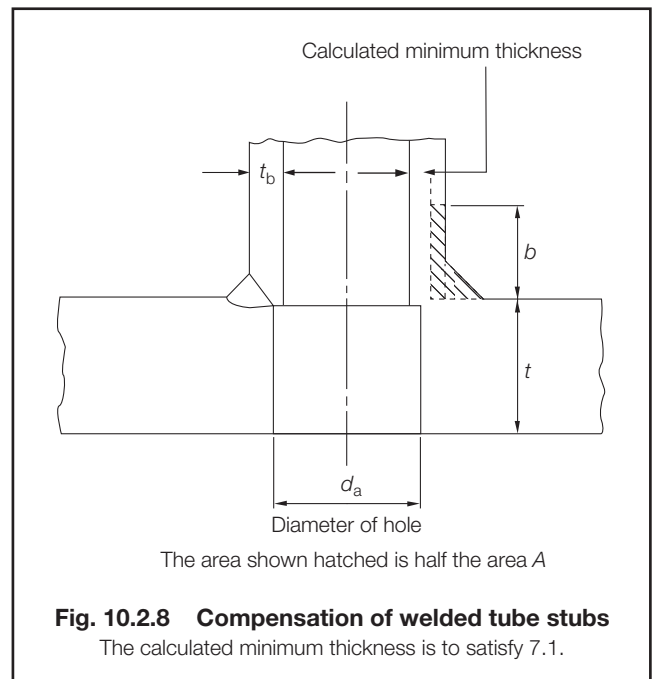
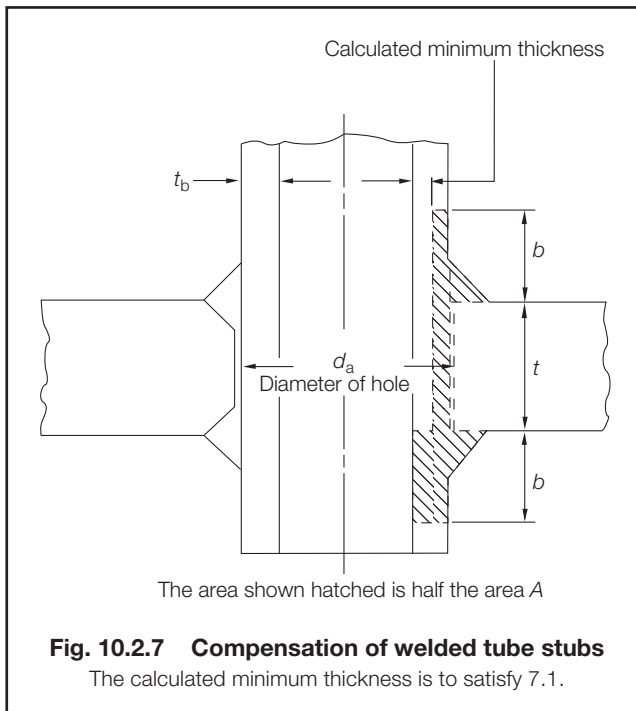
2.3.2 The compensating area,  $A$ , is to be measured in a plane through the axis of the tube stub parallel to the longitudinal axis of the drum or header and is to be calculated as follows, see Figs. 10.2.7 and 10.2.8:

- The cross-sectional area of the stub, in excess of that required by 7.1 for the minimum tube thickness, from the interior surface of the shell up to a distance,  $b$ , from the outer surface of the shell;
- plus the cross-sectional area of the stub projecting inside the shell within a distance,  $b$ , from the inner surface of the shell;
- plus the cross-sectional area of the welding fillets inside and outside the shell;

where

$$b = \sqrt{d_a t_b}$$

$t_b$  = actual thickness of tube stub, in mm.



2.3.3 Where the material of the tube stub has an allowable stress lower than that of the shell, the compensating cross-sectional area of the stub is to be multiplied by the ratio:

$$\frac{\text{allowable stress of stub at design metal temperature}}{\text{allowable stress of shell at design metal temperature}}$$

### 2.4 Unreinforced openings

2.4.1 Openings in a definite pattern, such as tube holes, may be designed in accordance with the Rules for ligaments in 2.2, provided that the diameter of the largest hole in the group does not exceed that permitted by 2.4.2.

2.4.2 The maximum diameter,  $d$ , of any unreinforced isolated openings is to be determined by the following formula:

$$d = 8,08 [D_o t (1 - K)]^{1/3} \text{ in mm}$$

The value of  $K$  to be used is calculated from the following formula:

$$K = \frac{p D_o}{18,2 \sigma t} \text{ but is not to be taken as greater than } 0,99$$

where

$p$ ,  $D_o$  and  $\sigma$  are as defined in 1.2

$t$  = actual thickness of shell, in mm.

2.4.3 For elliptical or oval holes,  $d$ , for the purposes of 2.4.2, refers to the major axis when this lies longitudinally or to the mean of the major and minor axes when the minor axis lies longitudinally.

2.4.4 No unreinforced opening is to exceed 200 mm in diameter.

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

### Section 2

2.4.5 Holes may be considered isolated if the centre distance between two holes on the longitudinal axis of a cylindrical shell is not less than:

$$d + 1,1\sqrt{Dt} \text{ with a minimum } 5d$$

$d$  = diameter of openings in shell (mean diameter if dissimilarly sized holes involved)

$D$  = mean diameter of shell

$t$  = actual thickness of shell

Where the centre distance is less than so derived, the holes are to be fully compensated.

Where two holes are offset on a diagonal line, the diagonal efficiency from Fig. 10.2.6 may be used to derive an equivalent longitudinal centre distance for the purposes of this paragraph.

## 2.5 Reinforced openings

2.5.1 Openings larger than those permitted by 2.4 are to be compensated in accordance with Fig. 10.2.9(a) or (b). The following symbols are used in Fig. 10.2.9(a) and (b):

$t_s$  = calculated thickness of a shell without joint or opening or corrosion allowance, in mm

$t_d$  = thickness calculated in accordance with 7.1 without corrosion allowance, in mm

$t_a$  = actual thickness of shell plate without corrosion allowance, in mm

$t_b$  = actual thickness of standpipe without minus tolerances and corrosion allowance, in mm

$t_r$  = thickness of added reinforcement, in mm

$D_i$  = internal diameter of cylindrical shell, in mm

$d_o$  = diameter of hole in shell, in mm

$L$  = width of added reinforcement not exceeding  $D$ , in mm

$$C = \sqrt{d_o t_b} \text{ in mm}$$

$$D = \sqrt{D_i t_a} \text{ and is not to exceed } 0,5d_o, \text{ in mm}$$

$\sigma$  = shell plate allowable stress, N/mm<sup>2</sup>

$\sigma_p$  = standpipe allowable stress, N/mm<sup>2</sup>

$\sigma_r$  = added reinforcement allowable stress, N/mm<sup>2</sup>

$\sigma_w$  = weld metal allowable stress, N/mm<sup>2</sup>

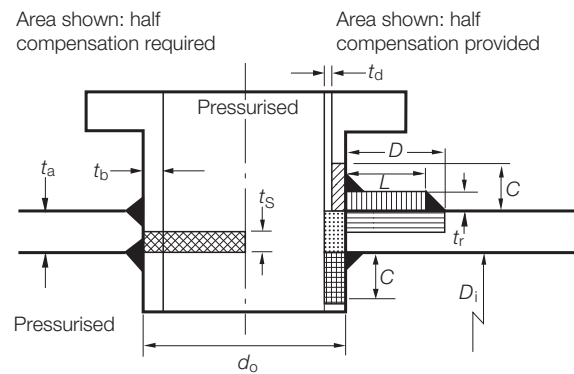
NOTE

$\sigma_p$ ,  $\sigma_r$  and  $\sigma_w$  are not to be taken as greater than  $\sigma$ .

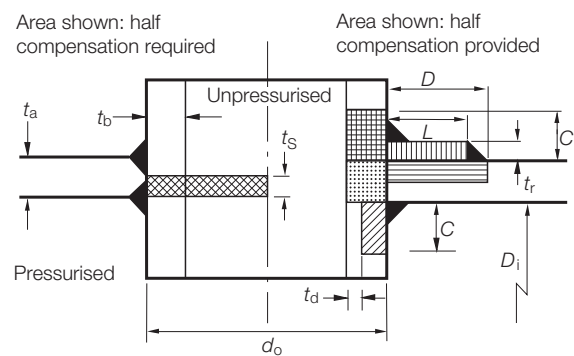
2.5.2 For elliptical or oval holes, the dimension on the meridian of the shell is to be used for  $d_o$  in 2.5.1.

2.5.3 Compensation is to be distributed equally on either side of the centreline of the opening.

2.5.4 The welds attaching standpipes and reinforcing plates to the shell are to be of sufficient size to transmit the full strength of the reinforcing areas and all other loadings to which they may be subjected.



(a) Standpipes or branches



(b) Insert pieces for internal doors

Compensation required:

$$A_1 = \text{[Cross-hatched area]} = d_o t_s \text{ mm}^2$$

Compensation provided:

$$A_2 = \text{[Horizontal lines area]} = 2D(t_a - t_s) \text{ mm}^2$$

$$A_3 = \text{[Dotted area]} = 2t_b t_a \frac{\sigma_p}{\sigma} \text{ mm}^2$$

$$A_4 = \text{[Vertical lines area]} = 2C t_b \frac{\sigma_p}{\sigma} \text{ mm}^2$$

$$A_5 = \text{[Diagonal lines area]} = 2C(t_b - t_d) \frac{\sigma_p}{\sigma} \text{ mm}^2$$

$$A_6 = \text{[Wavy lines area]} = 2L t_r \frac{\sigma_r}{\sigma} \text{ mm}^2$$

$$A_7 = \text{[Triangle area]} = (\text{Area of fillet welds}) \frac{\sigma_w}{\sigma} \text{ mm}^2$$

$$A_2 + A_3 + A_4 + A_5 + A_6 + A_7 \geq A_1$$

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**Fig. 10.2.9**  
**Compensation for standpipes or branches**  
**in cylindrical shells**

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

Sections 3 & 4

### Section 3 Spherical shells subject to internal pressure

#### 3.1 Minimum thickness

3.1.1 The minimum thickness of a spherical shell is to be determined by the following formula:

$$t = \frac{p R_i}{20\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t, p, R_i, \sigma$  and  $J$  are as defined in 1.2.

3.1.2 The formula in 3.1.1 is applicable only where the resulting thickness does not exceed half the internal radius.

3.1.3 Openings in spherical shells requiring compensation are to comply, in general, with 2.5, using the calculated and actual thicknesses of the spherical shell as applicable.

### Section 4 Dished ends subject to internal pressure

#### 4.1 Minimum thickness

4.1.1 The thickness,  $t$ , of semi-ellipsoidal and hemispherical unstayed ends, and the knuckle section of torispherical ends, dished from plate, having pressure on the concave side and satisfying the conditions listed below, is to be determined by the following formula:

$$t = \frac{p D_o K}{20\sigma J} + 0,75 \text{ mm}$$

where

$t, p, D_o, \sigma$  and  $J$  are as defined in 1.2

$K$  = a shape factor, see 4.2 and Fig. 10.4.1.

4.1.2 For semi-ellipsoidal ends:

the external height,  $H \geq 0,18D_o$

where

$D_o$  = the external diameter of the parallel portion of the end, in mm.

4.1.3 For torispherical ends:

the internal radius,  $R_i \leq D_o$

the internal knuckle radius,  $R_i \geq 0,1D_o$

the internal knuckle radius,  $R_i \geq 3t$

the external height,  $H \geq 0,18D_o$  and is determined as follows:

$$H = R_o - \sqrt{(R_o - 0,5D_o)(R_o + 0,5D_o - 2r_o)}.$$

4.1.4 In addition to the formula in 4.1.1 the thickness,  $t$ , of a torispherical head, made from more than one plate, in the crown section is to be not less than that determined by the following formula:

$$t = \frac{p R_i}{20\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t, p, R_i, \sigma$  and  $J$  are as defined in 1.2.

4.1.5 The thickness required by 4.1.1 for the knuckle section of a torispherical head is to extend past the common tangent point of the knuckle and crown radii into the cross-section for a distance not less than  $0,5 \sqrt{R_i t}$  mm, before reducing to the crown thickness permitted by 4.1.4, where

$t$  = the required thickness from 4.1.1.

4.1.6 In all cases,  $H$ , is to be measured from the commencement of curvature, see Fig. 10.4.2.

4.1.7 The minimum thickness of the head,  $t$ , is to be not less than 6,0 mm.

4.1.8 For ends which are butt welded to the drum shell, see 1.8, the thickness of the edge of the flange for connection to the shell is to be not less than the thickness of an unpierced seamless or welded shell, whichever is applicable, of the same diameter and material and determined by 2.1.

#### 4.2 Shape factors for dished ends

4.2.1 The shape factor,  $K$ , to be used in 4.1.1 is to be obtained from the curves in Fig. 10.4.1, and depends on the ratio of height to diameter  $\frac{H}{D_o}$ .

4.2.2 The lowest curve in the series provides the factor,  $K$ , for plain (i.e. unpierced) ends. For lower values of  $\frac{H}{D_o}$ ,

$K$  depends upon the ratio of thickness to diameter,  $\frac{t}{D_o}$ , as

well as on the ratio  $\frac{H}{D_o}$ , and a trial calculation may be necessary

to arrive at the correct value of  $K$ .

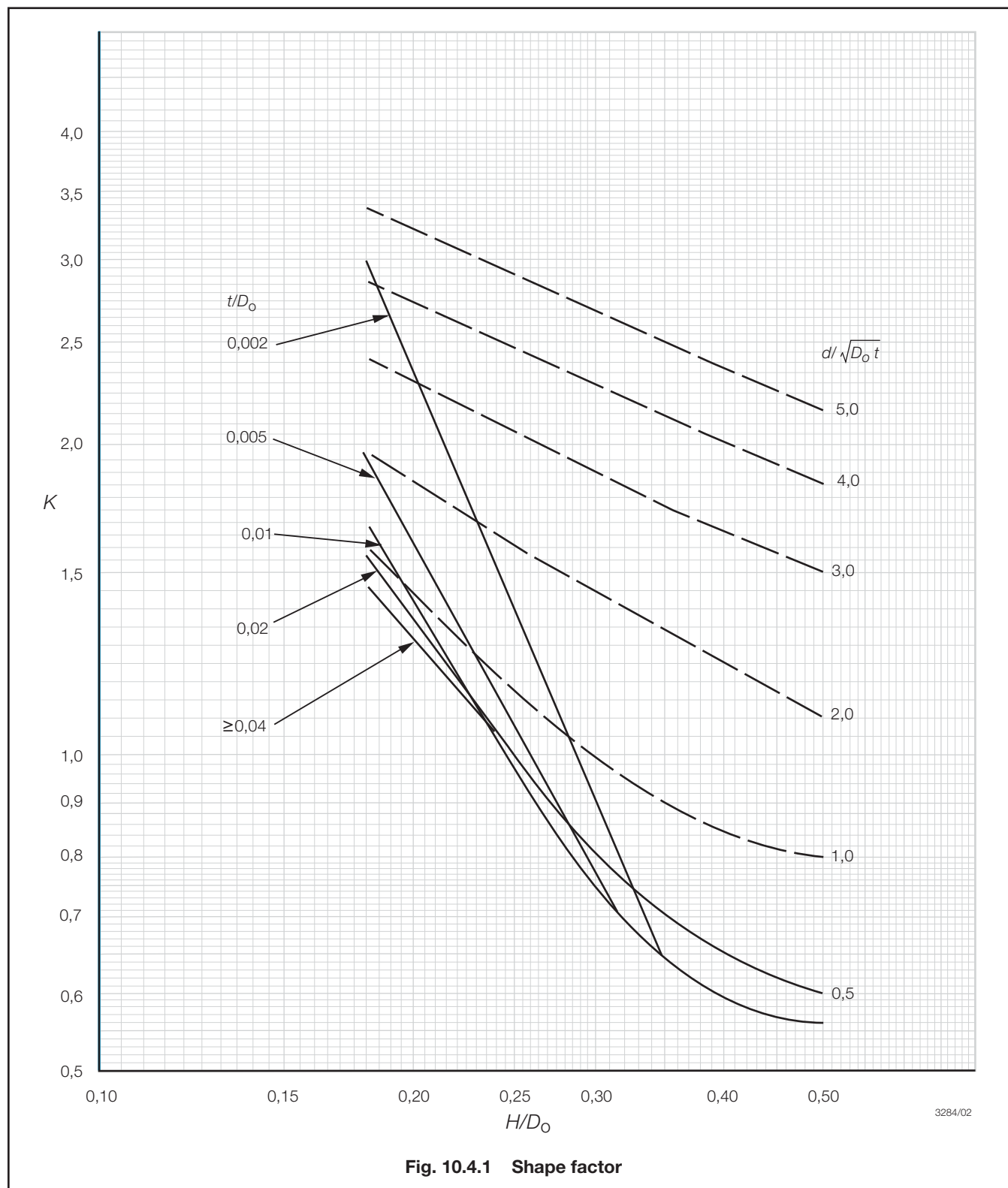
#### 4.3 Dished ends with unreinforced openings

4.3.1 Openings in dished ends may be circular, obround or approximately elliptical.

# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

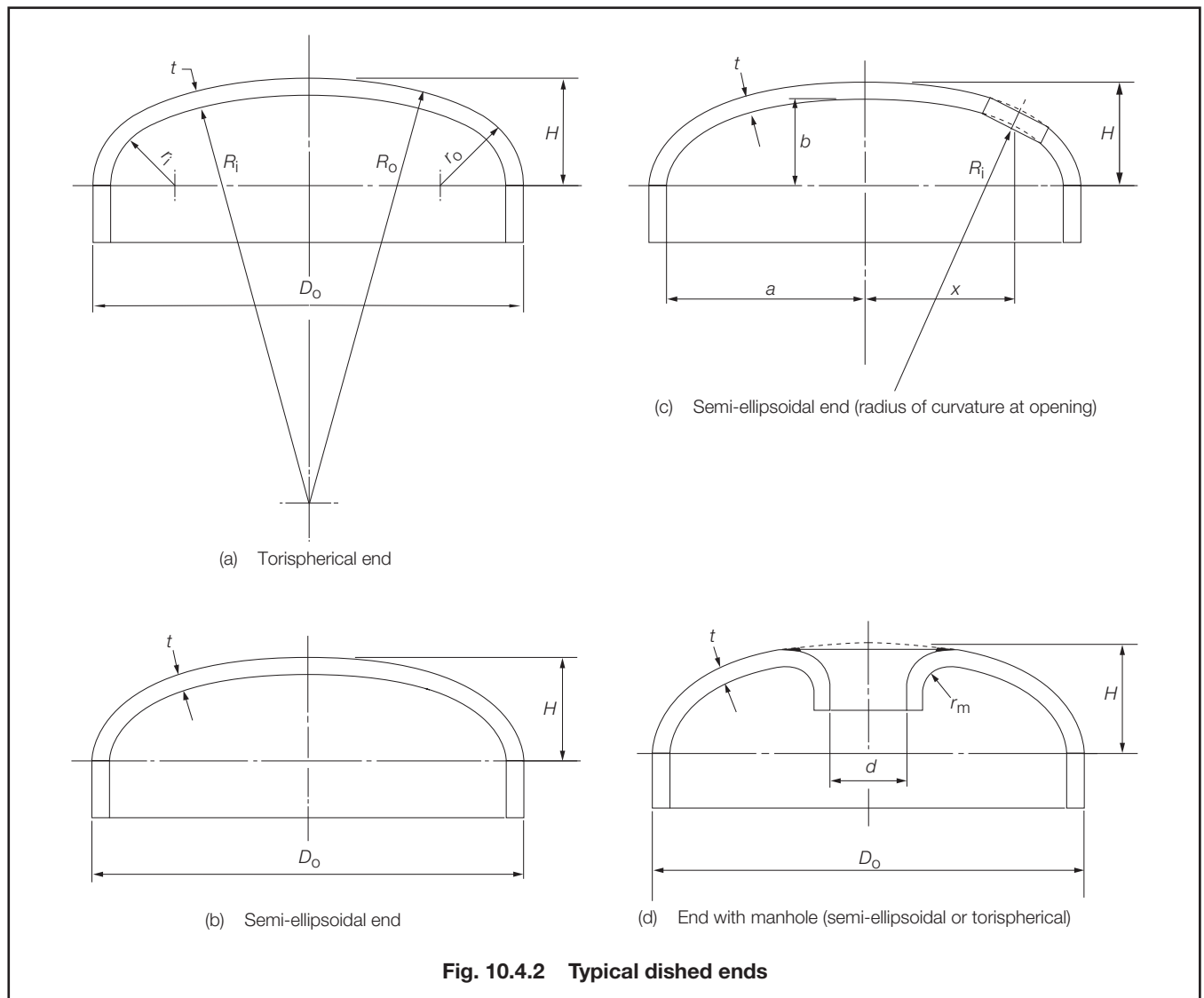
Section 4



# Steam Raising Plant and Associated Pressure Vessels

## Part 5, Chapter 10

Section 4



4.3.2 The upper curves in Fig. 10.4.1 provide values of  $K$ , to be used in 4.1.1, for ends with unreinforced openings. The selection of the correct curve depends on the value  $\frac{d}{\sqrt{D_o} t}$  and trial calculation is necessary to select the correct curve, where

$d$  = the diameter of the largest opening in the end plate, in mm (in the case of an elliptical opening, the larger axis of the ellipse)

$t$  = minimum thickness, after dishing, in mm

$D_o$  = outside diameter of dished end, in mm.

4.3.3 The following requirements must in any case be satisfied:

$$\frac{t}{D_o} \leq 0,1$$

$$\frac{d}{D_o} \leq 0,7.$$

4.3.4 From Fig.10.4.1 for any selected ratio of  $\frac{H}{D_o}$  the curve for unpierced ends gives a value for  $\frac{d}{\sqrt{D_o} t}$  as well as for  $K$ . Openings giving a value of  $\frac{d}{\sqrt{D_o} t}$  not greater than the value so obtained may thus be pierced through an end designed as unpierced without any increase in thickness.

### 4.4 Flanged openings in dished ends

4.4.1 The requirements in 4.3 apply equally to flanged openings and to unflanged openings cut in the plate of an end. No reduction may be made in end plate thickness on account of flanging.

4.4.2 Where openings are flanged, the radius,  $r_m$  of the flanging is to be not less than 25 mm, see Fig. 10.4.2(d). The thickness of the flanged portion may be less than the calculated thickness.

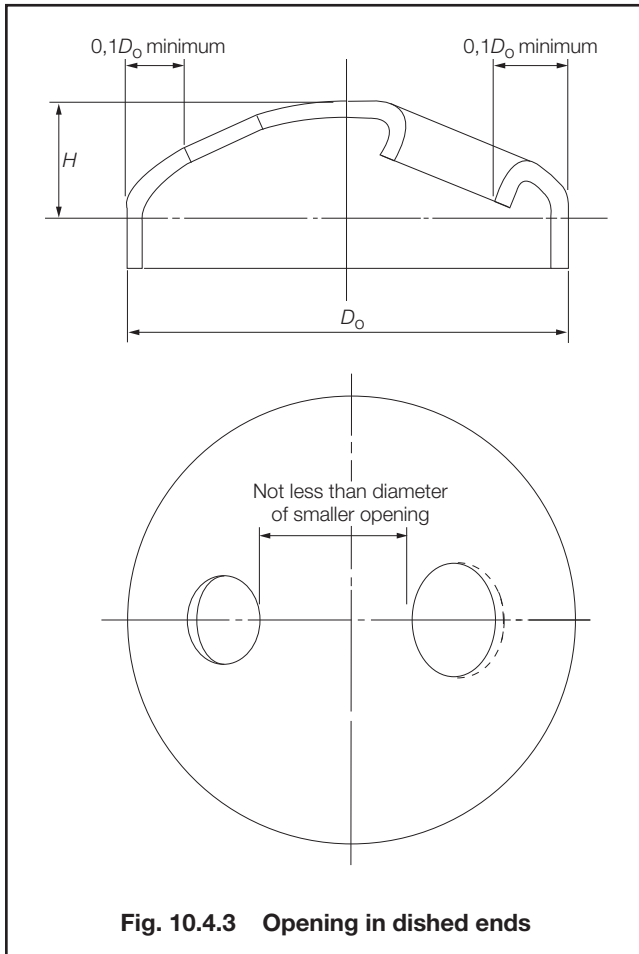
# Steam Raising Plant and Associated Pressure Vessels

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Section 4

### 4.5 Location of unreinforced and flanged openings in dished ends

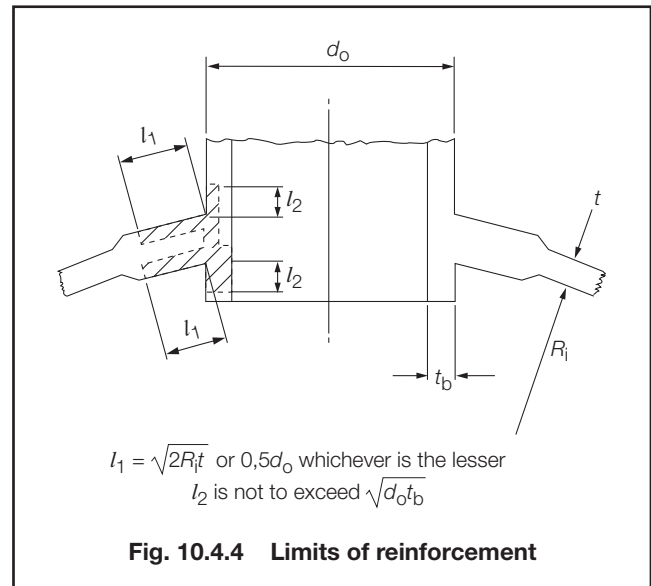
4.5.1 Unreinforced and flanged openings in dished ends are to be so arranged that the distance from the edge of the hole to the outside edge of the plate and the distance between openings are not less than those shown in Fig. 10.4.3.



**Fig. 10.4.3 Opening in dished ends**

### 4.6 Dished ends with reinforced openings

4.6.1 Where it is desired to use a large opening in a dished end of less thickness than would be required by 4.3, the end is to be reinforced. This reinforcement may consist of a ring or standpipe welded into the hole, or of reinforcing plates welded to the outside and/or inside of the end in the vicinity of the hole, or a combination of both methods, see Fig. 10.4.4. Forged reinforcements may be used.



**Fig. 10.4.4 Limits of reinforcement**

4.6.2 Reinforcing material with the following limits may be taken as effective reinforcement:

- The effective width,  $l_1$  of reinforcement is not to exceed  $\sqrt{2R_i t}$  or  $0,5d_o$  whichever is the lesser.
- The effective length,  $l_2$  of a reinforcing ring is not to exceed  $\sqrt{d_o t_b}$

where

$R_i$  = the internal radius of the spherical part of a torispherical end, in mm, or

$R_i$  = internal radius of the meridian of the ellipse at the centre of the opening, of a semi-ellipsoidal end, in mm, and is given by the following formula:

$$\frac{[a^4 - x^2(a^2 - b^2)]^{3/2}}{a^4 b}$$

where

$a$ ,  $b$  and  $x$  are shown in Fig. 10.4.2(c)

$d_o$  = external diameter of ring or standpipe, in mm

$l_1$  and  $l_2$  are shown in Fig. 10.4.4

$t_b$  = actual thickness of ring or standpipe, in mm.

4.6.3 The shape factor,  $K$ , for a dished end having a reinforced opening can be read from Fig. 10.4.1 using the value obtained from:

$$\frac{d_o - \frac{A}{t}}{\sqrt{D_o t}} \text{ instead of from } \frac{d}{\sqrt{D_o t}}$$

where

$A$  = the effective cross-sectional area of reinforcement and is to be twice the area shown shaded on Fig. 10.4.4.

As in 4.3, a trial calculation is necessary in order to select the correct curve.

4.6.4 The area shown in Fig. 10.4.4 is to be obtained as follows:

- Calculate the cross-sectional area of reinforcement both inside and outside the end plate within the length,  $l_1$
- plus the full cross-sectional area of that part of the ring or standpipe which projects inside the end plate up to a distance,  $l_2$



# Steam Raising Plant and Associated Pressure Vessels

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- plus the full cross-sectional area of that part of the ring or standpipe which projects outside the internal surface of the end plate up to a distance,  $l_2$  and deduct the sectional area which the ring or standpipe would have if its thickness were as calculated in accordance with 7.1.

4.6.5 If the material of the ring or the reinforcing plates has an allowable stress value lower than that of the end plate, then the effective cross-sectional area,  $A$ , is to be multiplied by the ratio:

$$\frac{\text{allowable stress of reinforcing plate at design temperature}}{\text{allowable stress of end plate at design temperature}}$$

### 4.7 Torispherical dished ends with reinforced openings

4.7.1 If an opening and its reinforcement are positioned entirely within the crown section, the compensation requirements are to be as for a spherical shell, using the crown radius as the spherical shell radius. Otherwise the requirements of 4.6 are to be applied.

## Section 5 Conical ends subject to internal pressure

### 5.1 General

5.1.1 Conical ends and conical reducing sections, as shown in Fig. 10.5.1, are to be designed in accordance with the equations given in 5.2.

5.1.2 Connections between cylindrical shell and conical sections and ends should preferably be by means of a knuckle transition radius. Typical permitted details are shown in Fig. 10.5.1. Alternatively, conical sections and ends may be butt welded to cylinders without a knuckle radius where the change in angle of slope,  $\psi$ , between the two sections under consideration does not exceed 30°.

5.1.3 Conical ends may be constructed of several ring sections of decreasing thickness, as determined by the corresponding decreasing diameter.

### 5.2 Minimum thickness

5.2.1 The minimum thickness,  $t$ , of cylinder, knuckle and conical section at the junction and within the distance,  $L$ , from the junction is to be determined by the following formula:

$$t = \frac{p D_o K}{20 \sigma J} + 0,75 \text{ mm}$$

where

$t, p, \sigma$  and  $J$  are as defined in 1.2

$K$  = a factor, taking into account the stress in the knuckle, see Table 10.5.1.

$D_o$  = outside diameter, in mm, of the conical section or end, see Fig. 10.5.1.

5.2.2 If the distance of a circumferential seam from the knuckle or junction is not to be less than  $L$ , then  $J$  is to be taken as 1,0; otherwise  $J$  is to be taken as the weld joint factor appropriate to the circumferential seam,

where

$L$  = distance, in mm, from the knuckle or junction within which meridional stresses determine the required thickness, see Fig. 10.5.1

$$= 0,5 \sqrt{\frac{D_o t}{\cos \psi}}$$

$r_i$  = inside radius of transition knuckle, in mm, which is to be taken as  $0,01 D_c$  in the case of conical sections without knuckle transition.

$\psi$  = difference between angle of slope of two adjoining conical sections, see Fig. 10.5.1.

5.2.3 The minimum thickness,  $t$ , of those parts of conical sections not less than a distance,  $L$ , from the junction with a cylinder or other conical section is to be determined by the following formula:

$$t = \frac{p D_c}{(20 \sigma J - p)} \frac{1}{\cos \alpha} + 0,75 \text{ mm}$$

where

$D_c$  = inside diameter, in mm of conical section or end at the position under consideration, see Fig. 10.5.1

$\alpha, \alpha_1, \alpha_2$  = angle of slope of conical section (at the point under consideration) to the vessel axis, see Fig. 10.5.1.

5.2.4 The greater of the two thicknesses determined by the formulae in 5.2.1 and 5.2.3 is to apply at the junction or knuckle and within the limits of reinforcement.

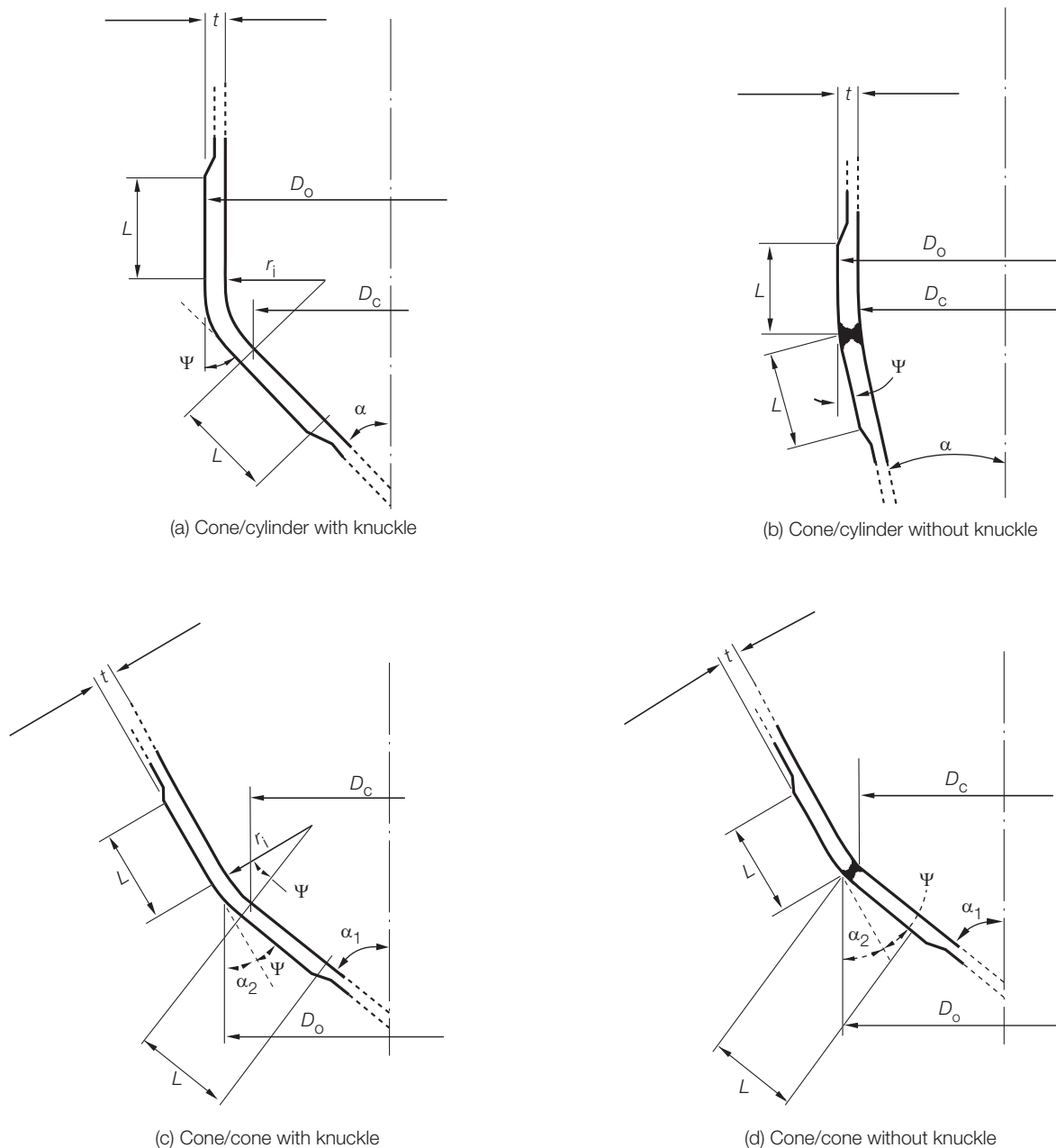
**Table 10.5.1 Values of  $K$  as a function of  $\psi$  and  $r_i/D_o$**

$\psi$	Values of $K$ for $r_i/D_o$ ratios of											
	0,01	0,02	0,03	0,04	0,06	0,08	0,10	0,15	0,20	0,30	0,40	0,50
10°	0,70	0,65	0,60	0,60	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55
20°	1,00	0,90	0,85	0,80	0,70	0,65	0,60	0,55	0,55	0,55	0,55	0,55
30°	1,35	1,20	1,10	1,00	0,90	0,85	0,80	0,70	0,65	0,55	0,55	0,55
45°	2,05	1,85	1,65	1,50	1,30	1,20	1,10	0,95	0,90	0,70	0,55	0,55
60°	3,20	2,85	2,55	2,35	2,00	1,75	1,60	1,40	1,25	1,00	0,70	0,55
75°	6,80	5,85	5,35	4,75	3,85	3,50	3,15	2,70	2,40	1,55	1,00	0,55

# Steam Raising Plant and Associated Pressure Vessels

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**Fig. 10.5.1 Conical ends and conical reducing sections**

5.2.5 The thickness of conical sections having an angle of inclination to the vessel axis of more than  $75^\circ$  is to be determined as for a flat plate.

# Steam Raising Plant and Associated Pressure Vessels

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Sections 6 & 7

### Section 6 Standpipes and branches

#### 6.1 Minimum thickness

6.1.1 The minimum wall thickness of standpipes and branches is to be not less than that determined by 7.1 increased by the addition of a corrosion allowance of 0,75 mm, making such additions as may be necessary on account of bending, static loads and vibration. The wall thickness, however, is to be not less than:

$$t = 0,015D_o + 3,2 \text{ mm}$$

This thickness need only be maintained for a length,  $L$ , from the outside surface of the vessel, but need not extend past the first connection, butt weld or flange, where:

$$L = 3,5 \sqrt{D_o t} \text{ mm}$$

where

$t$  and  $D_o$  are as defined in 1.2.

6.1.2 For boilers having a working pressure exceeding 50 bar and safety valves of full lift or full bore type, the thickness of the branch pipe carrying the superheater or drum safety valves is to be not less than:

$$t = \frac{1}{\sigma} \left[ 1,7d + \frac{DWK}{1,3d^2} \right] \text{ mm}$$

where

$t$  and  $\sigma$  are as defined in 1.2

$d$  = inside diameter of branch, in mm

$D$  = inside diameter of safety valve discharge, in mm

$K$  = 2 for superheater safety valves

= 1 for drum safety valves

$W$  = total valve throughput, in kg/h.

6.1.3 The offset from the centreline of the waste steam pipe to the centreline of the safety valve is not to exceed four times the outside diameter of the safety valve discharge pipe. The waste steam pipe system is to be supported and arrangements made for expansion such that no direct loading is imposed on the safety valve chests and the effects of vibration are to be minimised.

6.1.4 The pipe or header which carries the superheater safety valve is to be suitably thickened but is to be not less than the thickness required for the branch for a distance of  $\sqrt{D_2 t}$  on either side of the opening

where

$t$  = thickness required for the branch

$D_2$  = inside diameter of the pipe or header.

6.1.5 Except as required by 6.1.4, in no case need the wall thickness exceed the minimum shell thickness as required by 2.1, 3.1 or 4.1 as applicable.

6.1.6 Where a standpipe or branch is connected by screwing, the thickness is to be measured at the root of the thread.

6.1.7 For boiler, superheater or economiser tubes, the minimum thickness of the drum or the header connection or tube stub is to be calculated as part of the tube in accordance with 7.1.

### Section 7 Boiler tubes subject to internal pressure

#### 7.1 Minimum thickness

7.1.1 The minimum wall thickness of straight tubes subject to internal pressure is to be determined by the following formula:

$$t = \frac{p D_o}{20\sigma + p} \text{ mm}$$

where

$t$ ,  $p$ ,  $D_o$  and  $\sigma$  are as defined in 1.2.

NOTES

1. Provision must be made for minus tolerances where necessary and also in cases where abnormal corrosion or erosion is expected in service. For bending allowances, see 7.2.
2. Thickness is in no case to be less than the minimum shown in Table 10.7.1.

**Table 10.7.1 Minimum thickness of tubes**

Nominal outside diameter of tube, in mm	Minimum thickness, in mm
$\leq 38$	1,75
$> 38 > 50$	2,16
$\leq 50 \leq 70$	2,40
$> 70 \leq 75$	2,67
$> 75 \leq 95$	3,05
$> 95 \leq 100$	3,28
$> 100 \leq 125$	3,50

7.1.2 The minimum thickness of boiler, superheater, reheater and economiser tubes is to be determined by using the design stress appropriate to the mean wall temperature, which will be considered to be the metal temperature. Unless it is otherwise agreed between the manufacturer and LR, the metal temperature used to decide the value of  $\sigma$  for these tubes is to be determined as follows:

- (a) The calculation temperature for boiler tubes is to be taken as not less than the saturated steam temperature, plus 25°C for tubes mainly subject to convection heat, or plus 50°C for tubes mainly subject to radiant heat.
- (b) The calculation temperature for superheater and reheater tubes is to be generally taken as not less than the steam temperature expected in the part being considered, plus 35°C for tubes mainly subject to convection heat. For tubes mainly subject to radiant heat the calculation temperature is generally to be taken as not less than the steam temperature expected in the part being considered, plus 50°C, but the actual metal temperature expected is to be stated when submitting plans.
- (c) The calculation temperature for economiser tubes is to be taken as not less than 35°C in excess of the maximum temperature of the internal fluid.

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Sections 7 & 8

**7.1.3** The minimum thickness of downcomer tubes and pipes which form an integral part of the boiler and which are not exposed to combustion gases is to comply with the requirements for steam pipes.

### 7.2 Tube bending

**7.2.1** Where boiler, superheater, reheater and economiser tubes are bent, the resulting thickness of the tubes at the thinnest part is to be not less than that required for straight tubes, unless it can be demonstrated that the method of forming the bend results in no decrease in strength at the bend. The manufacturer is to demonstrate in connection with any new method of tube bending that this condition is satisfied.

**7.2.2** Tube bending, and subsequent heat treatment, where necessary, is to be carried out as to ensure that residual stresses do not adversely affect the strength of the tube for the design purpose intended.

### ■ Cross-references

For details of manholes, sight holes and doors, see 14.1.  
For details of tube holes and fitting of tubes, see 14.6.

## ■ Section 8 Headers

### 8.1 Circular section headers

**8.1.1** The minimum thickness of circular section headers is to be calculated in accordance with the formula for cylindrical shells in 2.1.

### 8.2 Rectangular section headers

**8.2.1** The thickness of the flat walls of rectangular section headers is to be determined at the centre of the sides, at all the lines of holes and at the corners. The minimum required is to be the greatest thickness determined by the following formula:

$$t = \frac{pn}{20\sigma J} + \sqrt{\frac{0.4Yp}{\sigma J_1}} + 0.75 \text{ mm}$$

where

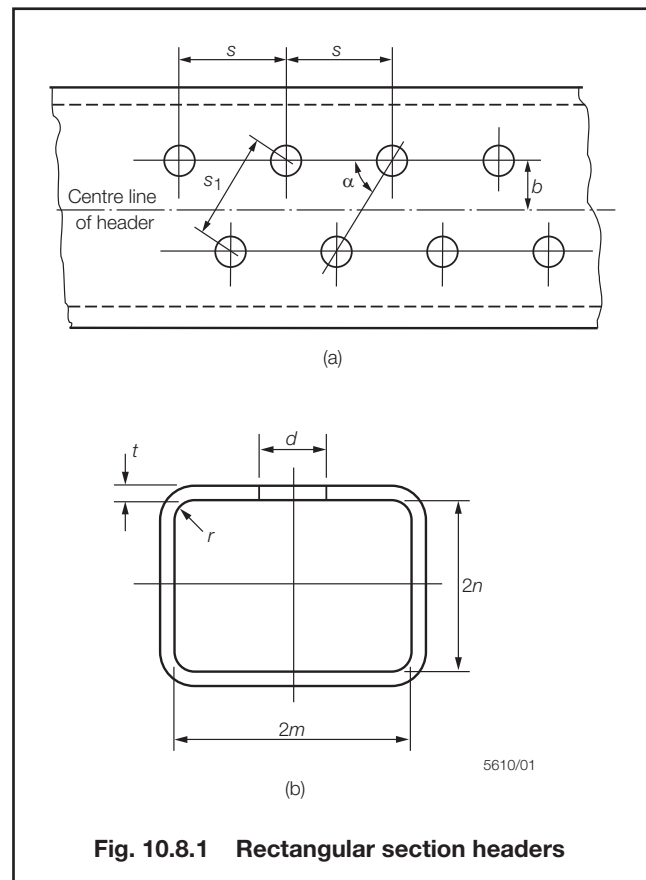
$t, p$  and  $\sigma$  are as defined in 1.2

$n$  = one half of the internal width of the wall perpendicular to that under consideration, in mm, see Fig. 10.8.1(b)

$J$  = ligament efficiency for membrane stresses determined in accordance with 8.2.3

$J_1$  = ligament efficiency for bending stresses determined in accordance with 8.2.3.

$Y$  = a coefficient determined in accordance with 8.2.2. In all cases if the value of  $Y$  is negative, the sign is to be ignored.



**Fig. 10.8.1 Rectangular section headers**

**8.2.2** The coefficient  $Y$  for use in 8.2.1 is to be determined as follows:

(a) at the centre of the side with internal width,  $2m$ :

$$Y = \frac{1}{3} \left( \frac{m^3 + n^3}{m + n} \right) - \frac{1}{2} m^2$$

where

$m$  = one half of the internal width of the wall under consideration, in mm, see Fig. 10.8.1(b)

(b) at a line of holes parallel to the longitudinal axis of the header on the wall of width,  $2m$ :

$$Y = \frac{1}{3} \left( \frac{m^3 + n^3}{m + n} \right) - \frac{m^2 - b^2}{2}$$

where

$b$  = distance from the centre of the holes to the centre-line of the wall, in mm, see Fig. 10.8.1(a)

(c) to check the effect of the off-set on a staggered hole arrangement where the holes are positioned equidistant from the centreline of the wall:

$$Y = \cos \alpha \left\{ \frac{1}{3} \left( \frac{m^3 + n^3}{m + n} \right) - \frac{m^2}{2} \right\}$$

where

$\alpha$  = the angle subtended by the diagonal ligament on the longitudinal ligament, see Fig. 10.8.1(a)

(d) at the corners:

$$Y = \frac{1}{3} \left( \frac{m^3 + n^3}{m + n} \right)$$

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8.2.3 The ligament efficiencies  $J$  and  $J_1$  are to be determined as follows:

(a) for a line of holes parallel to the longitudinal axis of the header:

$$J = \frac{s-d}{s}$$

Symbols are as defined in 8.2.4.

(b) for the diagonals:

$$J = \frac{s_1-d}{s_1}$$

Symbols are as defined in 8.2.4.

(c) for a line of holes parallel to the longitudinal axis of the header:

$$J_1 = \frac{s-d}{s} \text{ when } d < 0,6m$$

or

$$J_1 = \frac{s-0,6m}{s} \text{ when } d \geq 0,6m$$

Symbols are as defined in 8.2.4.

(d) for the diagonals:

$$J_1 = \frac{s_1-d}{s_1} \text{ when } d < 0,6m$$

or

$$J_1 = \frac{s_1-0,6m}{s_1} \text{ when } d \geq 0,6m$$

Symbols are as defined in 8.2.4.

8.2.4 Symbols, as used in 8.2.3, are defined as follows:

$d$  = diameter of the hole in the header, in mm

$m$ ,  $s$  and  $s_1$ , in mm, are as shown in Fig. 10.8.1.

8.2.5 In the case of elliptical holes the value of  $d$  to be used in the equations for  $J$  and  $J_1$  is to be the inside dimension of the hole measured parallel to the longitudinal axis of the header. For evaluating the two limiting values of  $d$  in the equations for  $J_1$ , the value of  $d$  is to be the inside dimension of the hole measured perpendicular to the longitudinal axis of the header.

8.2.6 The internal corner radius,  $r$ , is to be not less than one third of the mean of the nominal thicknesses of the two sides, but in no case to be less than 6,5 mm.

### 8.3 Toroidal furnace headers

8.3.1 The minimum thickness of a toroidal header forming the lower end of a waterwall furnace, and supporting the weight of the boiler and water, is to be determined by the following formula:

$$t = A + \sqrt{A^2 + \frac{4M}{JS\sigma}} + 0,75 \text{ mm}$$

where

$$A = \frac{pr}{30J\sigma} \text{ mm}$$

$t$ ,  $p$  and  $\sigma$  are as defined in 1.2

$d_e$  = equivalent diameter of the tube hole in accordance with 2.3

$r$  = inside radius of toroid circular cross-section, in mm, see Fig. 10.8.3

$J$  = ligament efficiency of tube holes around toroid

$$= \frac{S-d_e}{S}$$

$S$  = pitch of tubes around the toroid, in mm

$$M = \frac{Wr}{3} - \frac{pd^2r}{40} \text{ Nmm}$$

where

$W$  = imposed loading on each water wall tube due to the weight of the boiler and water, in N

$d$  = minimum diameter of the tube hole in the toroid, in mm

The calculation is to be performed at design pressure using the allowable stress at saturation temperature, and also at zero pressure using the allowable stress at 100°C.

### 8.4 Header ends

8.4.1 The shape and thickness of ends forged integrally with the bodies of headers are to be the subject of special consideration.

8.4.2 Where sufficient experience of previous satisfactory service of headers with integrally forged ends cannot be shown, the suitability of a proposed form of end is to be proved in accordance with the provisions of 1.10.

8.4.3 Ends attached by welding are to be designed as follows:

- Dished ends: these are to be in accordance with 4.1.
- Flat ends: the minimum thickness of flat end plates is to be determined by the following formula:

$$t = d_i \sqrt{\frac{pC}{\sigma}} + 0,75 \text{ mm}$$

where

$p$  and  $\sigma$  are as defined in 1.2.

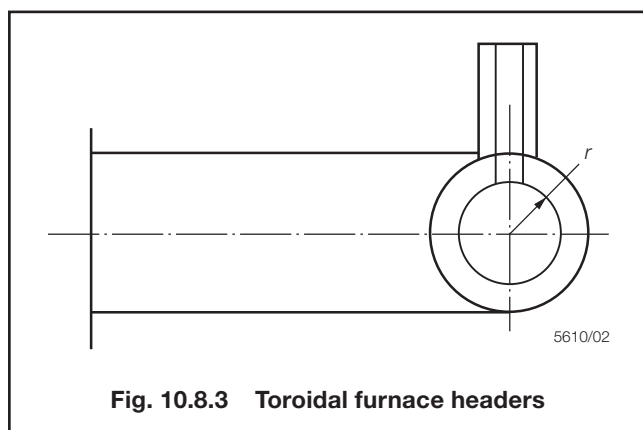
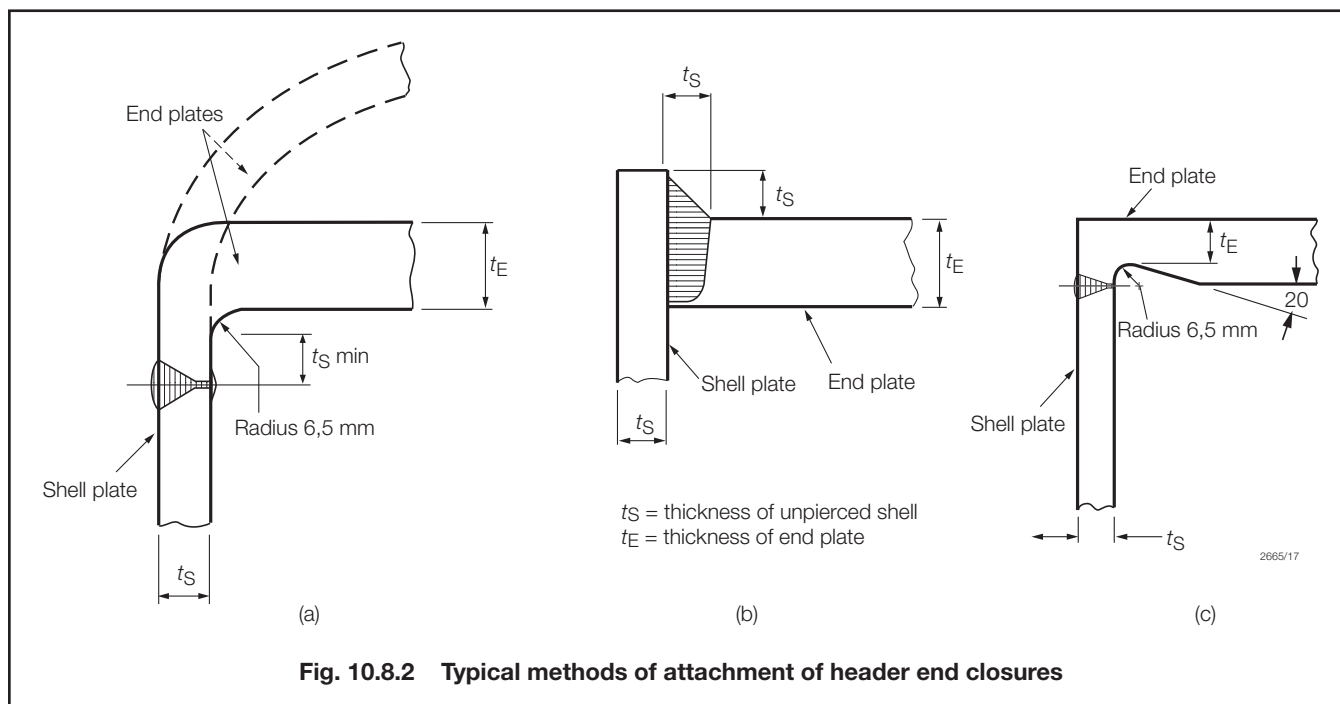
$t$  = minimum thickness of end plate, in mm

$d_i$  = internal diameter of circular header or least width between walls of rectangular header, in mm

$C$  = a constant depending on method of end attachment, see Fig. 10.8.2.

- For end plates welded as shown in Fig. 10.8.2(a):  
 $C$  = 0,019 for circular headers  
 $C$  = 0,032 for rectangular headers.
- For end plates welded as shown in Figs. 10.8.2(b) and (c):  
 $C$  = 0,028 circular headers  
 $C$  = 0,040 for rectangular headers.

8.4.4 Where flat end plates are bolted to flanges attached to the ends of headers, the flanges and end plates are to be in accordance with recognised pipe flange standards.



8.4.5 Openings in flat plates are to be compensated in accordance with Fig. 10.2.9 (a) or (b), with the value of  $A_1$  the compensation required, calculated as follows:

$$A_1 = \frac{d_o}{2,4} t_f \text{ mm}$$

where

$d_o$  = diameter of hole in flat plate, in mm

$t_f$  = required thickness of the flat plate in the area under consideration, in mm, calculated in accordance with 8.4.3, 8.3.3 or 9.1.6, as applicable, without corrosion allowance

Limit  $D = 0,5d_o$ .



## Section 9

### Flat surfaces and flat tube plates

#### 9.1 Stayed flat surfaces

9.1.1 Where flat end plates are flanged for connection to the shell, the inside radius of flanging is to be not less than 1,75 times the thickness of the plate, with a minimum of 38 mm.

9.1.2 Where combustion chamber or firebox plates are flanged for connection to the wrapper plate, the inside radius of flanging is to be equal to the thickness of the plate, with a minimum of 25 mm.

9.1.3 Where unflanged flat plates are connected to the shell by welding, typical methods of attachment are shown in Fig. 10.9.1. Similar forms of attachment may be used where unflanged combustion chamber or firebox plates are connected to the wrapper plate by welding.

9.1.4 Where the flange curvature is a point of support, this is to be taken at the commencement of curvature, or at a line distant 3,5 times the thickness of the plate from the outside of the plate, whichever is nearer to the flange.

9.1.5 Where a flat plate is welded directly to a shell or wrapper plate, the point of support is to be taken at the inside of the shell or wrapper plate.

9.1.6 The thickness,  $t$ , of those portions of flat plates supported by stays and around tube nests is to be determined by the following formula:

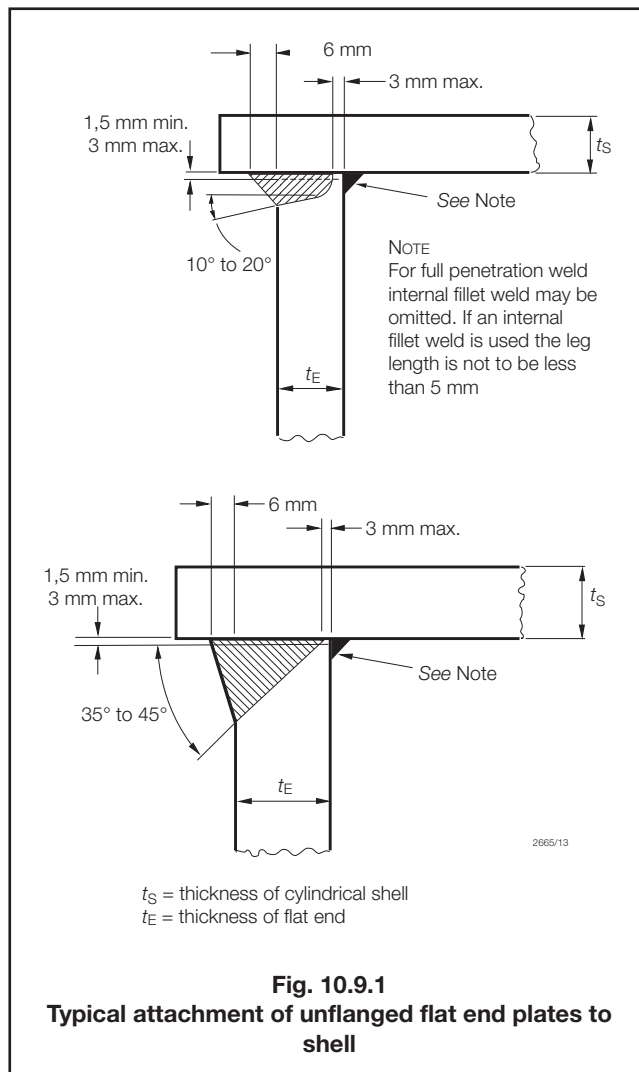
$$t = Cd \sqrt{\frac{p}{\sigma}} + 0,75 \text{ mm}$$

where

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$t$ ,  $p$  and  $\sigma$  are as defined in 1.2

$d$  = diameter of the largest circle which can be drawn through at least three points of support. At least one point of support must lie on one side of any diameter of the circle

$C$  = a constant, dependent on the method of support as detailed in 9.1.7. Where various forms of support are used,  $C$  is to be the mean of the values for the respective methods adopted.

9.1.7 The value of  $C$  in the formula in 9.1.6 is to be as follows:

(a) Where plain bar stays are strength welded into the plates as shown in Fig. 10.9.2

$C = 0,134$

(b) Where plain bar stays pass through holes in the plates and are fitted on the outside with washers as shown in Fig. 10.9.3

$C = 0,12$  where the diameter of the washer is 3,5 times the diameter of the stay

$C = 0,113$  where the diameter of the washer is 0,67 times the pitch of the stays.

(c) Where the flat plate is flanged for attachment to the shell, flue, furnace or wrapper or, alternatively, is welded directly to shell, flue, furnace or wrapper, see 9.1.4 and 9.1.5:

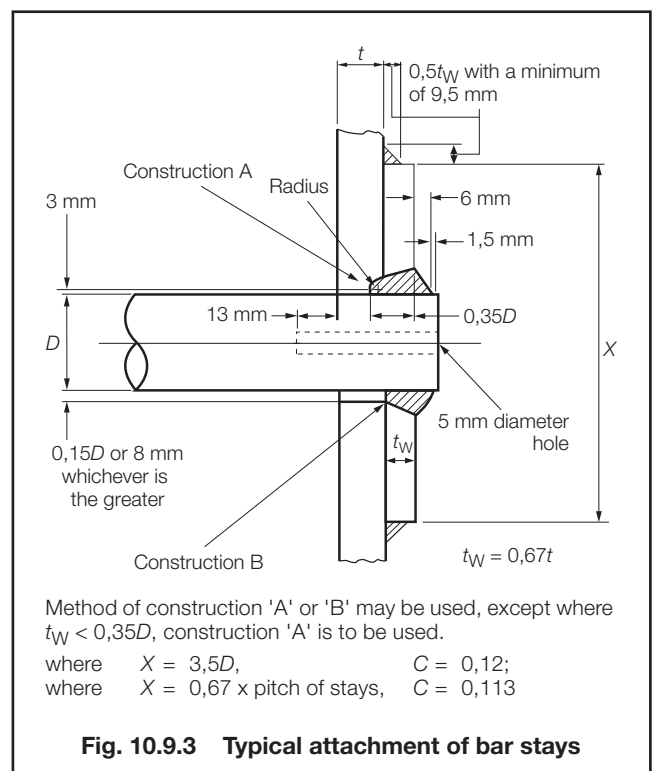
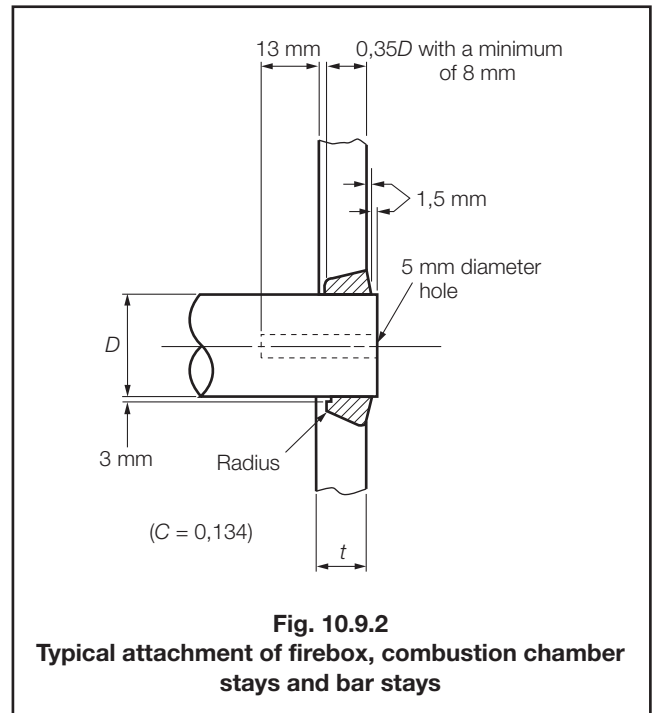
$C = 0,113$

(d) Where the support is a gusset stay

$C = 0,134$

(e) Where the support is a tube secured as shown in Fig. 10.9.4

$C = 0,144$ .



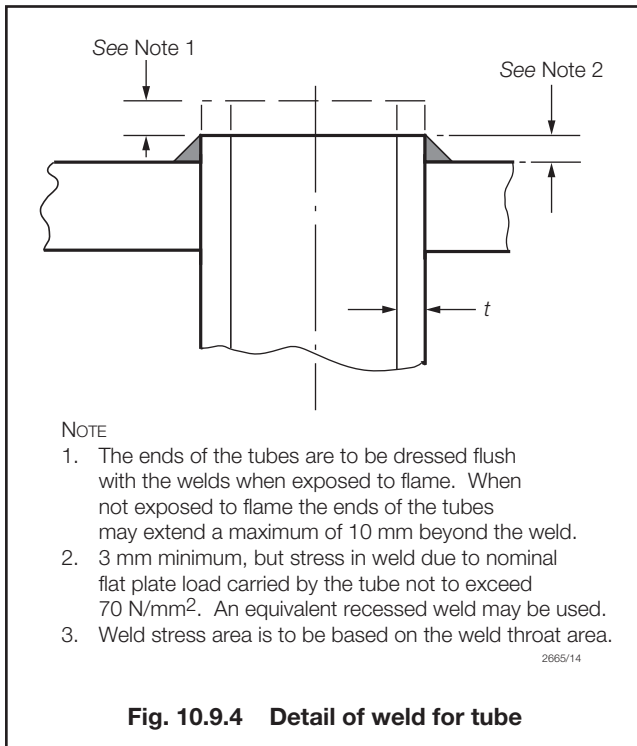


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**9.1.8** Where tubes are fixed by expanding only, sufficient tubes welded at both ends in accordance with Fig. 10.9.4 are to be provided within the tube nest to comply with 9.1.6, to carry the flat plate loading within the tube nest. Tubes welded in accordance with Fig. 10.9.4 are also to be provided in the boundary rows in sufficient numbers to carry the flat plate loading outside the tube areas.



**Fig. 10.9.4 Detail of weld for tube**

**9.1.9** In the case of small boilers with a single tube nest of expanded tubes which does not exceed an area of 0,65 m<sup>2</sup>, welded tubes need not be fitted provided the tubes are beaded at the inlet end. In this instance the support afforded by the expanded tubes is not to be taken to extend beyond the line enclosing the outer surfaces of the tubes except that, between the outside of the nest and the attachment of the end plate to shell, there may be an unsupported width equal to the flat plate margin, as given by the formula in 9.4.1. The required tube plate thickness within such a tube nest is to be determined using the formula in 9.1.6, where:

$$C = 0,154$$

$d$  = four times the mean pitch, in mm, of the expanded tubes in the nest.

**9.1.10** The thickness,  $t$ , of any tube plate in the tube area is to be not less than that required for the surrounding plate determined by 9.1.6 and in no case less than:

- 12,5 mm where the diameter of the tube hole does not exceed 50 mm, or
- 14 mm where the diameter of the tube hole is greater than 50 mm.

**9.1.11** Alternative methods of support will be specially considered.

**9.1.12** The spacing of tube holes is to be such that the minimum width,  $b$ , in mm of any ligament between tube holes is not less than:

for expanded tubes:

$$b = 0,125d + 12,5 \text{ mm}$$

for welded tubes:

$$b = 0,125d + 8 \text{ mm}$$

where

$d$  = diameter of the hole drilled in the plate, in mm.

**9.1.13** Where a flat plate has a manhole or sight hole and the opening is strengthened by flanging, the total depth,  $H$ , of the flange, measured from the outer surface of the plate, is to be not less than:

$$H = \sqrt{tW}$$

where

$t$  = thickness of plate, in mm

$H$  = depth of flange, in mm

$W$  = minor axis of manhole or sight hole, in mm.

**9.1.14** Where the flat top plates of combustion chambers are supported by welded-on girders, the equation in 9.1.6 is to apply as follows:

- (a) In the case of welded-on girders provided with waterways

$$C = 0,144$$

$$d = \sqrt{X^2 + Y^2}$$

where

$X$  = width of waterway in the girder plus the thickness of the girder, in mm

$Y$  = pitch of girders, in mm.

- (b) In the case of continuously welded-on girders

$$C = 0,175$$

$$d = D$$

where

$D$  = distance between inside faces of girders, in mm.

## 9.2 Combustion chamber tube plates under compression

**9.2.1** The thickness of combustion chamber tube plates under compression due to the pressure on the top plate, based on a compressive stress not exceeding 96 N/mm<sup>2</sup> is to be determined by the following formula:

$$t = \frac{pWs}{1930(s-d)} \text{ mm}$$

where

$t$  and  $p$  are as defined in 1.2

$d$  = internal diameter of the plain tubes, in mm

$s$  = pitch of tubes, in mm, measured horizontally where tubes are chain pitched, or diagonally where the tubes are staggered pitched and the diagonal pitch is less than the horizontal pitch

$W$  = internal width of the combustion chamber, in mm, measured from tube plate to back chamber plate.

## 9.3 Girders for combustion chamber top plates

**9.3.1** The formula in 9.3.2 is applicable to plate girders welded to the top combustion chamber plate by means of a full penetration weld.

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9.3.2 The thickness of steel plate girders supporting the tops of combustion chambers is to be determined by the following formula:

$$t = \frac{0,32p l^2 s}{d^2 R_{20}} \text{ mm}$$

where

- $t$  and  $p$  are as defined in 1.2
- $d$  = effective depth of girder, in mm
- $l$  = length of girder measured internally from tube plate to back chamber plate, in mm
- $s$  = pitch of the girders, in mm
- $R_{20}$  = specified minimum tensile strength of the girder plate, in N/mm<sup>2</sup>.

### 9.4 Flat plate margins

9.4.1 The width of margin,  $b$ , of a flat plate which may be regarded as being supported by the shell, furnaces or flues to which the flat plate is attached is not to exceed that determined by the following formula:

$$b = C(t - 0,75) \sqrt{\frac{\sigma}{\rho}} \text{ mm}$$

where

- $\rho$  and  $\sigma$  are as defined in 1.2
- $t$  = thickness of the flat plate, in mm
- $b$  = width of margin, in mm
- $C$  = 3,12.

9.4.2 Where an unflanged flat plate is welded directly to the shell, furnaces or flues and it is not practicable to effect the full penetration weld from both sides of the flat plate, the constant  $C$  used in the formula in 9.4.1 is to be:

$$C = 2,38.$$

9.4.3 In the case of plates which are flanged, the margin is to be measured from the commencement of curvature of flanging, or from a line 3,5 times the thickness of the plate measured from the outside of the plate, whichever is nearer to the flange.

9.4.4 Where the flat plate is not flanged for attachment to the shell, furnaces or flues, the margin is to be measured from inside of the shell or the outside of the furnaces or flues, whichever is applicable.

9.4.5 In no case is the diameter  $D$ , in mm, of the circle forming the boundary of the margin supported by the uptake of a vertical boiler to be greater than determined by the following formula:

$$D = \sqrt{\frac{345A}{\rho} + d^2}$$

where

- $\rho$  is as defined in 1.2
- $d$  = external diameter of uptake, in mm
- $d_i$  = internal diameter of uptake, in mm
- $A$  = cross-sectional area of the uptake tube material, i.e.  $\frac{\pi}{4} (d^2 - d_i^2)$  mm<sup>2</sup>.

## Section 10 Flat plates and ends of vertical boilers

### 10.1 Tube plates of vertical boilers

10.1.1 Where vertical boilers have a nest or nests of horizontal tubes, so that there is direct tension on the tube plates due to the vertical load on the boiler ends or to their acting as horizontal ties across the shell, the thickness of the tube plates in way of the outer rows of tubes is to be determined by the following formula:

$$t = \frac{pD}{5J R_{20}} + 0,75 \text{ mm}$$

where

- $t$  and  $p$  are as defined in 1.2
- $D$  = twice the radial distance of the centre of the outer row of tube holes from the axis of the shell, in mm
- $J$  = efficiency of ligaments between tube holes in the outer vertical rows (expressed as a fraction)
 
$$= \frac{s - d}{s}$$
- $R_{20}$  = specified minimum tensile strength of tube plate, in N/mm<sup>2</sup>

where

- $d$  = diameter of tube holes, in mm
- $s$  = vertical pitch of tubes, in mm.

10.1.2 Each alternate tube in the outer vertical rows of tubes is to be a tube welded at both ends as shown in Fig. 10.9.4. Further, the arrangement of tubes in the nests is to be such that the thickness of the tube plates meets the requirements of 9.1.

10.1.3 Where the vertical height of the tube plates between the top and bottom shelves exceeds 0,65 times the internal diameter of the boiler, the staying of the tube plates, and the scantlings of the tube plates and shell plates to which the sides of the tube plates are connected, will require to be specially considered. It is recommended, however, that for this type of boiler the vertical height of the tube plates between the top and bottom shelves should not exceed 1,25 times the internal diameter of the boiler.

### 10.2 Horizontal shelves of tube plates forming part of the shell

10.2.1 For vertical boilers of the type referred to in 10.1, in order to withstand vertical load due to pressure on the boiler ends, the horizontal shelves of the tube plates are to be supported by gussets in accordance with the following formula:

$$C = \frac{AD_i \rho}{t}$$

where

- $\rho$  = design pressure, in bar
- $t$  = thickness of the tube plate, in mm
- $A$  = maximum horizontal dimension of the shelf from the inside of the shell plate to the outside of the tube plate, in mm
- $D_i$  = inside diameter of the boiler, in mm.

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**10.2.2** For the combustion chamber tube plate the minimum number of gussets is to be:

- 1 gusset, where  $C$  exceeds 255 000
- 2 gussets, where  $C$  exceeds 350 000
- 3 gussets where  $C$  exceeds 420 000.

**10.2.3** For the smokebox tube plate the minimum number of gussets is to be:

- 1 gusset where  $C$  exceeds 255 000
- 2 gussets where  $C$  exceeds 470 000.

**10.2.4** The shell plates to which the sides of the tube plates are connected are to be not less than 1,6 mm thicker than is required by the formula applicable to shell plates with continuous circularity, and where gussets or other stays are not fitted to the shelves, the strength of the parts of the circumferential seams at the top and bottom of these plates from the outside of one tube plate to the outside of the other, is to be sufficient to withstand the whole load on the boiler end with a factor of safety of not less than 4,5 related to  $R_{20}$  (where  $R_{20}$  is the specified minimum tensile strength of the shell plates, in N/mm<sup>2</sup>).

### 10.3 Dished and flanged ends for vertical boilers

**10.3.1** The minimum thickness,  $t$ , of dished and flanged ends for vertical boilers which are subject to pressure on the concave side and are supported by central uptakes is to be determined by the following formula:

$$t = \frac{pR_i}{13\sigma} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $R_i$  and  $\sigma$  are as defined in 1,2.

**10.3.2** The inside radius of curvature,  $R_i$ , of the end plate is to be not greater than the external diameter of the cylinder to which it is attached.

**10.3.3** The inside knuckle radius,  $r_i$ , see Fig. 10.4.2(a), of the arc joining the cylindrical flange to the spherical surface of the end is to be not less than four times the thickness of the end plate, and in no case less than 65 mm.

**10.3.4** The inside radius of curvature of flange to uptake is to be not less than twice the thickness of the end plate, and in no case less than 25 mm.

**10.3.5** If the dished end has a manhole, the opening is to be strengthened by flanging. The total depth,  $H$ , of the flange, measured from the outer surface of the plate on the minor axis, is to be not less than:

$$H = \sqrt{tW}$$

where

- $t$  = thickness of the flange, in mm
- $H$  = depth of flange, in mm
- $W$  = minor axis of the manhole, in mm.

### 10.4 Flat crowns of vertical boilers

**10.4.1** The minimum thickness of flat crown plates of vertical boilers is to be determined as in 9,1;  $d$  and  $C$  are defined as follows:

- Where the crown is supported by an uptake only,
  - $d$  = diameter, in mm, of the largest circle which can be drawn between the connections to the shell or firebox and uptake, see 9.1.1 to 9.1.5
  - $C$  = 0,161
- Where bar stays are fitted in accordance with 9.1.6 and 9.1.7:
  - $d$  = diameter of the largest circle which can be drawn through at least three points of support, in mm
  - $C$  = the mean of the values for the respective points of support through which the circle passes.

## Section 11 Furnaces subject to external pressure

### 11.1 Maximum thickness

**11.1.1** Furnaces, plain or corrugated, are not to exceed 22,5 mm in thickness.

### 11.2 Corrugated furnaces

**11.2.1** The minimum thickness,  $t$ , of corrugated furnaces is to be determined by the following formula:

$$t = \frac{pD_o}{C} + 0,75 \text{ mm}$$

where

$p$  is as defined in 1.2

$t$  = thickness of the furnace plate measured at the bottom of the corrugations, in mm

$C$  = 1060 for Fox, Morison and Deighton corrugations  
= 1130 for Suspension Bulb corrugations

$D_o$  = external diameter of the furnace measured at the bottom of the corrugations, in mm.

### 11.3 Plain furnaces, flue sections and combustion chamber bottoms

**11.3.1** The minimum thickness,  $t$ , between points of substantial support, of plain furnaces or furnaces strengthened by stiffening rings, of flue sections and of the cylindrical bottoms of combustion chambers is to be determined by the following formulae, the greater of the two thicknesses obtained being taken:

$$t = \sqrt{\frac{pD_o(L + 610)}{102\,400}} + 0,75 \text{ mm}$$

$$t = \frac{CpD_o}{1100} + \frac{L}{320} + 0,75 \text{ mm}$$

where

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$t$  and  $p$  are as defined in 1.2

$$C = \frac{2x}{x + \sigma} \text{ or } 0,85 \text{ whichever is the greater}$$

$D_o$  = external diameter of the furnace, flue or combustion chamber, in mm

$L$  = length of section between the centres of points of substantial support, in mm

$x$  and  $\sigma$  are as defined in 11.7.1.

11.3.2 Where stiffeners are used for strengthening plain cylindrical furnaces, or combustion chambers, the second moment of area,  $I$ , of the stiffener is to be determined by the following formula:

$$I = \frac{p D_o^3 L}{13,3 \times 10^6} \text{ mm}^4$$

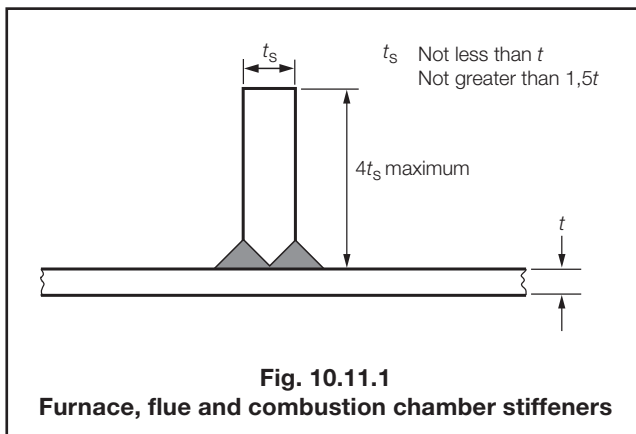
where

$p$  is as defined in 1.2

$D_o$  = external diameter of the furnace flue or combustion chamber, in mm

$L$  = length of section between the centres of points of substantial support, in mm

For proportion of stiffening rings, see Fig. 10.11.1.



### 11.4 Plain furnaces of vertical boilers

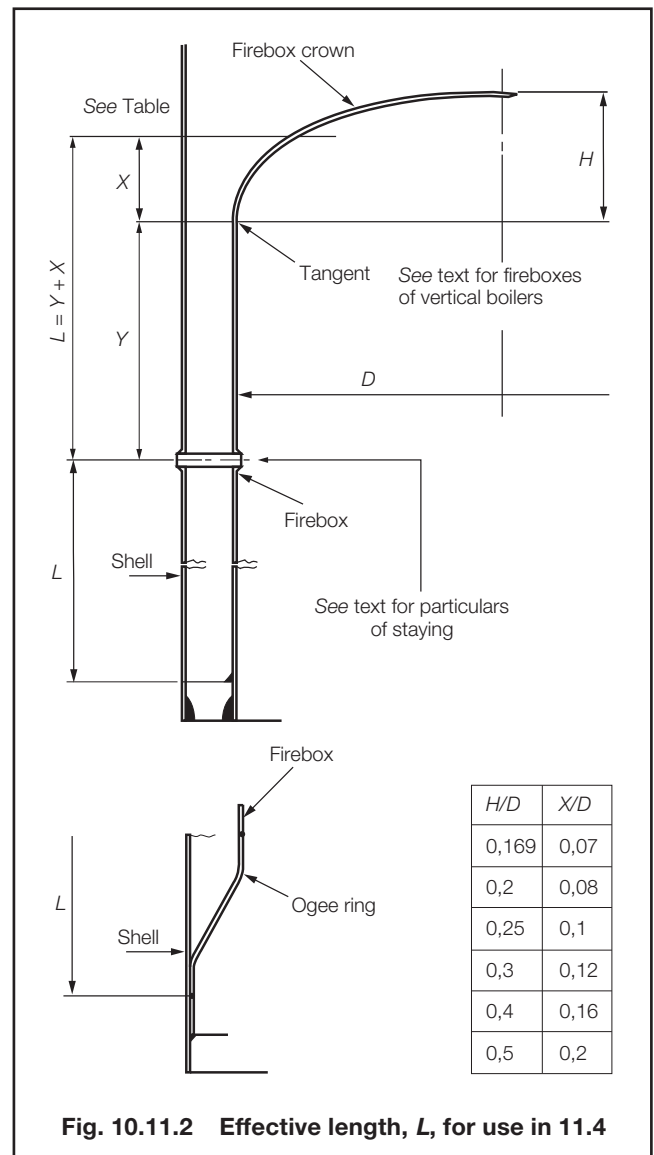
11.4.1 The thickness of plain furnaces not exceeding 2000 mm in external diameter is to be determined by the formulae given in 11.3.1, the greater of the two thicknesses being taken:

where

$D_o$  = external diameter of the furnace, in mm. Where the furnace is tapered, the diameter to be taken for calculation purposes is to be the mean of that at the top and that at the bottom where it meets the substantial support from flange, ring or row of stays

$L$  = effective length, in mm, of the furnace between the points of substantial support as indicated in Fig. 10.11.2.

11.4.2 For furnaces under 760 mm in external diameter, the thickness is to be not less than 8 mm, and for furnaces 760 mm in external diameter and over, the thickness is to be not less than 9,5 mm.



11.4.3 A circumferential row of stays connecting the furnace to the shell will be considered to provide substantial support to the furnace, provided that:

- The diameter of the stay is not less 22,5 mm or twice the thickness of the furnace, whichever is the greater.
- The pitch of the stays at the furnace does not exceed 14 times the thickness of the furnace.

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### 11.5 Hemispherical furnaces

11.5.1 The minimum thickness,  $t$ , of unsupported hemispherical furnaces subject to pressure on the convex surface is to be determined by the following formula:

$$t = \frac{C p R_o}{608} + 0,75 \text{ mm}$$

where

$t$  and  $p$  are as defined in 1.2

$x$  and  $\sigma$  are as defined in 11.7.1

$$C = \frac{2x}{x + \sigma} \text{ or } 0,85 \text{ whichever is the greater}$$

$R_o$  = outer radius of curvature of the furnace, in mm.

11.5.2 In no case is the maximum thickness to exceed 22,5 mm, or the ratio  $\frac{R_o}{t - 0,75}$  to exceed 100.

### 11.6 Dished and flanged ends for supported vertical boiler furnaces

11.6.1 The minimum thickness,  $t$ , of dished and flanged ends for vertical boiler furnaces that are subject to pressure on the convex side and are supported by central uptakes, is to be determined by the following formula:

$$t = \frac{p R_o}{10\sigma} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $R_o$  and  $\sigma$  are as defined in 1.2.

11.6.2 The inside radius of dishing and flanging are to be as required by 10.3.

### 11.7 Dished and flanged ends for unsupported vertical boiler furnaces

11.7.1 The minimum thickness,  $t$ , of dished and flanged ends for vertical boiler furnaces that are subject to pressure on the convex side and are without support from stays of any kind, is to be determined by the following formula, but is in no case to be less than the thickness of the firebox:

$$t = \frac{C p R_o}{660} + 0,75 \text{ mm}$$

where

$t$  and  $p$  are as defined in 1.2.

$x$  = specified minimum lower yield stress or 0,2 per cent proof stress in N/mm<sup>2</sup> at a temperature 90°C above the saturated steam temperature corresponding to the design pressure for carbon and carbon manganese steel with a specified minimum tensile strength of 400 N/mm<sup>2</sup>

$$C = \frac{2x}{x + \sigma} \text{ or } 0,85 \text{ whichever is the greater}$$

$R_o$  = outside radius of the crown plate, in mm

(in no case is  $\frac{R_o}{t}$  to exceed 88)

$\sigma$  = specified minimum lower yield stress or 0,2 per cent proof stress in N/mm<sup>2</sup> at a temperature 90°C above the saturated steam temperature corresponding to the design pressure for the steel actually used

11.7.2 The inside radius of curvature,  $R_i$ , of the end plate is to be not greater than the external diameter of the cylinder to which it is attached.

11.7.3 The inside knuckle radius,  $r_i$ , see Fig.10.4.2(a), of the arc joining the cylindrical flange to the spherical surface of the end is to be not less than four times the thickness of the end plate and in no case less than 65 mm.

### 11.8 Ogee rings

11.8.1 The minimum thickness,  $t$ , of the ogee ring which connects the bottom of the furnace to the shell of a vertical boiler and sustains the whole vertical load on the furnace is to be determined by the following formula:

$$t = \sqrt{\frac{p D_i (D_i - D_o)}{9\,900}} + 0,75 \text{ mm}$$

where

$t$  and  $p$  are as defined in 1.2

$D_i$  = inside diameter of boiler shell, in mm

$D_o$  = outside diameter of the lower part of the furnace where it joins the ogee ring, in mm.

11.8.2 Proposals to use a flat plate annular ring which connects the bottom of the furnace to the shell of a vertical boiler and sustains any unbalanced vertical load on the furnace will be the subject of special consideration.

### 11.9 Uptakes of vertical boilers

11.9.1 The minimum thickness,  $t$ , of internal uptakes of vertical boilers is to be determined by the following formulae, the greater of the two thicknesses obtained being taken:

$$t = \sqrt{\frac{p D_o (L + 610)}{102\,400}} + 4 \text{ mm}$$

$$t = \frac{p D_o}{1100} + \frac{L}{320} + 4 \text{ mm}$$

where

$t$  and  $p$  are as defined in 1.2

$D_o$  = external diameter of uptake, in mm

$L$  = length of uptake between the centres of points of substantial support, in mm.

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Sections 12 &amp; 13

### Section 12 Boiler tubes subject to external pressure

#### 12.1 Tubes

12.1.1 The thickness of tubes is to be in accordance with Table 10.12.1 for the appropriate outside diameter and design pressure.

12.1.2 Tubes may be welded at both ends, welded at the inlet end and expanded at the outlet end, or expanded at both ends. In addition to expanding, tubes may be bell mouthed or beaded at the inlet end. Where tubes are welded, the weld detail is to be as shown in Fig. 10.9.4 and the tubes are to be expanded into the tube plates in addition to welding, except as permitted by 12.1.3.

12.1.3 For tubes of thickness greater than 6,0 mm, expanding in addition to welding is not required if a recessed weld of depth not less than the tube thickness is provided.

### Section 13 Tubes welded at both ends and bar stays for cylindrical boilers

#### 13.1 Loads on tubes welded at both ends and bar stays

13.1.1 Each tube or bar stay is to be designed to carry its due proportion of the load on the plates which it supports.

13.1.2 For a tube or bar stay, the net area to be supported is to be the area, in mm<sup>2</sup>, enclosed by the lines bisecting at right angles the lines joining the stay and the adjacent points of support, less the area of any tubes or stays enclosed. In the case of a tube or bar stay in the boundary rows, the support afforded by the flat plate margin, where applicable, should be taken into account. Where flat margins overlap stays are not required.

13.1.3 The thickness of tubes welded at both ends to tube plates is to be such that the longitudinal stress due to the flat plate loading does not exceed 70 N/mm<sup>2</sup>.

13.1.4 Tubes may be welded into the boiler after post-weld heat treatment has been carried out.

13.1.5 The permissible longitudinal stress in combustion chamber bar stays or similar stays where an end is heated by flame, is not to exceed 70 N/mm<sup>2</sup>, and the diameter of this type of bar stay is not to be less than 19 mm.

13.1.6 The permissible longitudinal stress in longitudinal bar stays not subject to heating, is not to exceed 20 per cent of the minimum specified tensile strength, in N/mm<sup>2</sup>, and the diameter of this type of bar stay is not to be less than 25 mm.

**Table 10.12.1 Thickness of plain tubes under external pressure**

Design pressure, in bar											Thickness, in mm
Outside diameter, in mm											
38	44,5	51	57	63,5	70	76	82,5	89	95	102	
—	—	—	—	—	—	—	—	—	26,9	25,2	5,89
—	—	—	—	—	—	—	26,2	24,1	22,8	21,4	5,38
—	—	—	—	—	—	24,1	22,1	20,7	19,3	17,9	4,88
—	—	—	27,6	24,8	22,8	20,7	19,3	17,9	16,6	15,9	4,47
—	29,3	25,5	22,8	20,7	18,9	17,3	15,9	14,8	13,7	12,7	4,06
26,6	22,8	20,7	17,9	15,9	14,8	13,1	12,4	11,4	10,3	9,6	3,66
20,3	16,9	14,8	13,1	12,1	11,0	9,6	8,9	8,2	7,6	6,9	3,25
14,8	12,4	10,7	9,6	8,6	7,6	—	—	—	—	—	2,95



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## Part 5, Chapter 10

Section 14

### Section 14 Construction

#### 14.1 Access arrangements

14.1.1 In watertube boilers, manholes are to be provided in all drums of sufficient size to allow access for internal examination and cleaning, and for fitting and expanding the tubes. In the case of headers for water walls, superheaters or economisers, and of drums which are too small to permit entry, sight holes or mudholes sufficiently large and numerous for these purposes are to be provided.

14.1.2 Cylindrical boilers are to be provided, where possible with means for ingress to permit examination and cleaning of the inner surfaces of plates and tubes exposed to flame. Where the boilers are too small to permit this, there are to be sight holes and mudholes sufficiently large and numerous to allow the inside to be satisfactorily cleaned.

14.1.3 Where the cross tubes of vertical boilers are large, there is to be a sight hole in the shell opposite to one end of each tube sufficiently large to allow the tube to be examined and cleaned. These sight holes are to be in positions accessible for that purpose.

14.1.4 Manholes in cylindrical shells should preferably have their shorter axes arranged longitudinally.

14.1.5 Doors for manholes, mudholes and sight holes are to be formed from steel plate or other approved construction, and all jointing surfaces are to be machined.

14.1.6 Doors of the internal type are to be provided with spigots which have a clearance of not more than 1,5 mm all round, i.e. the axes of the opening are not to exceed those of the door by more than 3 mm. The width of the manhole gasket seat is to be not less than 16 mm.

14.1.7 Doors of the internal type for openings not larger than 230 mm x 180 mm need be fitted with one stud only, which may be forged integral with the door. Doors for openings larger than 230 mm x 180 mm are to be fitted with two studs or bolts. The strength of the attachment to the door is to be not less than the strength of the stud or bolt.

14.1.8 The crossbars or dogs for doors are to be of steel.

14.1.9 For smaller circular openings in headers and similar fittings, an approved type of plug may be used.

14.1.10 Circular flat cover plates may be fitted to raised circular manhole frames not exceeding 400 mm diameter, and for an approved design pressure not exceeding 18 bar.

14.1.11 External circular flat cover plates are to be in accordance with a recognised National Standard.

#### 14.2 Torispherical and semi-ellipsoidal ends

14.2.1 For typical acceptable types of attachment for dished ends to cylindrical shells, see Fig. 10.14.1.

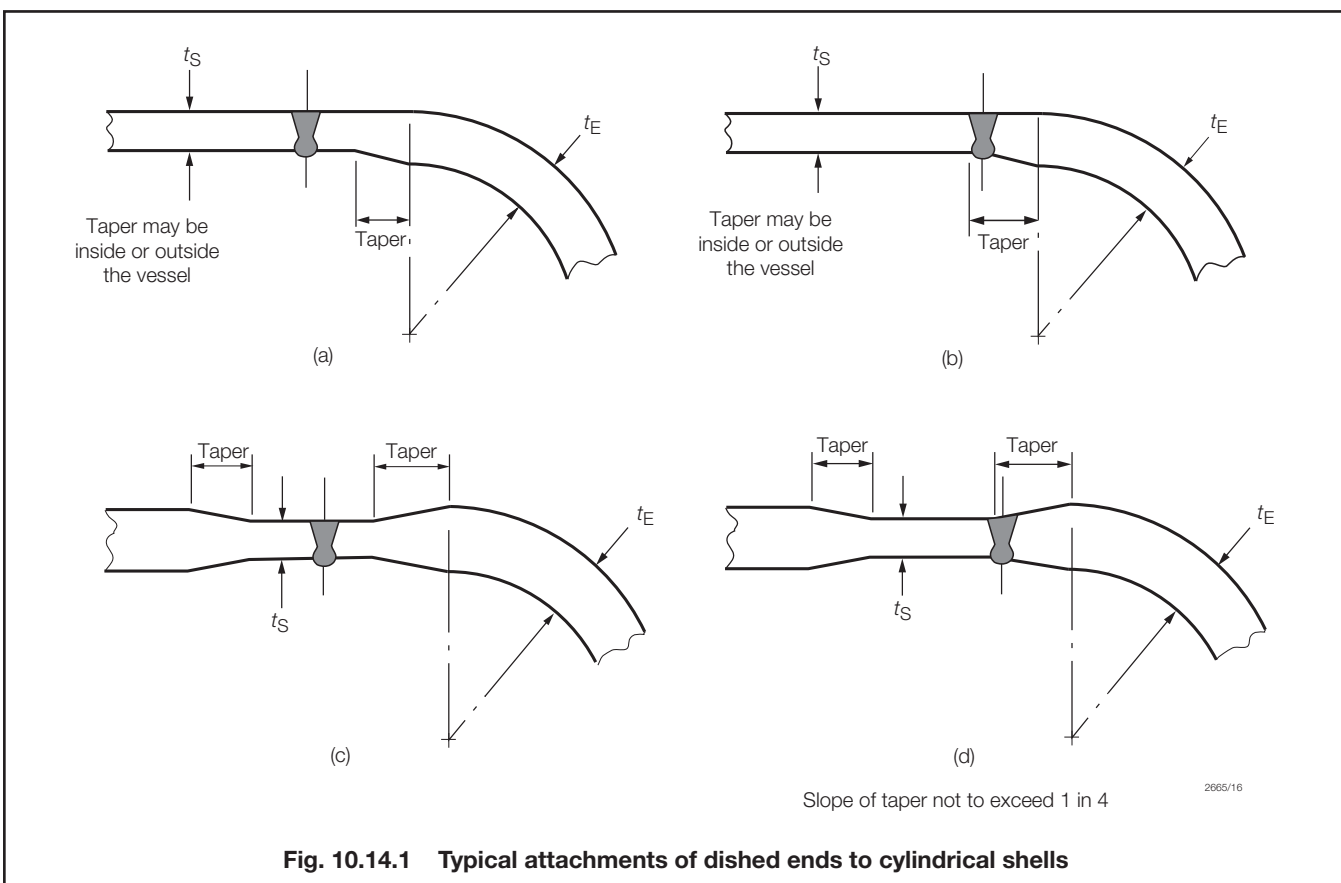


Fig. 10.14.1 Typical attachments of dished ends to cylindrical shells



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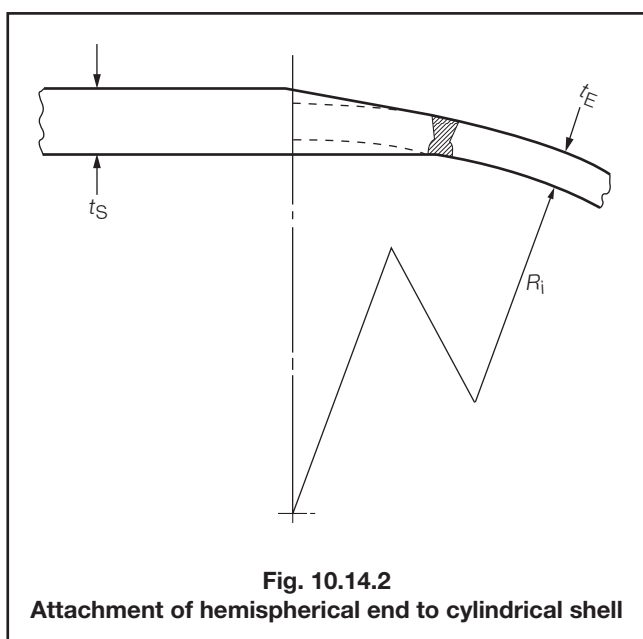
Section 14

14.2.2 Where the difference in thickness is the same throughout the circumference, the thicker plate is to be reduced in thickness by machining to a taper for a distance not less than four times the offset, so that the two plates are of equal thickness at the position of the circumferential weld. A parallel portion may be provided between the end of the taper and weld edge preparation; alternatively, if so desired, the width of the weld may be included as part of the smooth taper of the thicker plate.

14.2.3 The thickness of the plates at the position of the circumferential weld is to be not less than that of an unpierced cylindrical shell of seamless or welded construction, whichever is applicable, of the same diameter and material, see 4.1.

### 14.3 Hemispherical ends

14.3.1 Where hemispherical ends are butt welded to cylindrical shells, the thickness of the shell is to be reduced by taper to that of the end, and the centre of the hemisphere is to be so located that the entire tapered portion of the shell and the butt weld are within the hemisphere, see Fig. 10.14.2.



14.3.2 If the hemispherical end is provided with a parallel portion, the thickness of this portion is to be not less than that of a seamless or welded shell, whichever is applicable, of the same diameter and material.

### 14.4 Welded-on flanges, butt welded joints and fabricated branch pieces

14.4.1 Flanges may be cut from plates or may be forged or cast. Hubbed flanges are not to be machined from plate. Flanges are to be attached to branches by welding. Alternative methods of flange attachment will be subject to special consideration.

14.4.2 The types of welded-on flanges are to be suitable for the pressure, temperature and service for which the branches are intended.

14.4.3 Flange attachments and pressure-temperature ratings in accordance with materials and design of recognised Standards will be accepted.

14.4.4 Typical examples of welded-on flange connections are shown in Fig. 10.14.3(a) to (f), and limiting design conditions for the flange types are shown in Table 10.14.1. In Fig. 10.14.3  $t$  is the minimum Rule thickness of the standpipe or branch.

14.4.5 Welded-on flanges are not to be a tight fit on the branch. The maximum clearance between the bore of the flange and the outside diameter of the branch is to be 3 mm at any point, and the sum of the clearances diametrically opposite is not to exceed 5 mm.

14.4.6 Where butt welds are employed in the attachment of flange type (a), or in the construction of standpipes or branch pieces, the adjacent pieces are to be matched at the bores. This may be effected by drifting, roller expanding or machining, provided the pipe wall is not reduced below the designed thickness. If the parts to be joined differ in wall thickness, the thicker wall is to be gradually tapered to that of the thinner at the butt joint.

14.4.7 Welding may be carried out by means of the shielded metal arc, inert gas metal arc, oxy-acetylene or other approved process, but in general, oxy-acetylene welding is suitable only for flange type (a) and is not to be applied to branches exceeding 100 mm diameter or 9,5 mm thick. The welding is to be carried out in accordance with the appropriate paragraphs of Chapter 17.

14.4.8 Threaded sleeve joints complying with Ch 12,2.8.1 may be used on the steam and water piping of small oil fired package boilers of the once through coil type, used for auxiliary or domestic purposes, where the feed pump capacity limits the output.

14.4.9 Socket weld joints are not to be used where fatigue, severe erosion, crevice corrosion or stress corrosion is expected to occur, for example, blow down, drain, scum and chemical dosing connections.

### 14.5 Welded attachments to pressure vessels

14.5.1 Unless the actual thickness of the shell or end is at least twice that required by calculation for a seamless shell or end, whichever is applicable, doubling plates with well rounded corners are to be fitted in way of attachments such as lifting lugs, supporting brackets and feet, to minimise load concentrations on pressure shells and ends. Compensating plates, pads, brackets and supporting feet are to be bedded closely to the surface before being welded, and are to be provided with a 'tell-tale' hole not greater than 9,5 mm in diameter, open to the atmosphere to provide for the release of entrapped air during heat treatment of the vessel, or as a means of indicating any leakage during hydraulic testing and in service, see Chapter 17.

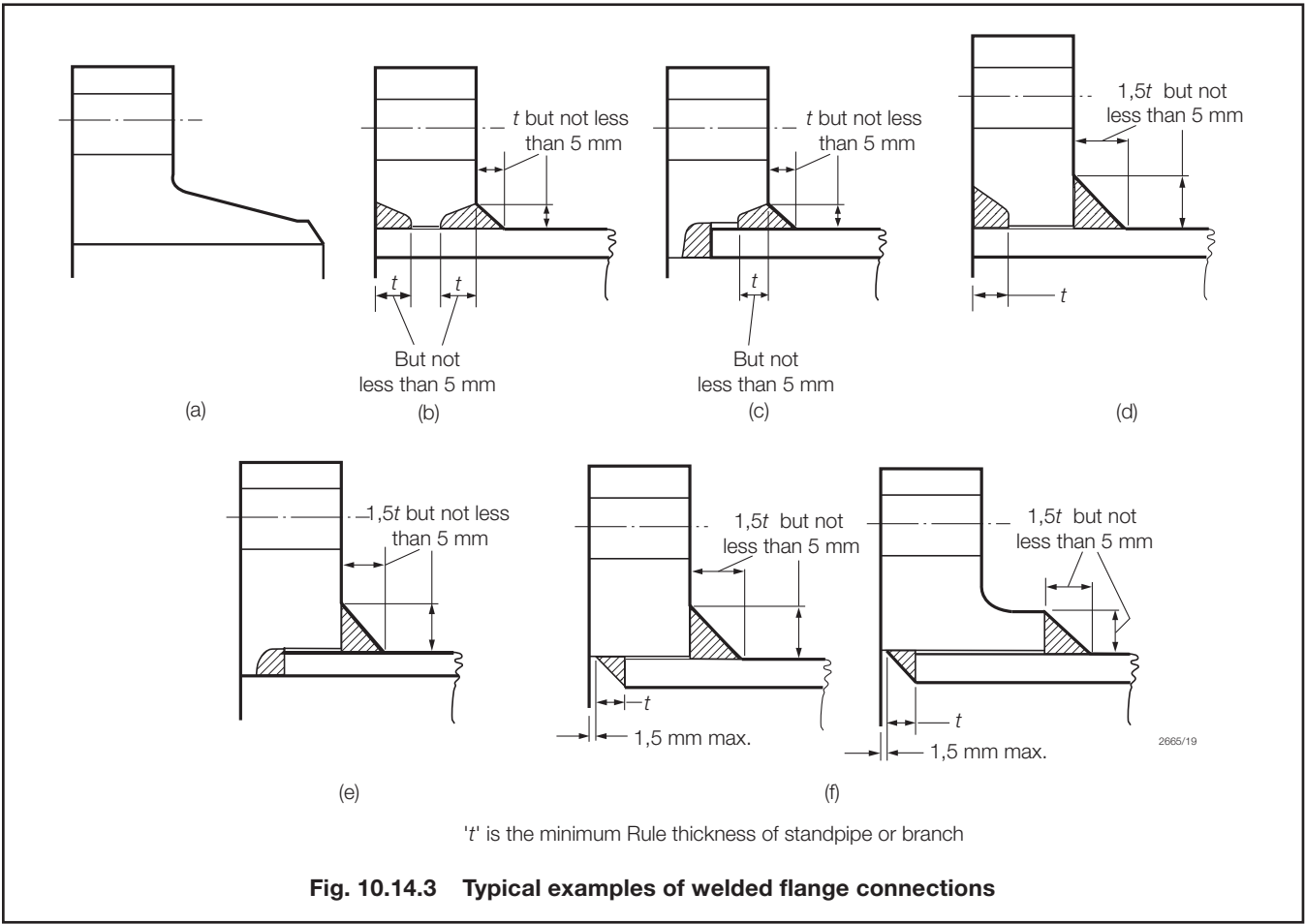


Table 10.14.1 Limiting design conditions for flanges

Flange type	Maximum pressure	Maximum temperature	Maximum pipe o.d.	Minimum pipe bore
		°C	mm	mm
(a)	Pressure-temperature ratings to be in accordance with a recognised standard	No restriction	No restriction	No restriction
(b)		No restriction	168,3 for alloy steels*	No restriction
(c)		No restriction	168,3 for alloy steels*	75
(d)		425	No restriction	No restriction
(e)		425	No restriction	75
(f)		425	No restriction	No restriction

\* No restriction for carbon steels

14.5.2 For acceptable methods of attaching standpipes, branches, compensating plates and pads, see Fig. 10.14.4. Alternative methods of attachment may be accepted provided details are submitted for consideration.

14.5.3 Where fillet welds are used to attach standpipes or set-in pads, there are to be equal sized welds both inside and outside the vessel, see Fig 10.14.4(a) and (f). The leg length of each of the fillet welds is to be not less than 1,4 times the actual thickness of the thinner of the parts being joined.

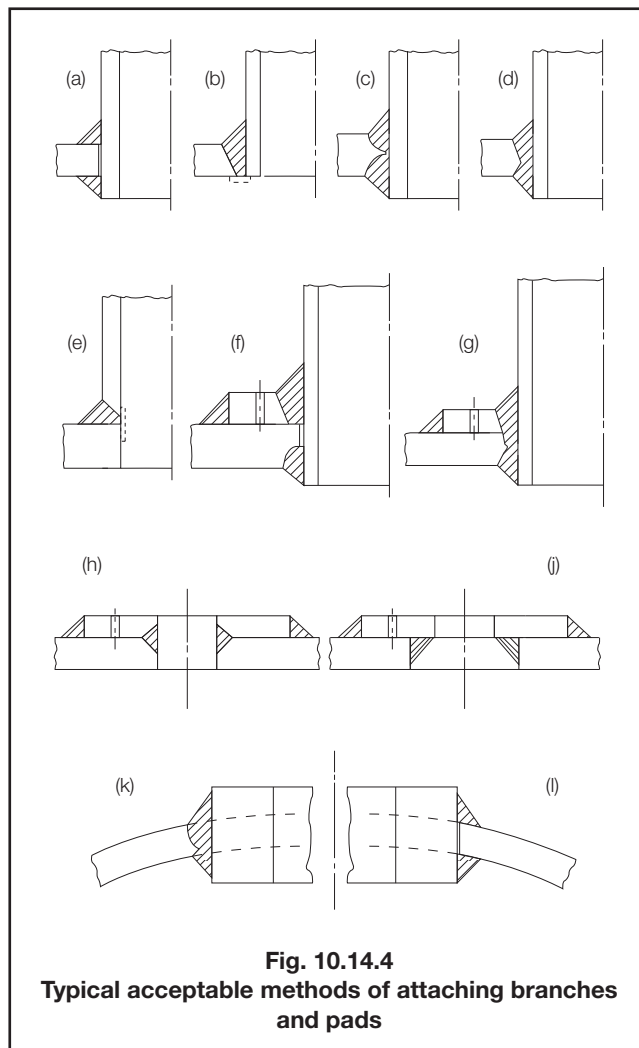
14.6 Fitting of tubes in water tube boilers

14.6.1 The tube holes in drums or headers are to be formed in such a way that the tubes can be effectively tightened in them. Where the tube ends are not normal to the tube plates, there is to be a neck or belt of parallel seating of at least 13 mm in depth, measured in a plane through the axis of the tube at the holes. Where the tubes are practically normal to their plates, this parallel seating is to be not less than 9,5 mm in depth.

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**Fig. 10.14.4**

**Typical acceptable methods of attaching branches and pads**

14.6.2 Tubes are to be carefully fitted in the tube holes and secured by means of welding, expanding and belling or by other approved methods. Tubes are to project through the neck or belt of parallel seating by at least 6 mm and where they are secured from drawing out by means of bellmouthing only, the included angle of belling is to be not less than 30°.

### Section 15 Mountings and fittings for cylindrical and vertical boilers, steam generators, pressurised thermal liquid and pressurised hot water heaters

#### 15.1 General

15.1.1 Valves over 38 mm diameter are to be fitted with outside screws, and the covers are to be secured by bolts or studs. All valves are to be arranged to shut with a right-hand (clockwise) motion of the wheels.

15.1.2 All valves and cocks connected to the boiler are to be such that it is seen without difficulty whether they are open or shut. Where boiler mountings are secured by studs, the studs are to have a full thread holding in the plate for a length of at least one diameter.

15.1.3 Where a superheater is fitted which can be shut-off from the boiler, it is to be provided with a separate safety valve fitted with easing gear. The valve as regards construction is to comply with the regulations for ordinary safety valves, but the easing gear may be fitted to be workable from the stokehold only. The superheater is also to be fitted with a drain valve or cock to free it from water when necessary.

15.1.4 Safety valve chests and other boiler and superheater mountings subjected to pressures exceeding 13,0 bar or to steam temperatures exceeding 220°C, and boiler blow-down fittings, are to be made of steel or other approved material.

#### 15.2 Safety valves

15.2.1 Boilers and steam generators are to be fitted with not less than two safety valves, each having a minimum internal diameter of 25 mm, but those having a total heating surface of less than 50 m<sup>2</sup> may have one valve not less than 50 mm diameter. Small oil fired package boilers of the once through coil type used for auxiliary or domestic purposes, where the feed pump capacity limits the output, may have one safety valve not less than 19 mm internal diameter, or two safety valves with internal diameters not less than 16 mm, provided the capacity is in accordance with 15.2.13.

15.2.2 The valves, spindles, springs and compression screws are to be so encased and locked or sealed that the safety valves and pilot valves, after setting to the working pressure, cannot be tampered with or overloaded in service.

15.2.3 Valves are to be so designed that in the event of fracture of springs they cannot lift out of their seats.

15.2.4 Easing gear is to be provided for lifting the safety valves and is to be operable by mechanical means at a safe position from the boiler or engine room platforms.

15.2.5 Safety valves are to be made with working parts having adequate clearances to ensure complete freedom of movement.

15.2.6 Valve seats are to be effectively secured in position. Any adjusting devices which control discharge capacity are to be positively secured so that the adjustment will not be affected when the safety valves are dismantled at surveys.

15.2.7 All the safety valves of each boiler and steam generator may be fitted in one chest, which is to be separate from any other valve chest and is to be connected directly to the shell by a strong and stiff neck, the passage through which is to be of cross-sectional area not less than the aggregate area of the safety valves in the chest in the case of full lift valves, and one-half of that area in the case of other valves. For the meaning of aggregate area, see 15.2.13.

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**15.2.8** For each safety valve, an individual unrestricted drain is to be provided. The drain pipe is to be fitted to the lowest part of the safety valve and is to be independently led with a continuous fall to a place where the high temperature steam and/or condensate can discharge, visibly clear of the boilers and where it cannot cause injury. No valves or cocks are to be fitted to these drain pipes. The bore of the drain pipes is not to be less than 19 mm.

**15.2.9** Safety valves for shell type exhaust gas steaming economisers are to incorporate fail safe features which will ensure operation of the valve even with solid matter deposits on the valve and guide, or features that will prevent the accumulation of solid matter in way of the valve and in the clearance between the valve spindle and guide. Alternatively, if the fitted valves do not incorporate the features described then a bursting disc discharging to a suitable waste steam pipe is to be fitted in addition to the valves. These bursting discs are to function at a pressure not exceeding 1,25 times the economiser approved design pressure and are to have sufficient capacity to prevent damage to the economiser when operating at its design heat input level.

**15.2.10** To avoid the accumulation of solid matter deposits on the outlet side of the safety valves and bursting discs required by 15.2.9, the discharge pipes and safety valve/bursting disc housings are to be fitted with drainage arrangements from the lowest part, directed with continuous fall to a position clear of the economiser where it will not pose a threat to either personnel or machinery. No valves or cocks are to be fitted in the drainage arrangements. The drainage arrangements required by 15.2.8 may be accepted as meeting these requirements where the arrangements comply with this paragraph.

**15.2.11** Full particulars of the proposed arrangements are to be submitted for consideration.

**15.2.12** Where the receiver is fitted with safety valves to relieve the steam output of the economiser and the economiser cannot be isolated from the receiver the requirements of 15.2.9 may be waived.

**15.2.13** The designed discharge capacities of the safety valves on each boiler and steam generator are to be found from the following formulae:

Saturated steam safety valves:

$$E = \frac{AC(p + 1,03)}{98,1}$$

Superheated steam safety valves:

$$E = \frac{AC(p + 1,03)}{98,1} \sqrt{\frac{V_S}{V_H}}$$

where

- $p$  = set pressure, in bar gauge
- $A$  = for ordinary, high lift or improved high lift safety valves, the aggregate area, in mm<sup>2</sup>, of the orifices through the seatings of the valves, neglecting the area of guides and other obstructions
- = for full lift safety valves, the net aggregate area, in mm<sup>2</sup>, through the seats after deducting the area of the guides or other obstructions when the valves are fully lifted

$$C = 4,8 \text{ for valves of ordinary type having a minimum lift of } \frac{D}{24}$$

$$= 7,2 \text{ for valves of high lift type, having a minimum lift of } \frac{D}{16}$$

$$= 9,6 \text{ for valves of improved high lift type having a minimum lift of } \frac{D}{12}$$

$$= 19,2 \text{ for valves of full lift type having a minimum lift of } \frac{D}{4}$$

$D$  = bore of valve seat, in mm

$E$  = the maker's specified peak load evaporation, in kg/hour (including all evaporation from water walls, integral, or steaming economisers and other heating surfaces in direct communication with the boiler)

$V_H$  = specific volume of superheated steam (m<sup>3</sup>/kg)

$V_S$  = specific volume of saturated steam (m<sup>3</sup>/kg).

**15.2.14** When the discharge capacity of a safety valve of approved design has been established by type tests, carried out in the presence of the Surveyors or by an independent authority recognised by LR, on valves representative of the range of sizes and pressures intended for marine application, consideration will be given to the use of a constant higher than  $C = 19,2$ , based on 90 per cent of the measured capacity up to a maximum of  $C = 45$  for full lift safety valves.

**15.2.15** Pressurised thermal liquid and pressurised hot water heaters are to be provided with a safety relief device. The safety valve is to be designed and constructed in accordance with a relevant National or International Standard acceptable to LR.

### 15.3 Waste steam pipes

**15.3.1** For ordinary, high lift and improved high lift type valves, the cross-sectional area of the waste steam pipe and passages leading to it is to be at least 10 per cent greater than the aggregate area of the safety valves as used in the formulae in 15.2.13. For full lift and other approved valves of high discharge capacity, the cross-sectional area of the waste steam pipe and passages is to be not less than 0,1C times the aggregate valve area.

**15.3.2** The cross-sectional area of the main waste steam pipe is to be not less than the combined cross-sectional areas of the branch waste steam pipes leading thereto from the boiler safety valves.

**15.3.3** Waste steam pipes are to be led to the atmosphere and are to be adequately supported and provided with suitable expansion joints, bends or other means to relieve the safety valve chests of undue loading.

**15.3.4** The scantlings of waste steam pipes and silencers are to be suitable for the maximum pressure to which the pipes may be subjected in service, and in any case not less than 10 bar.

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15.3.5 Silencers fitted to waste steam pipes are to be so designed that the clear area through the baffle plates is not less than that required for the pipes.

15.3.6 The safety valves of each exhaust gas heated economiser and exhaust gas heated boiler which may be used as an economiser are to be provided with entirely separate waste steam pipes.

15.3.7 External drains and exhaust steam vents to atmosphere are not to be led to waste steam pipes.

15.3.8 It is recommended that a scale trap and means for cleaning be provided at the base of each waste steam pipe.

### 15.4 Adjustment and accumulation tests

15.4.1 All safety valves are to be set under steam to a pressure not greater than the approved pressure of the boiler. As a working tolerance the setting is acceptable provided the valves lift at not more than 103 per cent of the approved design pressure. During a test of 15 minutes with the stop valves closed and under full firing conditions the accumulation of pressure is not to exceed 10 per cent of the design pressure. During this test no more feed water is to be supplied than is necessary to maintain a safe working water level.

### 15.5 Stop valves

15.5.1 One main stop valve is to be fitted to each boiler and secured directly to the shell. There are to be as few auxiliary stop valves as possible so as to avoid piercing the boiler shell more than is absolutely necessary.

15.5.2 Where two or more boilers are connected together:

- Stop valves of self-closing or non-return type are to be fitted.
- Essential services are to be capable of being supplied from at least two boilers.

### 15.6 Water level indicators

15.6.1 Every boiler designed to contain water at a specified level is to be fitted with at least two means for indicating its water level, at least one of which is to be a direct reading gauge glass. The other means is to be either an additional gauge glass or an approved equivalent device. The required water level indicators are to be independent of each other.

15.6.2 Where a pair of gauge glasses are set at different levels to provide an extended range of water level indication they will only be considered as one water level indicator.

15.6.3 An approved equivalent device for level indication may derive its level input signal from one of the low water level detection systems required by 15.7.1 provided that in the event of a power supply failure to that system an alarm is initiated and the oil fuel supply to the burners, or any other fuel used to fire the boiler, is automatically shut-off. The fuel supply shut-off will only be required if the power supply failure results in the direct reading gauge glass being the only functioning water level indicator.

15.6.4 The water gauges are to be readily accessible and placed so that the water level is clearly visible. The lowest visible parts of water gauges are to be situated at the lowest safe working level.

15.6.5 The level of the highest part of the effective heating surfaces, e.g. combustion chamber top of a horizontal boiler and the furnace crown of a vertical boiler, is to be clearly marked in a position adjacent to the glass water gauge.

15.6.6 The cocks of all water gauges are to be operable from positions free from danger in the event of the glass breaking.

### 15.7 Low water level fuel shut-off and alarm

15.7.1 Every fired boiler designed to contain water at a specified level is to be fitted with two systems of water level detection which are to be independent of each other, and which will operate an alarm and shut-off automatically the fuel supply to the burners, or any other fuel used to fire the boiler, when the water level falls to a predetermined low level. These level detectors, in addition, may be used for other functions, e.g. high level alarm, feed pump control, etc.

### 15.8 Feed check valves

15.8.1 Two feed check and stop valves, connected to separate feed lines, are to be provided for all main and auxiliary boilers which are required for essential services. The feed check and stop valves may be connected to a single standpipe at the shell. In the case of steam/steam generators one feed check valve is acceptable provided steam for essential services is simultaneously available from another source.

### 15.9 Pressure gauges

15.9.1 Each boiler is to be provided with a separate steam pressure gauge.

15.9.2 The gauges are to be placed where they are easily read.

### 15.10 Blow-down and scum valves

15.10.1 Each boiler is to be fitted with at least one blow-down valve.



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**15.10.2** The blow-down valve is to be attached, wherever practicable, direct to the lower part of the boiler. Where it is not practicable to attach the blow-down valve directly, a steel pipe supported from the boiler may be fitted between the boiler and valve.

**15.10.3** The blow-down valve and its connections to the sea need not be more than 38 mm, and is to be not less than 19 mm internal diameter. For cylindrical boilers the size of the valve may be generally 0,0085 times the diameter of the boiler.

**15.10.4** Blow-down valves and scum valves (where the latter are fitted) of two or more boilers may be connected to one common discharge, but where thus arranged there are to be screw-down non-return valves fitted for each boiler to prevent the possibility of the contents of one boiler passing to another.

**15.10.5** For blow-down valves or cocks on the ship's side and attachments, see Ch 13,2.

### 15.11 Sampling valve or cock

**15.11.1** Each boiler is to be provided with a sampling valve or cock secured direct to the boiler in a convenient position. The valve or cock is not to be on the water gauge standpipe.

### 15.12 Additional requirements for shell type exhaust gas steaming economisers

**15.12.1** The design and construction of shell type economisers are to pay particular attention to the welding, heat treatment and inspection arrangements at the tube plate connection to the shell.

**15.12.2** Every shell type economiser is to be provided with removable lagging at the circumference of the tube end plates to enable ultrasonic examination of the tube plate to shell connection.

**15.12.3** Every economiser is to be provided with arrangements for pre-heating and de-aeration, and addition of water treatment or combination thereof, to control the quality of feed water to within the manufacturer's recommendations.

**15.12.4** The manufacturer is to provide operating instructions for each economiser which is to include reference to:

- Feed water treatment and sampling arrangements.
- Operating temperatures – exhaust gas and feed water temperatures.
- Operating pressure.
- Inspection and cleaning procedures.
- Records of maintenance and inspection.
- The need to maintain adequate water flow through the economiser under all operating conditions.
- Periodical operational checks of the safety devices to be carried out by the operating personnel and to be documented accordingly.
- Procedures for using the exhaust gas economiser in the dry condition.

- Procedures for maintenance and overhaul of safety valves.
- Emergency operating procedures.

## Section 16 Mountings and fittings for water tube boilers

### 16.1 General

**16.1.1** Mountings and fittings not mentioned in this Section are to be in accordance with the requirements in Section 15.

### 16.2 Safety valves

**16.2.1** Water tube boilers are to be fitted with not less than two safety valves of area and design in general accordance with the requirements of 15.2.

**16.2.2** Each saturated steam drum and each superheater are to be provided with at least one safety valve.

**16.2.3** Where the superheater forms an integral part of the boiler, the relieving capacity of the superheater safety valve(s), based on the reduced pressure at the superheater outlet, may be included as part of the total relieving capacity required for the boiler. As some National Authorities limit the proportion of the superheater safety valve relieving capacity which may be credited towards the total capacity for the boiler, builders should give attention to any relevant Statutory Requirements of the National Authority of the country in which the ship is to be registered.

**16.2.4** The boiler and superheater valves are to be so disposed and proportioned between saturated steam drum and superheater outlet that the superheater will be protected from overheating under all service conditions, including an emergency stop of the ship at full power.

**16.2.5** Where it is proposed to fit full bore safety valves operated by independent pilot valves, the arrangements are to be submitted for consideration. The pipes connecting pilot valves and main valves are to be of ample bore and wall thickness to minimise the possibility of obstruction and damage.

**16.2.6** Where it is impracticable to attach safety valves directly to the superheater, the valves are to be located as near as possible thereto and fitted to a branch piece connected to the superheater outlet pipe.

**16.2.7** In high temperature installations the drains from safety valves are to be led to a tank or other place where high temperature steam can be safely discharged.

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### 16.3 Safety valve settings

16.3.1 All boiler and superheater safety valves are to be set under steam to their respective working pressures, which are not to be greater than the approved design pressure of the boiler. As a working tolerance the setting is acceptable provided the valves lift at not more than 103 per cent of the approved pressure.

16.3.2 In the setting of superheater safety valves, allowance is to be made for the pressure drop through the superheater so that under discharge conditions the pressure in the boiler will not exceed the approved boiler pressure.

16.3.3 In no case is the superheater safety valve setting to exceed by more than three per cent the pressure for which the steam piping is approved.

### 16.4 Waste steam pipes

16.4.1 The waste steam pipe and passages leading to it from the safety valves are to be in general accordance with the requirements of 15.3.

16.4.2 In installations operating with a high degree of superheat, consideration is to be given to the high temperatures which waste steam pipes, silencers and surrounding spaces will attain when the superheater safety valves are blowing during accumulation tests and in service, adequate protection against heat effects is to be provided to the Surveyor's satisfaction.

16.4.3 Waste steam pipes are to be led well clear of electric cables and any parts or structures sensitive to heat or likely to distort; the pipes are to be insulated where necessary. In these installations each boiler should have a separate waste steam pipe system to atmosphere, with supporting and expansion arrangements such that no direct loading is imposed on the safety valve chests.

### 16.5 Accumulation tests

16.5.1 Tests for accumulation of pressure are to be carried out with the stop valve closed and under full firing conditions for a period not exceeding seven minutes. The accumulation is not to exceed 10 per cent of the design pressure.

16.5.2 Where accumulation tests might endanger the superheaters, consideration will be given in cases of fired boilers to the omission of these tests, provided that application is made when the boiler plan and sizes of safety valves are submitted for approval, and that the safety valves are of an approved type for which the capacity has been established by test in the presence of the Surveyors or an approved independent authority, or for which LR is satisfied, by long experience of accumulation tests, that the capacity is adequate. When it is agreed to waive accumulation tests, it will be required that the valve makers provide a certificate for each safety valve, stating its rated capacity at the approved working conditions of the boilers and that the boiler makers provide a certificate for each boiler stating its maximum evaporation.

16.5.3 The safety valves are to be found satisfactory in operation under working conditions during the trials of the machinery on board ship.

### 16.6 Water level indicators

16.6.1 Every boiler designed to contain water at a specified level is to be fitted with at least two means for indicating its water level, at least one of which is to be a direct reading gauge glass. The other means is to be either an additional gauge glass or an approved equivalent device. The required water level indicators are to be independent of each other.

16.6.2 Where a pair of gauge glasses are set at different levels to provide an extended range of water level indication they will only be considered as one water level indicator.

16.6.3 An approved equivalent device for level indication may derive its level input signal from one of the low water level detection systems required by 16.7.1 provided that, in the event of a power supply failure to that system, an alarm is initiated and the oil fuel supply to the burners, or any other fuel used to fire the boiler, is automatically shut-off. The fuel supply shut-off will only be required if the power supply failure results in the direct reading gauge glass being the only functioning water level indicator.

16.6.4 Where a steam and water drum exceeding 4 m in length is fitted athwartships, two glass water gauges are to be fitted in suitable positions, one near each end of the drum.

16.6.5 The position of the glass water gauge of boilers in which the tubes are entirely drowned when cold is to be such that water is just showing in the glass when the water level in the steam drum is just above the top of the uppermost tubes when the boiler is cold.

16.6.6 In boilers, the tubes of which are not entirely drowned when cold, the glass water gauges are to be placed, to the Surveyor's satisfaction, in the positions which have been found by experience to indicate satisfactorily that the water content is sufficient for safety when the boiler is worked under all service conditions.

### 16.7 Low water level fuel shut-off and alarm

16.7.1 Every fired boiler designed to contain water at a specified level is to be fitted with two systems of water level detection which are to be independent of each other, and which will operate an alarm and shut-off automatically the fuel supply to the burners when the water level falls to a predetermined low level. These level detectors may be used for other functions, e.g. high level alarm, feed pump control, etc.

16.7.2 Any proposals to depart from these requirements in the case of small auxiliary boilers will be the subject of special consideration.

16.7.3 See Pt 6, Ch 1 for requirements for control, alarm and safety systems, and additional requirements for unattended operation.



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Sections 16, 17 & 18

### 16.8 Feed check valves and water level regulators

16.8.1 Two feed check and stop valves, connected to separate feed lines, are to be provided for each boiler and are to be attached, wherever practicable, direct to the boiler or to an economiser which forms an integral part of the boiler.

16.8.2 Where the arrangements necessitate the use of a common inlet pipe on the economiser for both main and auxiliary feed systems, this pipe is to be as short as practicable, and the arrangements of check valves are to be such that either feed line can be effectively isolated without interruption of the feed water supply to the boiler.

16.8.3 At least one of the feed water systems is to be fitted with an approved feed water regulator whereby the water level in the boilers is controlled automatically. See Ch 14,6 for arrangements and details of boiler feed systems.

16.8.4 The feed check valves are to be fitted with efficient gearing, whereby they can be satisfactorily worked from the stokehold floor, or other convenient position.

16.8.5 Standpipes on boilers, for feed inlets, are to be designed with an internal pipe to prevent direct contact between the feed pipe and the boiler shell or end plates with the object of minimising thermal stresses in these plates. Similar arrangements are to be provided for desuperheater and other connections where significant temperature differences occur in service.

## Section 17 Hydraulic tests

### 17.1 General

17.1.1 Boilers and pressure vessels, together with their components are to withstand the following hydraulic tests without any sign of weakness or defect.

17.1.2 Having regard to the variation in the types and design of boilers, the hydraulic test may be carried out by either of the methods indicated below:

- boilers are to be tested on completion to a pressure 1,5 times the approved design pressure, or
- where construction permits, all components of the boiler are to be tested on completion of the work including heat treatment to 1,5 times the design pressure. In the case of components such as drums or headers, which are to be drilled for tube holes, the test may be before drilling the tube holes, but is to be after the attachment of standpipes, stubs and similar fittings and also after heat treatment has been carried out. Where all the components have been tested as above, each completed boiler after assembly is to be tested to 1,25 times the design pressure.

### 17.2 Mountings

17.2.1 All boiler mountings are to be subjected to a hydraulic test of twice the approved design pressure with the exception of feed check valves and other mountings connected to the main feed system which are to be tested to 2,5 times the approved boiler design pressure, or twice the maximum pressure which can be developed in the feed line in normal service, whichever is greater.

## Section 18 Control and monitoring

### 18.1 General

18.1.1 Control engineering systems are to be in accordance with the requirements of Pt 6, Ch 1.

### 18.2 Unattended machinery

18.2.1 Where boilers are fitted with automatic or remote controls so that under normal operating conditions they do not require any manual intervention by the operators, they are to be provided with the alarms and safety arrangements required by 18.2 to 18.3, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

18.2.2 Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions which could hazard the machinery.

18.2.3 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

18.2.4 Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm.

### 18.3 Main, auxiliary and other boilers

18.3.1 Alarms and safeguards are indicated in 18.3.2 to 18.3.9 and Table 10.18.1.

18.3.2 The following boiler services are to be fitted with automatic controls so as to maintain steady state conditions throughout the normal operating range of the boiler:

- Combustion system.
- Oil fuel supply temperature or viscosity, heavy oil only.
- Boiler drum water level.
- De-aerator water level, where applicable.
- Superheated steam pressure, where applicable.
- Superheated steam temperature, where applicable.

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**Table 10.18.1 Main, auxiliary and other boilers: Alarms and safeguards**

Item	Alarm	Note
Water level*	Low	Two water level sensors are to be provided, each to operate independently, and automatically to shut off the oil fuel to the burners and operate alarms, see Notes 1 to 3 and 5
Water level	1st stage high 2nd stage high	— Where applicable, automatic closure of turbine steam inlet valves, see 18.2.4
Steam drum or superheater outlet pressure*	High and Low	—
Superheated steam temperature	High	—
De-superheated steam temperature*	High	—
Feed water or water forced circulation flow (if fitted)	Low	Oil fuel to burners to be shut off automatically, see Notes 5 and 6
Feed water pH	Low	When automatic dosing of feed water fitted
Feed water salinity	High	Fitted in boiler feed system
Feed water temperature	Low	When automatic temperature control fitted
Combustion air pressure*	Low	Oil fuel burners to be shut off automatically in operation or not released during start up, see Note 5. Purge sequences to be inhibited, see Ch 14,3.1.9
Oil fuel pressure*	Low	—
Oil fuel temperature or viscosity*	High and Low	Heavy oil only
Oil fuel atomising steam/air pressure	Low	—
Burner flame*	Failure	Each burner to be monitored. Oil fuel to burner(s) to be shut off automatically, see Ch 14,3.1.11 and 3.1.12 and Note 5
Flame monitoring device(s)*	Failure	See 18.3.7 and Note 5
Igniter power supply*	Failure	Each igniter to be checked before oil fuel is supplied to burner, see 18.3.6 and Note 5
Forced draft fan*	Power failure	Oil fuel to burners to be shut off automatically. Control using alternative arrangements is to remain available, see Pt 6, Ch 1,2.5.8
Air registers and dampers (including those in the uptake)*	Not fully open	Purge sequence to be inhibited, see Ch 14,3.1.9
Control system*	Power failure	Oil fuel burners to be shut off automatically. Control using alternative arrangement is to remain available, see Pt 6, Ch 1,2.5.8
Uptake temperature	High	Where economiser and/or gas air heaters are integral with the boiler and also for independent exhaust gas boilers/economisers, to monitor for soot fires. See Note 7
<b>NOTES</b> 1. For dual-evaporation boilers, the primary circuit is to be fitted with two independent low water level detectors which will operate alarms and shut off the oil fuel to the burners automatically. The secondary circuit is to be fitted with one low water level detector which will operate alarms and shut off the oil fuel to the burners automatically. Additionally one high water level alarm is to be fitted on the secondary circuit which may be operated by the same detector as that provided for low water level detection. 2. Only one independent system of low water level detection, alarm and automatic oil fuel shut-off need be fitted in the case of small forced circulation or re-circulation coiled water tube 'package' type boilers when evaporation is less than 2900 kg/hr or the heating surface is less than 100 m <sup>2</sup> . 3. Where two level sensors are provided these may be used for other functions, e.g., high level alarm, level control, trip systems, etc. 4. For boilers not supplying steam for propulsion or for services essential for the safety or operation of the ship at sea, only the items marked * are required. 5. These safeguards are to remain operative during automatic, manual and emergency operation. 6. For exhaust gas economisers/boilers requiring feed water or forced water circulation, the low flow alarm is to be fitted with provision to override the alarm if the exhaust gas economiser/boiler is to be operated in the dry condition. See also Ch 14,6.2.5. 7. Alternatively, details of an appropriate fire detection system are to be submitted for consideration.		

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- (g) De-superheated steam pressure, where applicable.
- (h) De-superheated steam temperature, where applicable.

18.3.3 Safety systems and overrides are to comply with the requirements of Pt 6, Ch 1,2.4.9.

18.3.4 Burner controls are to be arranged such that light off is only possible at the minimum firing rate compatible with flame establishment. If ignition is set to occur at a fuel rich condition then the burner is to revert to the correct operating air/fuel ratio on establishment of a stable flame.

18.3.5 Where water level indicators are dependent upon an external power supply, the oil fuel supply to the burners is to be automatically shut off in the event of power or signal failure.

18.3.6 Arrangements are to be such that burner oil fuel valve(s) do not open:

- (a) prior to completion of required warm up times for residual fuel oil; or
- (b) when the power supply to the igniter has failed, as applicable; or
- (c) until a pilot flame is established, as applicable; or
- (d) prior to the completion of furnace purging, see Ch 14,3.1.7.

18.3.7 Arrangements for flame failure detection are to be provided with self-monitoring capabilities which ensure that the flame detector is not erroneously indicating the presence of a flame. In the event of failure being detected by these self-monitoring capabilities:

- an alarm is to be activated;
- in the event of loss of flame detection capability for a burner;
- oil fuel to the burner is to be shut off automatically; and
- an alarm is to be activated.

18.3.8 Where established as necessary by Ch 14,3.1.8, means are to be provided to prevent starting of the ignition sequence following multiple flame failures until completion of the identified lock-out period.

18.3.9 Following burner shut-down, the furnace is to be purged automatically for at least the required pre-purging time. In the event of shut-down due to activation of a required safeguard, this purging is to be manually initiated.

# Other Pressure Vessels

# Part 5, Chapter 11

Section 1

## Section

- 1 **General requirements**
- 2 **Cylindrical shells and drums subject to internal pressure**
- 3 **Spherical shells subject to internal pressure**
- 4 **Dished ends subject to internal pressure**
- 5 **Dished ends for Class 3 pressure vessels**
- 6 **Conical ends subject to internal pressure**
- 7 **Standpipes and branches**
- 8 **Construction**
- 9 **Mountings and fittings**
- 10 **Hydraulic tests**
- 11 **Plate heat exchangers**

## ■ Section 1 General requirements

### 1.1 Application

1.1.1 The requirements of this Chapter are applicable to fusion welded pressure vessels and plate heat exchangers, intended for marine purposes but not included in Chapter 10. The equations in this Chapter may be used for determining the thickness of seamless pressure vessels using a joint factor of 1,0. Seamless pressure vessels are to be manufactured and tested in accordance with the requirements of Chapter 5 of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials). For the construction and design of pressure vessels and plate heat exchangers for liquefied gas or chemical cargo applications, see the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk* (hereinafter referred to as the Rules for Ships for Liquefied Gases) or the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquid Chemicals in Bulk* (hereinafter referred to as the Rules for Ships for Liquid Chemicals) as applicable.

1.1.2 Where the required design criteria for pressure vessels are not indicated within this Chapter, the relevant Sections of Chapter 10 are applicable.

1.1.3 Seamless pressure vessels are to be manufactured in accordance with the requirements of the Rules for Materials where applicable.

### 1.2 Definition of symbols

1.2.1 The symbols used in the various formulae in Sections 2 to 7 inclusive, unless otherwise stated, are defined as follows, and are applicable to the specific part of the pressure vessel under consideration:

- $d$  = diameter of hole, or opening, in mm
- $p$  = design pressure, see 1.3, in bar
- $r_i$  = inside knuckle radius, in mm
- $r_o$  = outside knuckle radius, in mm
- $s$  = pitch, in mm
- $t$  = minimum thickness, in mm
- $D_i$  = inside diameter, in mm
- $D_o$  = outside diameter, in mm
- $J$  = joint factor applicable to welded seams, see 1.9, or ligament efficiency between tube holes (expressed as a fraction, see Ch 10,2.2)
- $R_i$  = inside radius, in mm
- $R_o$  = outside radius, in mm
- $T$  = design temperature, in °C
- $\sigma$  = allowable stress, see 1.8, in N/mm<sup>2</sup>.

1.2.2 Where reference is made to calculated or actual plate thickness for the derivation of other values, these thicknesses are to be minus the standard Rule corrosion allowance of 0,75 mm, if not so stated.

### 1.3 Design pressure

1.3.1 The design pressure is the maximum permissible working pressure, and is to be not less than the highest set pressure of any relief valve.

1.3.2 Calculations made to determine the scantlings of the pressure parts are to be based on the design pressure, adjusted where necessary to take account of pressure variations corresponding to the most severe operational conditions.

1.3.3 It is desirable that there should be a margin between the normal pressure at which the pressure vessel operates and the lowest pressure at which any relief valve is set to lift, to prevent unnecessary lifting of the relief valve.

### 1.4 Metal temperature

1.4.1 The metal temperature,  $T$ , used to evaluate the allowable stress,  $\sigma$ , is to be taken as the actual metal temperature expected under operating conditions for the pressure part concerned, and is to be stated by the manufacturer when plans of the pressure parts are submitted for consideration.

1.4.2 The design temperature,  $T$ , for calculation purposes is to be not less than 50°C.

### 1.5 Classification of fusion welded pressure vessels

1.5.1 For Rule purposes, pressure vessels are graded as Class 1 where the shell thickness exceeds 38 mm.

# Other Pressure Vessels

# Part 5, Chapter 11

Section 1

1.5.2 For Rule purposes, pressure vessels are graded as Class 2/1 and Class 2/2 if they comply with the following conditions:

- (a) where the design pressure exceeds 17,2 bar, or
- (b) where the metal temperature exceeds 150°C, or
- (c) where the design pressure, in bar, multiplied by the actual thickness of the shell, in mm, exceeds 157, or
- (d) where the shell thickness does not exceed 38 mm.

1.5.3 For Rule purposes, Class 3 pressure vessels are to have a maximum shell thickness of 16 mm, and are pressure vessels not included in Classes 1, 2/1 or 2/2.

1.5.4 Pressure vessels which are constructed in accordance with Classes 2/1, 2/2 or 3 standards (as indicated above) will, if manufactured in accordance with the requirements of superior Class, be approved with the scantlings appropriate to that Class.

1.5.5 Pressure vessels which only have circumferential fusion welded seams, will be considered as seamless with no Class being assigned. Preliminary weld procedure tests and non-destructive examination for the circumferential seam welds should be carried out for the equivalent Class as determined by 1.5.1, 1.5.2 and 1.5.3.

1.5.6 In special circumstances relating to service conditions, materials, operating temperature, the carriage of dangerous gases and liquids, etc., it may be required that certain pressure vessels be manufactured in accordance with the requirements of a superior Class.

1.5.7 Details of heat treatment, non-destructive examination and routine tests (where required) are given in Chapter 13 of the Rules for Materials.

1.5.8 Hydraulic testing is required for all Classes of pressure vessels.

1.5.9 For a full definition of Classes of pressure vessels relating to boilers and associated pressure vessels, see Ch 10,1.

## 1.6 Plans

1.6.1 Plans of pressure vessels are to be submitted in triplicate for consideration where all the conditions in (a) or (b) are satisfied:

- (a) The vessel contains vapours or gases, e.g. air receivers, hydrophore or similar vessels and gaseous CO<sub>2</sub> vessels for fire-fighting, and
  - $pV > 600$
  - $p > 1$
  - $V > 100$
  - $V$  = volume (litres) of gas or vapour space
- (b) The vessel contains liquefied gases, or flammable liquids
  - $p > 7$
  - $V > 100$
  - $V$  = volume (litres)
  - $p$  is as defined in 1.2.1.

1.6.2 Plans of full constructional features of the vessel and dimensional details of the weld preparations for longitudinal and circumferential seams and attachments, together with particulars of the welding consumables and of the mechanical properties of the materials, are to be submitted before construction is commenced.

## 1.7 Materials

1.7.1 Materials used in the construction of Class 1, 2/1 and 2/2 pressure vessels are to be manufactured, tested and certified in accordance with the requirements of the Rules for Materials. Materials used in the construction of Class 3 pressure vessels may be in accordance with the requirements of an acceptable national or international specification. The manufacturer's certificate will be accepted in lieu of Lloyd's Register's (hereinafter referred to as LR) material certificate for such materials.

1.7.2 The specified minimum tensile strength of carbon and carbon-manganese steel plates, pipes, forgings and castings is to be within the general limits of 340 to 520 N/mm<sup>2</sup>.

1.7.3 The specified minimum tensile strength of low alloy steel plates, pipes, forgings and castings is to be within the general limits of 400 to 500 N/mm<sup>2</sup>, and pressure vessels made in these steels are to be either seamless or Class 1 fusion welded.

1.7.4 Where it is proposed to use materials other than those specified in the Rules for Materials, details of the chemical compositions, heat treatment and mechanical properties are to be submitted for approval. In such cases, the values of the mechanical properties used for deriving the allowable stress are to be subject to agreement by LR.

## 1.8 Allowable stress

1.8.1 The term 'allowable stress',  $\sigma$ , is the stress to be used in the formulae for the calculation of scantlings of pressure parts.

1.8.2 The allowable stress,  $\sigma$ , is to be the lowest of the following values:

$$\sigma = \frac{E_t}{1,5} \quad \sigma = \frac{R_{20}}{2,7} \quad \sigma = \frac{S_R}{1,5}$$

where

$E_t$  = specified minimum lower yield stress or 0,2 per cent proof stress at temperature,  $T$ , for carbon and carbon-manganese steels. In the case of austenitic steels, the 1,0 per cent proof stress at temperature,  $T$ , is to be used

$R_{20}$  = specified minimum tensile strength at room temperature

$S_R$  = average stress to produce rupture in 100 000 hours at temperature,  $T$

$T$  = metal temperature, see 1.4.

1.8.3 The allowable stress for steel castings is to be taken as 80 per cent of the value determined by the method indicated in 1.8.2 using the appropriate values for cast steel.

1.8.4 Where steel castings, which have been tested in accordance with the Rules for Materials are also subjected to non-destructive tests, consideration will be given to increasing the allowable stress using a factor up to 90 per cent in lieu of the 80 per cent referred to in 1.8.3. Particulars of the non-destructive test proposals are to be submitted for consideration.

## 1.9 Joint factors

1.9.1 The following joint factors are to be used in the equations in Sections 2 to 6, where applicable. Fusion welded pressure parts are to be made in accordance with Chapter 17.

Class of pressure vessel	Joint factor
Class 1	1,0
Class 2/1	0,85
Class 2/2	0,75
Class 3	0,60

1.9.2 The longitudinal joints for all Classes of vessels are to be butt joints. Circumferential joints for Class 1 vessels are also to be butt welds. Circumferential joints for Classes 2/1, 2/2 and 3 vessels should also be butt joints with the following exceptions:

- (a) Circumferential joints for Classes 2/1, 2/2 and 3 vessels may be of the joggle type provided neither plate at the joints exceeds 16 mm thickness.
- (b) Circumferential joints for Class 3 vessels may be of the lap type provided neither plate at the joint exceeds 16 mm thickness nor the internal diameter of the vessel exceeds 610 mm.

For typical acceptable methods of attaching flat ends, see Fig. 10.8.2 and Fig. 10.9.1 in Chapter 10.

For typical acceptable methods of attaching dished ends, see Fig 11.8.1.

1.9.3 Where a pressure vessel is to be made of alloy steel, particulars of the welding consumables to be used, including typical mechanical properties and chemical composition of the deposited weld metal, are to be submitted for approval.

## 1.10 Pressure parts of irregular shape

1.10.1 Where pressure parts are of such irregular shape that it is impracticable to design their scantlings by the application of the formulae in Sections 2 to 7, the suitability of their construction is to be determined by hydraulic proof test of a prototype or by an agreed alternative method.

## 1.11 Adverse working conditions

1.11.1 Where working conditions are adverse, special consideration may require to be given to increasing the scantlings derived from the formulae. In this connection, where necessary, account should also be taken of any excess of loading resulting from:

- (a) impact loads, including rapidly fluctuating pressures,
- (b) weight of the vessel and normal contents under operating and test conditions,
- (c) superimposed loads, such as other pressure vessels, operating equipment, insulation, corrosion-resistant or erosion-resistant linings and piping,
- (d) reactions of supporting lugs, rings, saddles or other types of supports, or
- (e) the effect of temperature gradients on maximum stress.

## Section 2 Cylindrical shells and drums subject to internal pressure

### 2.1 Minimum thickness

2.1.1 The minimum thickness,  $t$ , of a cylindrical shell is to be determined by the following formula:

$$t = \frac{p R_i}{10\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t, p, R_i$  and  $\sigma$  are as defined in 1.2

$J$  = the joint factor of the longitudinal joints (expressed as a fraction). See 1.9 in the case of seamless shells clear of openings  $J = 1,0$ .

2.1.2 The formula in 2.1.1 is applicable only where the resulting thickness does not exceed half the internal radius, i.e. where  $R_o$  is not greater than  $1,5R_i$ .

2.1.3 Irrespective of the thickness determined by the formula in 2.1.1,  $t$  is to be not less than  $3 + \frac{D_i}{1500}$  mm, where

$D_i$  is as defined in 1.2. The minimum thickness permitted for vessels manufactured in corrosion resistant steels will be the subject of special consideration.

## Cross-references

For efficiency of ligaments between tube holes, see Ch 10,2.2.

For compensating effect of tube stubs, see Ch 10,2.3.

For unreinforced openings, see Ch 10,2.4.

For reinforced openings, see Ch 10,2.5.



# Other Pressure Vessels

# Part 5, Chapter 11

Sections 3 & 4

## Section 3 Spherical shells subject to internal pressure

### 3.1 Minimum thickness

3.1.1 The minimum thickness,  $t$ , of a spherical shell is to be determined by the following formula:

$$t = \frac{p R_i}{20\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $R_i$ ,  $\sigma$  and  $J$  are as defined in 1.2.

3.1.2 The formula in 3.1.1 is applicable only where the resulting thickness does not exceed half the internal radius.

3.1.3 Irrespective of the thickness determined by the formula in 3.1.1,  $t$  is to be not less than  $3 + \frac{D_i}{1500}$  mm, where

$D_i$  is as defined in 1.2. The minimum thickness permitted for vessels manufactured in corrosion resistant steels will be the subject of special consideration.

3.1.4 Openings in spherical shells requiring compensation are to comply, in general, with Ch 10,2.5, using the calculated and actual thickness of the spherical shell as applicable.

## Section 4 Dished ends subject to internal pressure

### 4.1 Minimum thickness

4.1.1 The thickness,  $t$ , of semi-ellipsoidal and hemispherical unstayed ends and the knuckle section of torispherical ends, dished from plate, having pressure on the concave side and satisfying the conditions listed below, is to be determined by the following formula:

$$t = \frac{p D_o K}{20\sigma J} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $D_o$ ,  $\sigma$  and  $J$  are as defined in 1.2

$K$  = a shape factor, see Ch 10,4.2 and Fig. 10.4.1.

4.1.2 For semi-ellipsoidal ends:

the external height,  $H \geq 0,18D_o$

where

$D_o$  = the external diameter of the parallel portion of the end, in mm.

4.1.3 For torispherical ends:

the internal radius,  $R_i \leq D_o$

the internal knuckle radius,  $r_i \geq 0,1D_o$

the internal knuckle radius,  $r_i \geq 3t$

the external height,  $H \geq 0,18D_o$ , and is determined as follows:

$$H = R_o - \sqrt{(R_o - 0,5D_o)(R_o + 0,5D_o - 2r_o)}$$

4.1.4 In addition to the formula in 4.1.1 the thickness,  $t$ , of a torispherical head, made from more than one plate, in the crown section, is to be not less than that determined by the following formula:

$$t = \frac{p R_i}{20\sigma J - 0,5p} + 0,75 \text{ mm}$$

where

$t$ ,  $p$ ,  $R_i$ ,  $\sigma$ , and  $J$  are as defined in 1.2.

4.1.5 The thickness required by 4.1.1 for the knuckle section of a torispherical head is to extend past the common tangent point of the knuckle and crown radii into the crown section for a distance not less than  $0,5 \sqrt{R_i t}$  mm, before reducing to the crown thickness permitted by 4.1.4 where

$t$  = the required thickness from 4.1.1.

4.1.6 In all cases,  $H$  is to be measured from the commencement of curvature, shown in Fig. 10.4.2, in Chapter 10.

4.1.7 The minimum thickness of the head,  $t$ , is in no case to be less than  $3 + \frac{D_i}{1500}$  mm, where  $D_i$  is as defined in

1.2. The minimum thickness permitted for vessels manufactured in corrosion resistant steels will be the subject of special consideration.

4.1.8 For ends which are butt welded to the drum shell, see 1.9, the thickness of the edge of the flange for connection to the shell is to be not less than the thickness of an unpierced seamless or welded shell, whichever is applicable, of the same diameter and material and determined by 2.1.

## Cross-references

For shape factors for dished ends, see Ch 10,4.2.

For dished ends with unreinforced openings, see Ch 10,4.3.

For flanged openings in dished ends, see Ch 10,4.4.

For location of unreinforced and flanged openings in dished ends, see Ch 10,4.5.

For dished ends with reinforced openings, see Ch 10,4.6 and 4.7.



## Section 5

### Dished ends for Class 3 pressure vessels

#### 5.1 Minimum thickness

5.1.1 As an alternative to the formula in 4.1.1, for Class 3 vessels only, the minimum thickness,  $t$ , of a torispherical unstayed end dished from plate and having pressure on the concave or convex side is to be determined by the following formula:

$$t = \frac{p R_i}{CS}$$

where

$t, p$ , and  $R_i$  are as defined in 1.2

$C = 2,57$  for ends concave to pressure

$= 1,65$  for ends convex to pressure

$S =$  specified minimum tensile strength of plate, in  $N/mm^2$ , which should be not less than  $410 N/mm^2$ .

5.1.2 The inside radius of curvature,  $R_i$ , of the end plate is to be not greater than the external diameter of the cylinder to which it is attached.

5.1.3 The inside knuckle radius,  $r_i$ , of the arc joining the cylindrical flange to the spherical surface of the end is to be not less than four times the thickness of the end plate, and in no case less than 65 mm.

5.1.4 Ends convex to pressure are not to be used for vessels exceeding 610 mm internal diameter.

5.1.5 Where the end is provided with a flanged manhole, the thickness of the end, in mm, determined by 5.1.1, is to be increased by 3 mm, and the total depth,  $H$ , of the manhole flange, measured from the outer surface of the plate on the minor axis, is to be not less than:

$$H = \sqrt{t_1 W}$$

where

$t_1 =$  required thickness of the plate, in mm

$H =$  depth of flange, in mm

$W =$  minor axis of the manhole, in mm.

## Section 6

### Conical ends subject to internal pressure

#### 6.1 General

6.1.1 Conical ends and conical reducing sections, as shown in Fig. 10.5.1 in Chapter 10, are to be designed in accordance with the equations given in 6.2.

6.1.2 Connections between cylindrical shell and conical sections and ends should preferably be by means of a knuckle transition radius. Typical permitted details are shown in Fig. 10.5.1 in Chapter 10. Alternatively, conical sections and ends may be butt welded to cylinders without a knuckle radius when the change in angle of slope,  $\psi$ , between the two sections under consideration does not exceed  $30^\circ$ .

6.1.3 Conical ends may be constructed of several ring sections of decreasing thickness as determined by the corresponding decreasing diameter.

#### 6.2 Minimum thickness

6.2.1 The minimum thickness,  $t$ , of the cylinder, knuckle and conical section at the junction and within the distance  $L$  from the junction is to be determined by the following formula:

$$t = \frac{p D_o K}{20 \sigma J} + 0,75 \text{ mm}$$

where

$t, p, \sigma$  and  $J$  are as defined in 1.2

$D_o =$  outside diameter, in mm of the conical section or end, see Fig. 10.5.1 in Chapter 10

$K =$  a factor, taking into account the stress in the knuckle, see Table 10.5.1 in Chapter 10.

6.2.2 If the distance of a circumferential seam from the knuckle or junction is not less than  $L$ , then  $J$  is to be taken as 1,0; otherwise  $J$  is to be taken as the weld joint factor appropriate to the circumferential seam, where

$r_i =$  inside radius of transition knuckle, in mm, which is to be taken as  $0,01 D_o$  in the case of conical sections without knuckle transition

$L =$  distance, in mm, from knuckle or junction within which meridional stresses determine the required thickness, see Fig. 10.5.1 in Chapter 10

$$= 0,5 \sqrt{\frac{D_o t}{\cos \psi}}$$

$\psi =$  difference between angle of slope of two adjoining conical sections, see Fig. 10.5.1 in Chapter 10.

6.2.3 The minimum thickness,  $t$ , of those parts of conical sections not less than a distance  $L$  from the junction with a cylinder or other conical section, is to be determined by the following formula:

$$t = \frac{p D_c}{20 \sigma J - p} \frac{1}{\cos \alpha} + 0,75 \text{ mm}$$

where

$D_c =$  inside diameter, in mm, of conical section or end at the position under consideration, see Fig. 10.5.1 in Chapter 10

$\alpha, \alpha_1, \alpha_2 =$  angle of slope of conical section (at the point under consideration) to the vessel axis, see Fig. 10.5.1 in Chapter 10.

6.2.4 The thickness of conical sections having an angle of inclination to the vessel axis of more than  $75^\circ$  is to be determined as for a flat plate.

## Section 7 Standpipes and branches

### 7.1 Minimum thickness

7.1.1 The minimum wall thickness,  $t$ , of standpipes and branches is to be not less than the greater of the two values determined by the following formulae, making such additions as may be necessary on account of bending, static loads and vibrations:

$$t = \frac{p D_o}{20\sigma + p} + 0,75 \text{ mm, or}$$

$$t = 0,015D_o + 3,2 \text{ mm}$$

where

$t$ ,  $p$ ,  $D_o$  and  $\sigma$  are defined in 1.2.

If the second formula applies, the thickness need only be maintained for a length,  $L$ , from the outside surface of the vessel, but need not extend past the first connection, butt weld or flange, where:

$$L = 3,5 \sqrt{D_o t} \text{ mm}$$

7.1.2 In no case need the wall thickness exceed the minimum shell thickness as required by 2.1, 3.1 or 4.1 as applicable.

## Section 8 Construction

### 8.1 Access arrangements

8.1.1 Pressure vessels are to be so made that the internal surfaces may be examined. Wherever practicable, the openings for this purpose are to be sufficiently large for access and for cleaning the inner surfaces.

8.1.2 Manholes in cylindrical shells should preferably have their shorter axes arranged longitudinally.

8.1.3 Doors for manholes and sightholes are to be formed from steel plate or of other approved construction, and all jointing surfaces are to be machined.

8.1.4 Doors of the internal type are to be provided with spigots which have a clearance of not more than 1,5 mm all round, i.e. the axes of the opening are not to exceed those of the door by more than 3 mm. The width of the manhole gasket seat is not to be less than 16 mm.

8.1.5 Doors of the internal type for openings not larger than 230 x 180 mm need be fitted with only one stud, which may be forged integral with the door. Doors for openings larger than 230 mm x 180 mm are to be fitted with two studs or bolts. The strength of the attachment to the door is not to be less than the strength of the stud or bolt.

8.1.6 The crossbars or dogs for doors are to be of steel.

8.1.7 External circular flat cover plates are to be in accordance with a Recognised Standard.

### 8.2 Torispherical and semi-ellipsoidal ends

8.2.1 For typical acceptance types of attachment for dished ends to cylindrical shells, see Fig. 11.8.1. Types (d) and (e) are to be made a tight fit in the cylindrical shell.

8.2.2 Where the difference in thickness is the same throughout the circumference, the thicker plate is to be reduced in thickness by machining to a taper for a distance not less than four times the offset, so that the two plates are of equal thickness at the position of the circumferential weld. A parallel portion may be provided between the end of the taper and the weld edge preparation; alternatively, if so desired, the width of the weld may be included as part of the smooth taper of the thicker plate.

8.2.3 The thickness of the plates at the position of the circumferential weld is to be not less than that of an unpierced cylindrical shell of seamless or welded construction, whichever is applicable, of the same diameter and material, see 2.1.

## Cross-references

For hemispherical ends, see Ch 10,14.3.

For openings in flat ends, see Ch 10,8.4.

For unstayed circular flat end plates, see Ch 10,8.4.

For welded-on flanges, butt joints and fabricated branch pieces, see Ch 10,14.4.

For welded attachments to pressure vessels, see Ch 10,14.5.

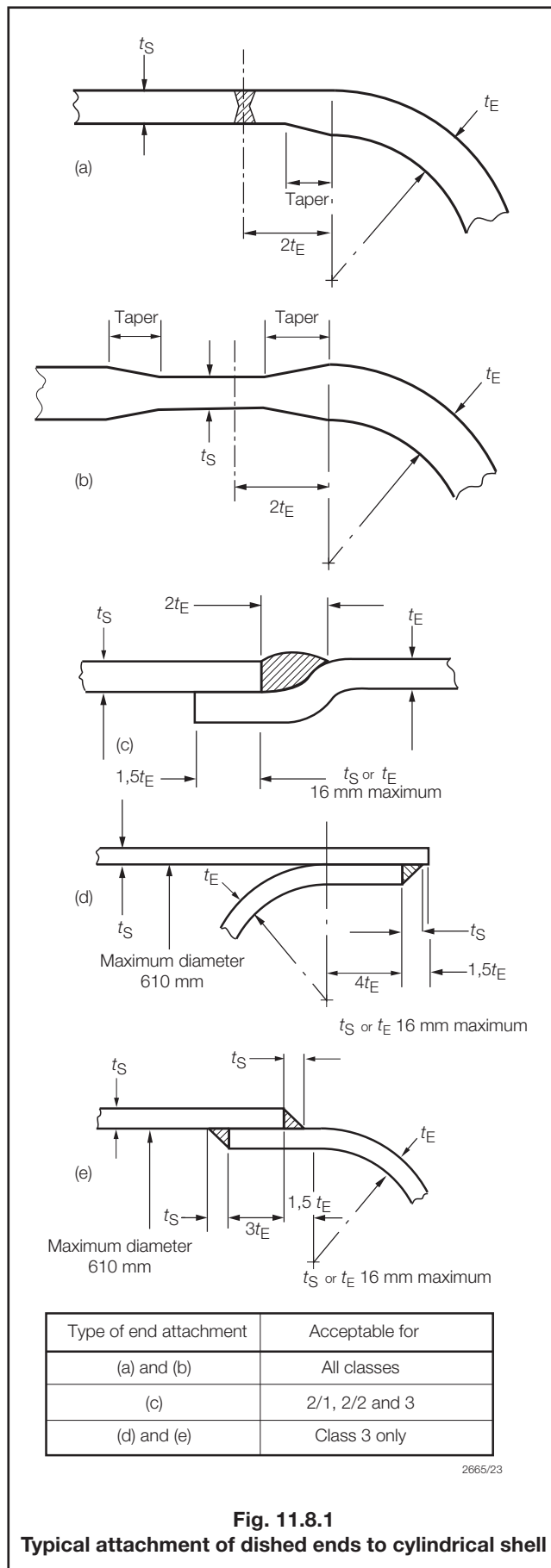


Fig. 11.8.1

Typical attachment of dished ends to cylindrical shell

## Section 9

### Mountings and fittings

#### 9.1 General

9.1.1 Each pressure vessel or system is to be fitted with a stop valve situated as close as possible to the shell.

9.1.2 Adequate arrangements are to be provided to prevent over-pressure of any part of a pressure vessel which can be isolated. Pressure gauges are to be fitted in positions where they can be easily read.

9.1.3 Adequate arrangements are to be provided for draining and venting the separate parts of each pressure vessel.

#### 9.2 Receivers containing pressurised gases

9.2.1 Each air receiver is to be fitted with a drain arrangement at its lowest part, permitting oil and water to be blown out.

9.2.2 Each receiver which can be isolated from a relief valve is to be provided with a suitable fusible plug to discharge the contents in case of fire. The melting point of the fusible plug is to be approximately 150°C, see also 9.2.3 and 9.2.4.

9.2.3 Where a fixed system utilising fire-extinguishing gas is fitted, to protect a machinery space containing an air receiver(s), fitted with a fusible plug, it is recommended that the discharge from the fusible plug be piped to the open deck.

9.2.4 Receivers used for the storage of air for the control of remotely operated valves are to be fitted with relief valves and not fusible plugs.

## Cross-references

For starting air pipe systems and safety fittings, see Ch 2.8.  
For mountings for liquefied gas vessels, see the Rules for Ships for Liquefied Gases.

# Other Pressure Vessels

# Part 5, Chapter 11

Sections 10 & 11

## ■ Section 10 Hydraulic tests

### 10.1 General

10.1.1 Pressure vessels covered by this Chapter are to be tested on completion to a pressure,  $p_T$ , determined by the following formula, without showing signs of weakness or defect:

$$p_T = 1,3 \frac{\sigma_{50}}{\sigma_T} \frac{t}{(t - 0,75)} p$$

but in no case is to exceed

$$= 1,5 \frac{t}{(t - 0,75)} p$$

where

- $p$  = design pressure, in bar
- $p_T$  = test pressure, in bar
- $t$  = nominal thickness of shell as indicated on the plan, in mm
- $\sigma_T$  = allowable stress at design temperature, in N/mm<sup>2</sup>
- $\sigma_{50}$  = allowable stress at 50°C, in N/mm<sup>2</sup>.

### 10.2 Mountings

10.2.1 Mountings are to be subjected to a hydraulic test of twice the approved design pressure.

## ■ Section 11 Plate heat exchangers

### 11.1 General

11.1.1 Plate heat exchangers are to be classed as follows. Class 2 where either of the following conditions apply:

- (a) the maximum metal design temperature is 150°C or greater, or
  - (b) design pressure is 17,2 bar or greater.
- Class 3 in all other cases.

11.1.2 Where the design temperature is equal to or lower than minus 10°C, a higher class is to apply.

# Piping Design Requirements

# Part 5, Chapter 12

Section 1

## Section

1	<b>General</b>
2	<b>Carbon and low alloy steels</b>
3	<b>Copper and copper alloys</b>
4	<b>Cast iron</b>
5	<b>Plastics pipes</b>
6	<b>Valves</b>
7	<b>Flexible hoses</b>
8	<b>Hydraulic tests on pipes and fittings</b>
9	<b>Piping for LPG/LNG carriers, gas fuelled ships and classed refrigeration systems</b>
10	<b>Austenitic stainless steels</b>
<b>Appendix</b>	
11	<b>Guidance notes on metal pipes for water services</b>

## Section 1 General

### 1.1 Application

1.1.1 The requirements of this Chapter apply to the design and construction of piping systems, including pipe fittings forming parts of such systems.

1.1.2 The materials used for pipes, valves and fittings are to be suitable for the medium and the service for which the piping is intended.

1.1.3 The piping systems for LPG and LNG carriers, gas fuelled ships and classed refrigeration systems are to comply with the relevant Sections of this Chapter where applicable and the additional requirements in Section 9 as well as the requirements contained in the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk* (hereinafter referred to as the Rules for Ships for Liquefied Gases).

### 1.2 Design symbols

1.2.1 The symbols used in this Chapter are defined as follows:

- $a$  = percentage negative manufacturing tolerance on thickness
- $c$  = corrosion allowance, in mm
- $d$  = inside diameter of pipe, in mm, see 1.2.3
- $e$  = weld efficiency factor, see 1.2.4
- $p$  = design pressure, in bar (kgf/cm<sup>2</sup>), see 1.3
- $p_t$  = hydraulic test pressure, in bar (kgf/cm<sup>2</sup>)

- $t$  = the minimum thickness of a straight pipe, in mm, including corrosion allowance and negative tolerance, where applicable
- $t_b$  = the minimum thickness of a straight pipe to be used for a pipe bend, in mm, including bending allowance, corrosion allowance and negative tolerance, where applicable
- $D$  = outside diameter of pipe, in mm, see 1.2.2
- $R$  = radius of curvature of a pipe bend at the centreline of the pipe, in mm
- $T$  = design temperature, in °C, see 1.4
- $\sigma$  = maximum permissible design stress, in N/mm<sup>2</sup> (kgf/cm<sup>2</sup>).

1.2.2 The outside diameter,  $D$ , is subject to manufacturing tolerances, but these are not to be used in the evaluation of formulae.

1.2.3 The inside diameter,  $d$ , is not to be confused with nominal size, which is an accepted designation associated with outside diameters of standard rolling sizes.

1.2.4 The weld efficiency factor,  $e$ , is to be taken as 1 for seamless and electric resistance and induction welded steel pipes. Where other methods of pipe manufacture are proposed, the value of  $e$  will be specially considered.

### 1.3 Design pressure

1.3.1 The design pressure,  $p$ , is the maximum permissible working pressure and is to be not less than the highest set pressure of the safety valve or relief valve.

1.3.2 In water tube boiler installations, the design pressure for steam piping between the boiler and integral superheater outlet is to be taken as the design pressure of the boiler, i.e., not less than the highest set pressure of any safety valve on the boiler drum. For piping leading from the superheater outlet, the design pressure is to be taken as the highest set pressure of the superheater safety valves.

1.3.3 The design pressure of feed piping and other piping on the discharge from pumps is to be taken as the pump pressure at full rated speed against a shut valve. Where a safety valve or other protective device is fitted to restrict the pressure to a lower value than the shut valve load, the design pressure is to be the highest set pressure of the device.

1.3.4 For design pressure of steering gear components and piping, see Ch 19,3.1.5.

### 1.4 Design temperature

1.4.1 The design temperature is to be taken as the maximum temperature of the internal fluid, but in no case is it to be less than 50°C.

# Piping Design Requirements

## Part 5, Chapter 12

Section 1

1.4.2 In the case of pipes for superheated steam, the temperature is to be taken as the designed operating steam temperature for the pipeline, provided that the temperature at the superheater outlet is closely controlled. Where temperature fluctuations exceeding 15°C above the designed temperature are to be expected in normal service, the steam temperature to be used for determining the allowable stress is to be increased by the amount of this excess.

### 1.5 Classes of pipes

1.5.1 Pressure piping systems are divided into three classes for the purpose of assigning appropriate testing requirements, types of joints to be adopted, heat treatment and weld procedure.

1.5.2 Dependent on the service for which they are intended, Class II and III pipes are not to be used for design pressure or temperature conditions in excess of those shown in Table 12.1.1. Where either the maximum design pressure or temperature exceeds that applicable to Class II pipes, Class I pipes are to be used. To illustrate this, see Fig. 12.1.1.

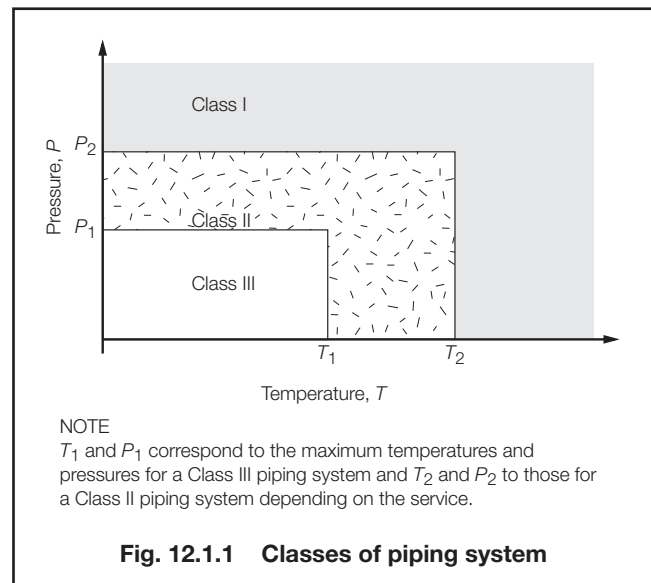
**Table 12.1.1 Maximum pressure and temperature conditions for Class II and III piping systems**

Piping system	Class II		Class III	
	p	T	p	T
	bar	°C	bar	°C
Steam	16,0	300	7,0	170
Thermal oil	16,0	300	7,0	150
Flammable Liquids, see Note 1	16,0	150	7,0	60
Other media	40,0	300	16,0	200
Cargo oil	40,0	300	16,0	200
NOTES 1. Flammable liquids include: oil fuel, lubricating oil and flammable hydraulic oil. 2. For grey cast iron, see also 4.2.2.				

1.5.3 In addition to the pressure piping systems in Table 12.1.1, Class III pipes may be used for open ended piping, e.g., overflows, vents, boiler waste steam pipes, open ended drains, etc.

### 1.6 Materials

1.6.1 Materials for ferrous castings and forgings of Class I and Class II piping systems are to be produced at a works approved by Lloyd's Register (hereinafter referred to as 'LR') and are in general to be tested in accordance with the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).



1.6.2 The manufacturer's certificate for materials for pipes, valves and fittings of Class I and Class II piping systems will be accepted in lieu of LR's materials certificate where the maximum conditions are less than either of the values shown in Table 12.1.2. See Ch 1,3.1.3(c) of the Rules for Materials.

**Table 12.1.2 Maximum conditions for pipes, valves and fittings for which manufacturer's materials test certificate is acceptable**

Material	Working temperature °C	$DN$ = nominal diameter, mm $p_w$ = working pressure, bar
Carbon and low alloy steel Austenitic stainless steel Spheroidal or nodular cast iron	< 300	$DN < 50$ or $p_w \times DN < 2500$
Copper alloy	< 200	$DN < 50$ or $p_w \times DN < 1500$

1.6.3 The manufacturer's certificate validated by LR for materials for ship-side valves and fittings and valves on the collision bulkhead equal to or less than 500 mm nominal diameter will be accepted in lieu of LR's materials certificate where the valves and fittings are in accordance with a recognised National Standard applicable to the intended application and are manufactured and tested in accordance with the appropriate requirements of the Rules for Materials. See Ch 1,3.1.3(b) of the Rules for Materials.



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#### Carbon and low alloy steels

#### 2.1 Carbon and low alloy steel pipes, valves and fittings

2.1.1 Materials for Class I and Class II piping systems, also for ship-side valves and fittings and valves on the collision bulkhead, are to be manufactured and tested in accordance with the appropriate requirements of the Rules for Materials, see also 1.6.

2.1.2 Materials for Class III piping systems are to be manufactured and tested in accordance with the requirements of acceptable national specifications. Pipes having forge butt welded longitudinal seams are not to be used for oil fuel systems, for heating coils in oil tanks, or for pressures exceeding 4,0 bar (4,1 kgf/cm<sup>2</sup>). The manufacturer's certificate will be acceptable and is to be provided for each consignment of material. See Ch 1,3.1.3(c) of the Rules for Materials.

2.1.3 Steel pipes, valves and fittings may be used within the temperature limits indicated in Tables 12.2.1 and 12.2.2. Where rimming steel is used for pipes manufactured by electric resistance or induction welding processes, the design temperature is limited to 400°C, see Ch 6,3 of the Rules for Materials.

#### 2.2 Wrought steel pipes and bends

2.2.1 The maximum permissible design stress,  $\sigma$ , is to be taken as the lowest of the following values:

$$\sigma = \frac{E_t}{1,6} \quad \sigma = \frac{R_{20}}{2,7} \quad \sigma = \frac{S_R}{1,6}$$

where

$E_t$  = specified minimum lower yield or 0,2 per cent proof stress at the design temperature; in the case of stainless steel, the 1,0 per cent proof stress at design temperature is to be used

$R_{20}$  = specified minimum tensile strength at ambient temperature

$S_R$  = average stress to produce rupture in 100 000 hours at the design temperature

Values of the maximum permissible design stress,  $\sigma$ , obtained from the properties of the steels specified in Chapter 6 of the Rules for Materials are shown in Tables 12.2.1 and 12.2.2. For intermediate values of specified minimum strengths and temperatures, values of the permissible design stress may be obtained by interpolation.

2.2.2 Where it is proposed to use, for high temperature service, alloy steels other than those detailed in Table 12.2.2 particulars of the tube sizes, design conditions and appropriate national or proprietary material specifications are to be submitted for consideration.

2.2.3 The minimum thickness,  $t$ , of straight steel pipes is to be determined by the following formula:

$$t = \left( \frac{pD}{20\sigma e + p} + c \right) \frac{100}{100 - a} \text{ mm}$$

$$\left( t = \left( \frac{pD}{2\sigma e + p} + c \right) \frac{100}{100 - a} \text{ mm} \right)$$

where

$p$ ,  $D$ ,  $e$  and  $a$  are as defined in 1.2.1

$c$  is obtained from Table 12.2.3

$\sigma$  is defined in 2.2.1 and obtained from Table 12.2.1 or Table 12.2.2

For pipes passing through tanks, an additional corrosion allowance is to be added to take account of external corrosion; the addition will depend on the external medium and the value is to be in accordance with Table 12.2.3. Where the pipes are efficiently protected, the corrosion allowance may be reduced by not more than 50 per cent.

**Table 12.2.1 Carbon and carbon-manganese steel pipes**

Specified minimum tensile strength, N/mm <sup>2</sup> (kgf/mm <sup>2</sup> )	Maximum permissible stress, N/mm <sup>2</sup> (kgf/cm <sup>2</sup> )												
	Maximum design temperature, °C												
	50	100	150	200	250	300	350	400	410	420	430	440	450
320 (33)	107 (1091)	105 (1070)	99 (1010)	92 (938)	78 (795)	62 (632)	57 (581)	55 (561)	55 (561)	54 (551)	54 (551)	54 (551)	49 (500)
360 (37)	120 (1224)	117 (1193)	110 (1122)	103 (1050)	91 (928)	76 (775)	69 (704)	68 (693)	68 (693)	68 (693)	64 (653)	56 (571)	49 (500)
410 (42)	136 (1387)	131 (1336)	124 (1264)	117 (1193)	106 (1081)	93 (948)	86 (877)	84 (857)	79 (806)	71 (724)	64 (653)	56 (571)	49 (500)
460 (47)	151 (1540)	146 (1489)	139 (1417)	132 (1346)	122 (1244)	111 (1132)	101 (1030)	99 (1010)	98 (999)	85 (876)	73 (744)	62 (632)	53 (540)
490 (50)	160 (1632)	156 (1591)	148 (1509)	141 (1438)	131 (1336)	121 (1234)	111 (1132)	109 (1111)	98 (999)	85 (867)	73 (744)	62 (632)	53 (540)

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Table 12.2.2 Alloy steel pipes

Type of steel	Specified minimum tensile strength, N/mm <sup>2</sup> (kgf/mm <sup>2</sup> )	Maximum permissible stress, N/mm <sup>2</sup> (kgf/cm <sup>2</sup> )									
		Maximum design temperature, °C									
		50	100	200	300	350	400	440	450	460	470
1 Cr 1/2 Mo	440 (46)	159 (1621)	150 (1530)	137 (1397)	114 (1162)	106 (1081)	102 (1040)	101 (1030)	101 (1030)	100 (1020)	99 (1010)
2 1/4 Cr 1 Mo annealed	410 (42)	76 (775)	67 (683)	57 (581)	50 (510)	47 (479)	45 (459)	44 (449)	43 (438)	43 (438)	42 (428)
2 1/4 Cr 1 Mo normalised and tempered, see Note 1	490 (50)	167 (1703)	163 (1662)	153 (1550)	144 (1468)	140 (1428)	136 (1387)	130 (1326)	128 (1305)	127 (1295)	116 (1183)
2 1/4 Cr 1 Mo normalised and tempered, see Note 2	490 (50)	167 (1703)	163 (1662)	153 (1560)	144 (1468)	140 (1428)	136 (1387)	130 (1326)	122 (1244)	114 (1162)	105 (1071)
1/2 Cr 1/2 Mo 1/4 V	460 (47)	166 (1693)	162 (1652)	147 (1499)	120 (1224)	115 (1173)	111 (1132)	106 (1081)	105 (1071)	103 (1050)	102 (1040)
		Maximum design temperature, °C									
		480	490	500	510	520	530	540	550	560	570
1 Cr 1/2 Mo	440 (46)	98 (999)	97 (989)	91 (928)	76 (775)	62 (632)	51 (520)	42 (428)	34 (347)	27 (275)	22 (224)
2 1/4 Cr 1 Mo annealed	410 (42)	42 (428)	42 (428)	41 (418)	41 (418)	41 (418)	40 (408)	40 (408)	40 (408)	37 (377)	32 (326)
2 1/4 Cr 1 Mo normalised and tempered, see Note 1	490 (50)	106 (1081)	96 (979)	86 (877)	76 (775)	67 (683)	58 (591)	49 (500)	43 (438)	37 (377)	32 (326)
2 1/4 Cr 1 Mo normalised and tempered, see Note 2	490 (50)	96 (979)	88 (897)	79 (806)	72 (734)	64 (653)	56 (571)	49 (500)	43 (438)	37 (377)	32 (326)
1/2 Cr 1/2 Mo 1/4 V	460 (47)	101 (1030)	99 (1010)	97 (989)	94 (959)	82 (836)	72 (734)	62 (632)	53 (540)	45 (459)	37 (377)

NOTES

- Maximum permissible stress values applicable when the tempering temperature does not exceed 750°C.
- Maximum permissible stress values applicable when the tempering temperature exceeds 750°C.

Table 12.2.3 Values of *c* for steel pipes

Piping service	<i>c</i> mm
Superheated steam systems	0,3
Saturated steam systems	0,8
Steam coil systems in cargo tanks	2,0
Feed water for boilers in open circuit systems	1,5
Feed water for boilers in closed circuit systems	0,5
Blow down (for boilers) systems	1,5
Compressed air systems	1,0
Hydraulic oil systems	0,3
Lubricating oil systems	0,3
Oil fuel systems	1,0
Cargo oil systems	2,0
Refrigerating plants	0,3
Fresh water systems	0,8
Sea-water systems in general	3,0

2.2.4 The minimum thickness,  $t_b$ , of a straight steel pipe to be used for a pipe bend is to be determined by the following formula, except where it can be demonstrated that the use of a thickness less than  $t_b$  would not reduce the thickness below  $t$  at any point after bending:

$$t_b = \left[ \left( \frac{pD}{20\sigma e + p} \right) \left( 1 + \frac{D}{2,5R} \right) + c \right] \frac{100}{100 - a} \text{ mm}$$

$$\left( t_b = \left[ \left( \frac{pD}{2\sigma e + p} \right) \left( 1 + \frac{D}{2,5R} \right) + c \right] \frac{100}{100 - a} \text{ mm} \right)$$

where

$p$ ,  $D$ ,  $R$ ,  $e$  and  $a$  are as defined in 1.2.1

$\sigma$  and  $c$  are as defined in 2.2.3. In general,  $R$  is to be not less than  $3D$ .

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2.2.5 Where the minimum thickness calculated by 2.2.3 or 2.2.4 is less than that shown in Table 12.2.4, the minimum nominal thickness for the appropriate standard pipe size shown in the Table is to be used. No allowance is required for negative tolerance, corrosion or reduction in thickness due to bending on this nominal thickness. For larger diameters, the minimum thickness will be considered. For threaded pipes, where permitted, the minimum thickness is to be measured at the bottom of the thread.

2.2.6 For sounding pipes, except those for cargo tanks with cargo having a flash point of less than 60°C, the minimum thickness is intended to apply to the part outside the tank.

2.2.7 For air, bilge, ballast, fuel, overflow, sounding and venting pipes as listed in Table 12.2.4, where the pipes are efficiently protected against corrosion, the thickness may be reduced by not more than 1 mm.

2.2.8 The internal diameter for bilge, venting and overflow pipes listed in Table 12.2.4 is to be not less than 50 mm. The internal diameter for sounding pipes is to be not less than 32 mm.

## 2.3 Pipe joints – General

2.3.1 Joints in pressure pipelines may be made by:

- Screwed-on or welded-on bolted flanges, see 2.5 and 2.6.

- Butt welds between pipes or between pipes and valve chests or other fittings, see 2.6.
- Socket weld joints, see 2.8.
- Welded sleeve joints, see 2.9.
- Threaded sleeve joints, see 2.10.
- Special types of approved joints that have been shown to be suitable for the design conditions. Details are to be submitted for consideration.

2.3.2 The dimensions and materials of flanges, gaskets and bolting, and the pressure – temperature rating of bolted flanges in pressure pipelines, are to be in accordance with National or other established Standards.

2.3.3 With the welded pressure piping systems referred to in 2.3.1 it is desirable that a few flanged joints be provided at suitable positions to facilitate installation, cold 'pull up' and inspection at Periodical Surveys.

2.3.4 Piping with joints is to be adequately adjusted, aligned and supported. Supports or hangers are not to be used to force alignment of piping at the point of connection.

2.3.5 Pipes passing through, or connected to, watertight decks are to be continuous or provided with an approved bolted or welded connection to the deck or bulkhead.

2.3.6 Consideration will be given to accepting joints in accordance with a recognised National Standard which is applicable to the intended service and media conveyed.

**Table 12.2.4 Minimum thickness for steel pipes**

External diameter, <i>D</i> , in mm	Pipes in general, in mm	Venting, overflow and sounding pipes for structural tanks, in mm	Bilge, ballast and general sea-water pipes, in mm	Bilge, air, overflow sounding pipes through ballast and fuel tanks, ballast lines through fuel tanks and fuel lines through ballast tanks, in mm	Air, overflow and sounding pipes for fuel oil tanks passing through cargo holds of bulk carriers, in mm
10,2–12	1,6	—	—	—	—
13,5–19	1,8	—	—	—	—
20	2,0	—	—	—	—
21,3–25	2,0	—	3,2	—	—
26,9–33,7	2,0	—	3,2	—	—
38–44,5	2,0	4,5	3,6	6,3	—
48,3	2,3	4,5	3,6	6,3	—
51–63,5	2,3	4,5	4,0	6,3	6,3
70	2,6	4,5	4,0	6,3	6,3
76,1–82,5	2,6	4,5	4,5	6,3	7,6
88,9–108	2,9	4,5	4,5	7,1	8,0
114,3–127	3,2	4,5	4,5	8,0	8,8
133–139,7	3,6	4,5	4,5	8,0	8,8
152,4–168,3	4,0	4,5	4,5	8,8	8,8
177,8	4,5	5,0	5,0	8,8	8,8
193,7	4,5	5,4	5,4	8,8	8,8
219,1	4,5	5,9	5,9	8,8	12,5
244,5–273	5,0	6,3	6,3	8,8	12,5
298,5–368	5,6	6,3	6,3	8,8	12,5
406,4–457,2	6,3	6,3	6,3	8,8	12,5

NOTE  
The pipe diameters and wall thicknesses given in the Table are based on common International Standards. Diameter and thickness according to other National or International Standards will be considered.

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### 2.4 Steel pipe flanges

2.4.1 Flanges may be cut from plates or may be forged or cast. The material is to be suitable for the design temperature. Flanges may be attached to the pipes by screwing and expanding or by welding. Alternative methods of flange attachment may be accepted provided details are submitted for consideration.

2.4.2 Flange attachments to pipes and pressure – temperature ratings in accordance with National or other approved Standards will be accepted.

### 2.5 Screwed-on flanges

2.5.1 Where flanges are secured by screwing, as indicated in Fig. 12.2.1, the pipe and flange are to be screwed with a vanishing thread and the diameter of the screwed portion of the pipe over the thread is not to be appreciably less than the outside diameter of the unscrewed pipe. After the flange has been screwed hard home the pipe is to be expanded into the flange.

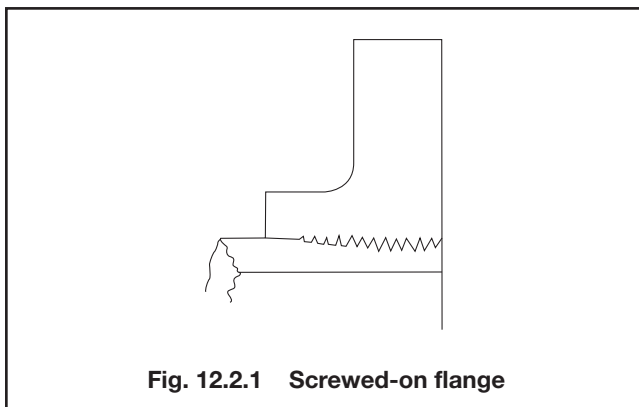


Fig. 12.2.1 Screwed-on flange

2.5.2 The vanishing thread on a pipe is to be not less than three pitches in length, and the diameter at the root of the thread is to increase uniformly from the standard root diameter to the diameter at the top of the thread. This may be produced by suitably grinding the dies, and the flange should be tapered out to the same formation.

2.5.3 Such screwed and expanded flanges may be used for steam for a maximum design pressure of 30,0 bar (30,5 kgf/cm<sup>2</sup>) and a maximum design temperature of 370°C and for feed for a maximum design pressure of 50 bar (51 kgf/cm<sup>2</sup>).

### 2.6 Welded-on flanges, butt welded joints and fabricated branch pieces

2.6.1 The types of welded-on flanges are to be suitable for the pressure, temperature and service for which the pipes are intended.

2.6.2 Typical examples of welded-on flange attachments are shown in Fig. 12.2.2, and limiting design conditions for flange types (a) to (f) are shown in Table 12.2.5.

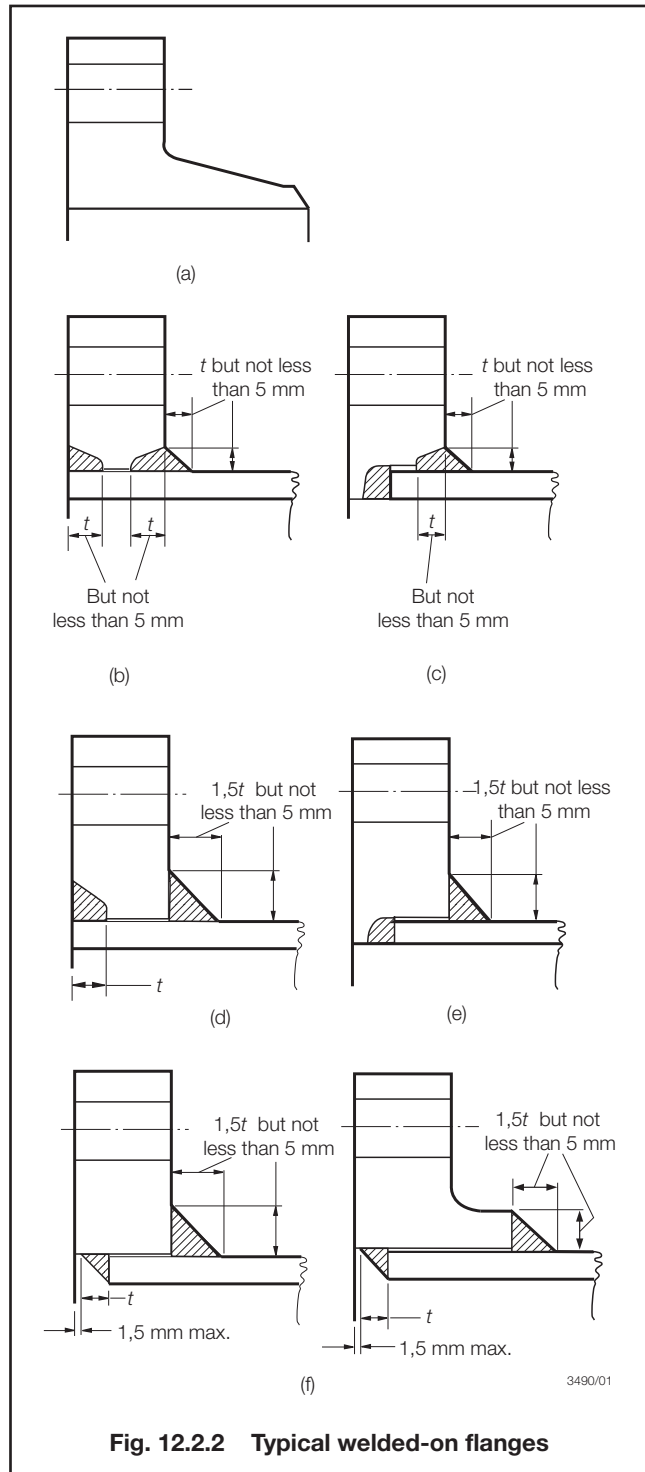


Fig. 12.2.2 Typical welded-on flanges

2.6.3 Butt welded joints are generally to be of the full penetration type and are to meet the requirements of Chapter 13 of the Rules for Materials.

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**Table 12.2.5 Limiting design conditions for flange types**

Flange type	Maximum pressure	Maximum temperature, in °C	Maximum pipe o.d., in mm	Minimum pipe bore, in mm
(a)	Pressure-temperature ratings to be in accordance with a Recognised Standard	No restriction	No restriction	No restriction
(b)		No restriction	168,3 for alloy steels*	No restriction
(c)		No restriction	168,3 for alloy steels*	75
(d)		425	No restriction	No restriction
(e)		425	No restriction	75
(f)		425	No restriction	No restriction
* No restriction for carbon steels				

2.6.4 Welded-on flanges are not to be a tight fit on the pipes. The maximum clearance between the bore of the flange and the outside diameter of the pipe is to be 3 mm at any point, and the sum of the clearances diametrically opposite is not to exceed 5 mm.

2.6.5 Where butt welds are employed in the attachment of flange type (a), in pipe-to-pipe joints or in the construction of branch pieces, the adjacent pieces are to be matched at the bores. This may be effected by drifting, roller expanding or machining, provided that the pipe wall is not reduced below the designed thickness. If the parts to be joined differ in wall thickness, the thicker wall is to be gradually tapered to the thickness of the thinner at the butt joint. The welding necks of valve chests are to be sufficiently long to ensure that the valves are not distorted as the result of welding and subsequent heat treatment of the joints.

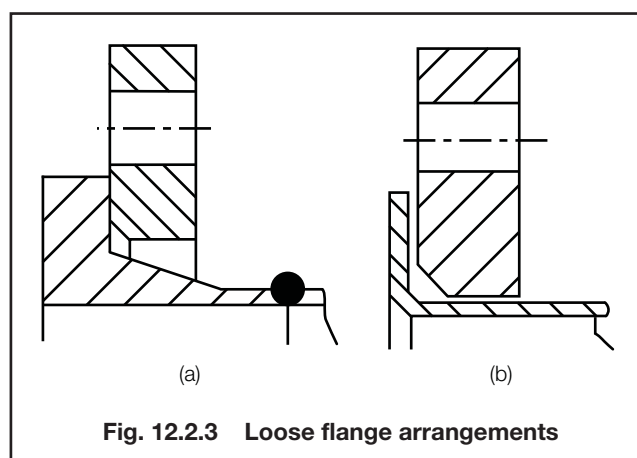
2.6.6 Where backing rings are used with flange type (a) they are to fit closely to the bore of the pipe and should be removed after welding. The rings are to be made of the same material as the pipes or of mild steel having a sulphur content not greater than 0,05 per cent.

2.6.7 Branches may be attached to pressure pipes by means of welding provided that the pipe is reinforced at the branch by a compensating plate or collar or other approved means, or, alternatively, that the thickness of pipe and branch is increased to maintain the strength of the pipe. These requirements also apply to fabricated branch pieces.

2.6.8 Welding may be carried out by means of the shielded metal arc, inert gas metal arc, oxy-acetylene or other approved process, but in general oxy-acetylene welding is suitable only for flange type (a) and is not to be applied to pipes exceeding 100 mm diameter or 9,5 mm thick. The welding is to be carried out in accordance with the appropriate paragraphs of Chapter 17.

### 2.7 Loose flanges

2.7.1 Loose flange designs as shown in Fig. 12.2.3 may be used provided they are in accordance with a recognised National or International Standard.

**Fig. 12.2.3 Loose flange arrangements**

2.7.2 Loose flange designs where the pipe end is flared as shown in Fig 12.2.3(b) are only to be used for water pipes and on open ended lines.

### 2.8 Socket weld joints

2.8.1 Socket weld joints may be used in Class III systems with carbon steel pipes of any outside diameter. Socket weld fittings are to be of forged steel and the material is to be compatible with the associated piping. In particular cases, socket welded joints may be permitted for piping systems of Class I and II having outside diameter not exceeding 88,9 mm. Such joints are not to be used where fatigue, severe erosion or crevice corrosion is expected to occur or where toxic media are conveyed. See also Ch 10, 14.4.9.

2.8.2 The thickness of the socket weld fittings is to meet the requirements of 2.2.3 but is to be not less than 1,25 times the nominal thickness of the pipe or tube. The diametrical clearance between the outside diameter of the pipe and the bore of the fitting is not to exceed 0,8 mm, and a gap of approximately 1,5 mm is to be provided between the end of the pipe and the bottom of the socket. See also Ch 13, 5.2.9 of the Rules for Materials.

2.8.3 The leg lengths of the fillet weld connecting the pipe to the socket weld fitting are to be such that the throat dimension of the weld is not less than the nominal thickness of the pipe or tube.

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### 2.9 Welded sleeve joints

2.9.1 Welded sleeve joints may be used in Class III systems with carbon steel pipes of any outside diameter. In particular cases, welded sleeve joints may be permitted for piping systems of Class I and II having outside diameter not exceeding 88,9 mm. Such joints are not to be used where fatigue, severe erosion or crevice corrosion is expected to occur or where toxic media are conveyed.

2.9.2 Welded sleeve joints are not to be used in the following locations:

- Bilge pipes in way of deep tanks.
- Cargo oil piping outside of the cargo area for bow or stern loading/discharge.
- Air and sounding pipes passing through cargo tanks.

2.9.3 Welded sleeve joints may be used in piping systems for the storage, distribution and utilisation of oil fuel, lubricating or other flammable oil systems in machinery spaces provided they are located in readily visible and accessible positions. See also Ch 14,2.9.2.

2.9.4 Welded sleeve joints are not to be used at deck/bulkhead penetrations that require continuous pipe lengths.

2.9.5 The thickness of the sleeve is to satisfy the requirements of 2.2.3 and Table 12.2.4 but is to be not less than 1,42 times the nominal thickness of the pipe in order to satisfy the throat thickness requirement in 2.9.6. The radial clearance between the outside diameter of the pipe and the internal diameter of the sleeve is not to exceed 1 mm for pipes up to a nominal diameter of 50 mm, 2 mm on diameters up to 200 mm nominal size and 3 mm for larger size pipes. The pipe ends are to be separated by a clearance of approximately 2 mm at the centre of the sleeve. Alternatively, consideration will be given to sleeve thickness in accordance with a relevant National Standard

2.9.6 The sleeve material is to be compatible with the associated piping and the leg lengths of the fillet weld connecting the pipe to the sleeve are to be such that the throat dimension of the weld is not less than the nominal thickness of the pipe or tube.

2.9.7 The minimum length of the sleeve is to conform to the following formula:

$$L_{si} = 0,14D + 36 \text{ mm}$$

where

$L_{si}$  is the length of the sleeve

$D$  is defined in 1.2.1.

### 2.10 Threaded sleeve joints

2.10.1 Threaded sleeve joints, in accordance with National or other established Standards, may be used with carbon steel pipes within the limits given in Table 12.2.6. Such joints are not to be used where fatigue, severe erosion or crevice corrosion is expected to occur or where flammable or toxic media is conveyed.

**Table 12.2.6 Limiting design conditions for threaded sleeve joints**

Thread type	Outside pipe diameter, in mm		
	Class I	Class II	Class III
Tapered thread	<33,7	<60,3	<60,3
Parallel thread	–	–	<60,3

### 2.11 Screwed fittings

2.11.1 Screwed fittings, including compression fittings, of an approved type may be used in piping systems for pipes not exceeding 51 mm outside diameter. Where the fittings are not in accordance with an acceptable standard then LR may require the fittings to be subjected to special tests to demonstrate their suitability for the intended service and working conditions.

### 2.12 Other mechanical couplings

2.12.1 Pipe unions, compression couplings, or slip-on joints, as shown in Fig. 12.2.4, may be used if Type Approved for the service conditions and the intended application. The Type Approval is to be based on the results of testing of the actual joints. The acceptable use for each service is indicated in Table 12.2.7 and dependence upon the Class of piping, with limiting pipe dimensions, is indicated in Table 12.2.8.

2.12.2 Where the application of mechanical joints results in a reduction in pipe wall thickness due to the use of bite type rings or other structural elements, this is to be taken into account in determining the minimum wall thickness of the pipe to withstand the design pressure.

2.12.3 Construction of mechanical joints is to prevent the possibility of tightness failure affected by pressure pulsation, piping vibration, temperature variation and other similar adverse effects occurring during operation on board.

2.12.4 Materials of mechanical joints are to be compatible with the piping material and internal and external media.

2.12.5 Mechanical joints for pressure pipes are to be tested to a burst pressure of 4 times the design pressure. For design pressures above 200 bar the required burst pressure will be specially considered.

2.12.6 In general, mechanical joints are to be of fire resistant type where required by Table 12.2.7.

2.12.7 Mechanical joints, which in the event of damage could cause fire or flooding, are not to be used in piping sections directly connected to the sea openings or tanks containing flammable fluids.

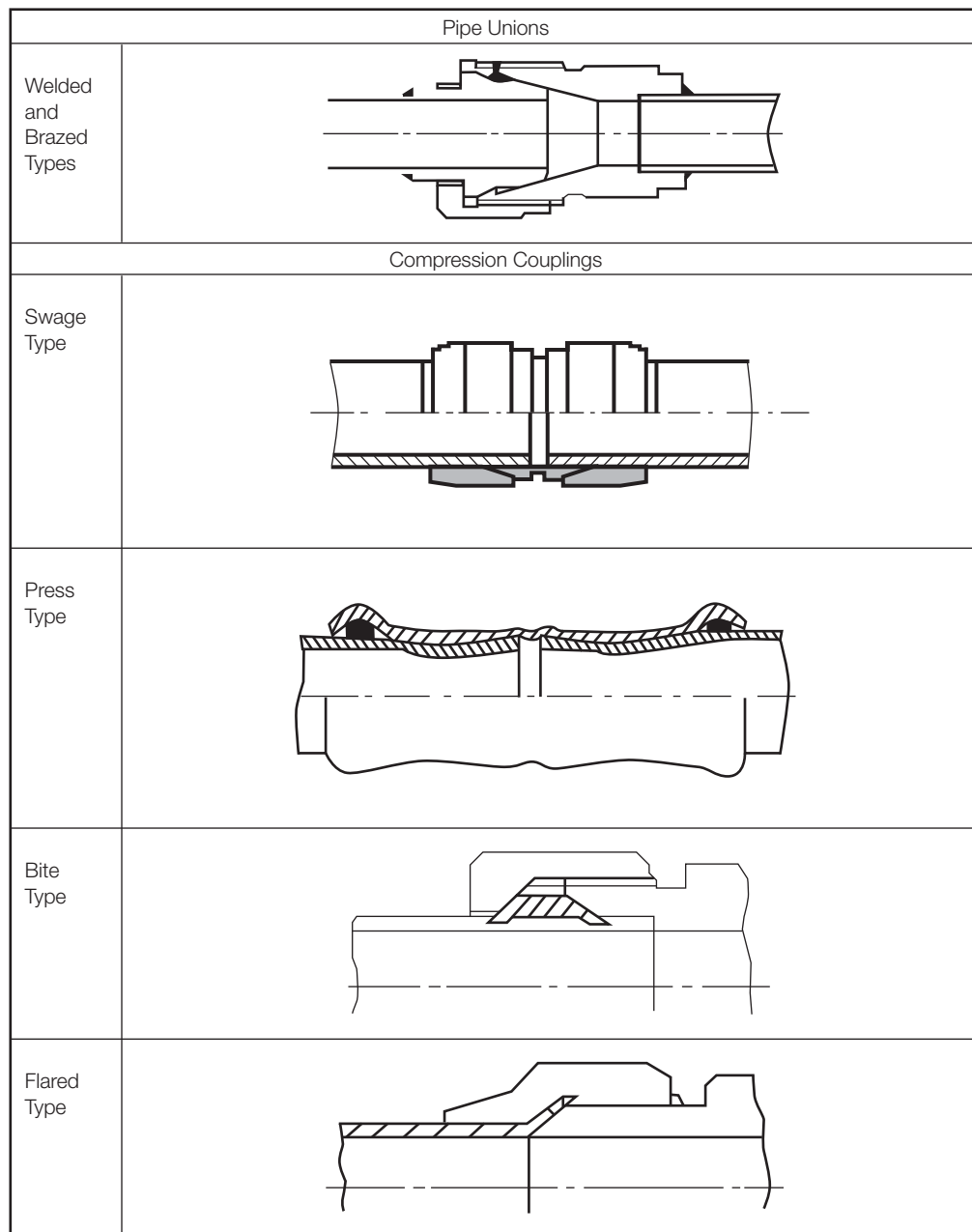
2.12.8 The mechanical joints are to be designed to withstand internal and external pressure as applicable and where used in suction lines are to be capable of operating under vacuum.



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**Fig. 12.2.4 Examples of mechanical joints** (see continuation)

2.12.9 Generally, slip-on joints are not to be used in pipelines in cargo holds, tanks, and other spaces which are not easily accessible. Application of these joints inside tanks may only be accepted where the medium conveyed is the same as that in the tanks.

2.12.10 Unrestrained slip-on joints are only to be used in cases where compensation of lateral pipe deformation is necessary. Usage of these joints as the main means of pipe connection is not permitted.

2.12.11 Restrained slip-on joints are permitted in steam pipes with a design pressure of 10 bar or less on the weather decks of oil and chemical tankers to accommodate axial pipe movement, see Ch 13,2.7.

2.12.12 Mechanical joints are to be tested in accordance with a program approved by LR, which is to include the following tests as relevant to the service conditions and the intended application:

- leakage test;
- vacuum test (where necessary);
- vibration (fatigue) test;
- fire endurance test (where necessary);
- burst pressure test;
- pressure pulsation test (where necessary);
- assembly test (where necessary);
- pull out test (where necessary);
- static displacement/misalignment test (where necessary).

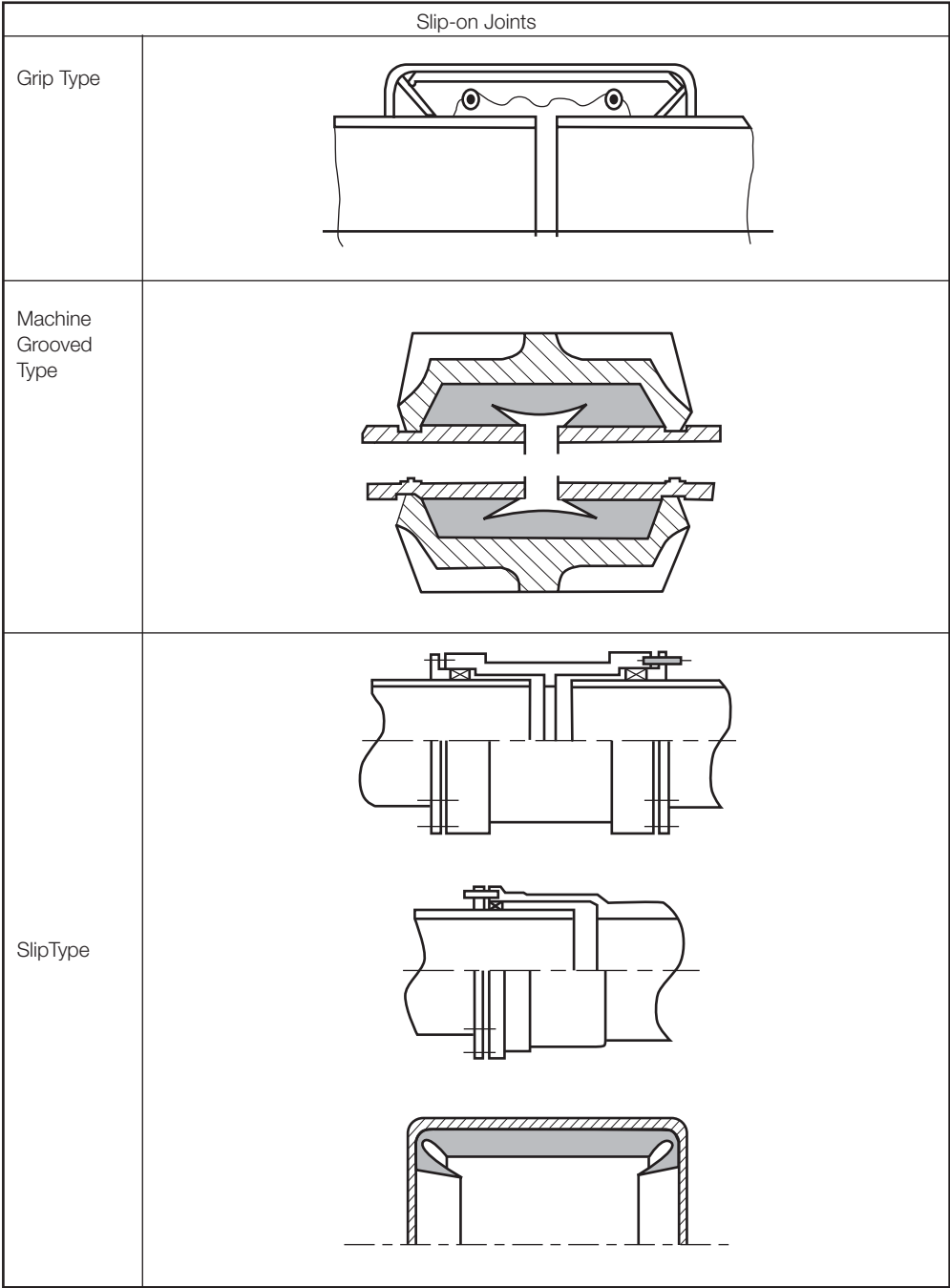


Fig. 12.2.4 Examples of mechanical joints (conclusion)

2.13 Non-destructive testing

2.13.1 For details of non-destructive tests on piping systems, other than hydraulic tests, see Chapter 13 of the Rules for Materials.

# Piping Design Requirements

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**Table 12.2.7 Application of mechanical joints**

Systems	Kind of connections		
	Pipe unions	Compression couplings (6)	Slip-on joints
<b>Flammable fluids (Flash point &lt;60°)</b>			
Cargo oil lines	+	+	+5
Crude oil washing lines	+	+	+5
Vent lines	+	+	+3
<b>Inert gas</b>			
Water seal effluent lines	+	+	+
Scrubber effluent lines	+	+	+
Main lines	+	+	+2,5
Distribution lines	+	+	+5
<b>Flammable fluids (Flash point &gt; 60°)</b>			
Cargo oil lines	+	+	+5
Fuel oil lines	+	+	+2,3
Lubricating oil lines	+	+	+2,3
Hydraulic oil	+	+	+2,3
Thermal oil	+	+	+2,3
<b>Sea-water</b>			
Bilge lines	+	+	+1
Fire main and water spray	+	+	+3
Foam system	+	+	+3
Sprinkler system	+	+	+3
Ballast system	+	+	+1
Cooling water system	+	+	+1
Tank cleaning services	+	+	+
Non-essential systems	+	+	+
<b>Fresh water</b>			
Cooling water system	+	+	+1
Condensate return	+	+	+1
Non-essential system	+	+	+
<b>Sanitary/Drains/Scuppers</b>			
Deck drains (internal)	+	+	+4
Sanitary drains	+	+	+
Scuppers and discharge (overboard)	+	+	—
<b>Sounding/vent</b>			
Water tanks/Dry spaces	+	+	+
Oil tanks (f.p.> 60°C)	+	+	+2,3
<b>Miscellaneous</b>			
Starting/Control air (1)	+	+	—
Service air (non-essential)	+	+	+
Brine	+	+	+
CO <sub>2</sub> system	+	+	—
Steam	+	+	+7
<b>KEY</b> + Application is allowed — Application is not allowed			
<b>NOTES</b> 1. Inside machinery spaces of Category A – only approved fire resistant types. 2. Not inside machinery spaces of Category A or accommodation spaces. May be accepted in other machinery spaces provided the joints are located in easily visible and accessible positions. 3. Approved fire resistant types. Fire resistant type is a type of connection which, when installed in the system and in the event of failure caused by fire, the failure would not result in fire spread, flooding or the loss of an essential service. 4. Above freeboard deck only. 5. In pump rooms and open decks – only approved fire resistant types. 6. If compression couplings include any components which are sensitive to heat, they are to be of approved fire resistant type as required for slip-on joints. 7. See 2.12.11.			

# Piping Design Requirements

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Sections 2 & 3

**Table 12.2.8 Application of mechanical joints depending on class of piping**

Types of joints	Classes of piping systems		
	Class I	Class II	Class III
<b>Pipe unions</b> Welded and brazed type	+(OD ≤ 60,3 mm)	+(OD ≤ 60,3 mm)	+
<b>Compression couplings</b> Swage type Bite type Flared type Press type	– +(OD ≤ 60,3 mm) +(OD ≤ 60,3 mm) –	– +(OD ≤ 60,3 mm) +(OD ≤ 60,3 mm) –	– + + + +
<b>Slip-on joints</b> Machine grooved type Grip type Slip type	– + – –	– + + +	– + + +
<b>KEY</b> + Application is allowed – Application is not allowed			

### Section 3 Copper and copper alloys

#### 3.1 Copper and copper alloy pipes, valves and fittings

3.1.1 Materials for Class I and Class II piping systems, also for ship-side valves and fittings and valves on the collision bulkhead, are to be manufactured and tested in accordance with the requirements of Chapter 9 of the Rules for Materials, see also 1.6.

3.1.2 Materials for Class III piping systems are to be manufactured and tested in accordance with the requirements of acceptable National Specifications. The manufacturer's certificate will be acceptable and is to be provided for each consignment of material. See Ch 1, 3.1.3(c) of the Rules for Materials.

3.1.3 Pipes are to be seamless, and branches are to be provided by cast or stamped fittings, pipe pressings or other approved fabrications.

3.1.4 Brazing and welding materials are to be suitable for the operating temperature and for the medium being carried. All brazing and welding are to be carried out to the satisfaction of the Surveyors.

3.1.5 In general, the maximum permissible service temperature of copper and copper alloy pipes, valves and fittings is not to exceed 200°C for copper and aluminium brass, and 300°C for copper-nickel. Cast bronze valves and fittings complying with the requirements of Chapter 9 of the Rules for Materials may be accepted up to 260°C.

3.1.6 The minimum thickness,  $t$ , of straight copper and copper alloy pipes is to be determined by the following formula:

$$t = \left( \frac{pD}{20\sigma + p} + c \right) \frac{100}{100 - a} \text{ mm}$$

$$\left( t = \left( \frac{pD}{2\sigma + p} + c \right) \frac{100}{100 - a} \text{ mm} \right)$$

where

$p$ ,  $D$  and  $a$  are as defined in 1.2.1

$c$  = corrosion allowance

= 0,8 mm for copper, aluminium brass, and copper-nickel alloys where the nickel content is less than 10 per cent

= 0,5 mm for copper-nickel alloys where the nickel content is 10 per cent or greater

= 0 where the media are non-corrosive relative to the pipe material

$\sigma$  = maximum permissible design stress, in N/mm<sup>2</sup> (kgf/cm<sup>2</sup>), from Table 12.3.1. Intermediate values of stresses may be obtained by linear interpolation.

3.1.7 The minimum thickness,  $t_b$ , of a straight seamless copper or copper alloy pipe to be used for a pipe bend is to be determined by the formula below, except where it can be demonstrated that the use of a thickness less than  $t_b$  would not reduce the thickness below  $t$  at any point after bending:

$$t_b = \left[ \left( \frac{pD}{20\sigma + p} \right) \left( 1 + \frac{D}{2,5R} \right) + c \right] \frac{100}{100 - a} \text{ mm}$$

$$\left( t_b = \left[ \left( \frac{pD}{2\sigma + p} \right) \left( 1 + \frac{D}{2,5R} \right) + c \right] \frac{100}{100 - a} \text{ mm} \right)$$

where

$p$ ,  $D$ ,  $R$  and  $a$  are as defined in 1.2.1

$\sigma$  and  $c$  are as defined in 3.1.6. In general,  $R$  is to be not less than  $3D$ .

# Piping Design Requirements

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**Table 12.3.1 Copper and copper alloy pipes**

Pipe material	Condition of supply	Specified minimum tensile strength, N/mm <sup>2</sup> (kgf/mm <sup>2</sup> )	Permissible stress, N/mm <sup>2</sup> (kgf/cm <sup>2</sup> )											
			Maximum design temperature, °C											
			50	75	100	125	150	175	200	225	250	275	300	
Copper	Annealed	220 (22)	41,2 (420)	41,2 (420)	40,2 (410)	40,2 (410)	34,3 (350)	27,5 (280)	18,6 (190)	–	–	–	–	
Aluminium brass	Annealed	320 (33)	78,5 (800)	78,5 (800)	78,5 (800)	78,5 (800)	78,5 (800)	51,0 (520)	24,5 (250)	–	–	–	–	
90/10 Copper-nickel-iron	Annealed	270 (28)	68,6 (700)	68,6 (700)	67,7 (690)	65,7 (670)	63,7 (650)	61,8 (630)	58,8 (600)	55,9 (570)	52,0 (530)	48,1 (490)	44,1 (450)	
70/30 Copper-nickel	Annealed	360 (37)	81,4 (830)	79,4 (810)	77,5 (790)	75,5 (770)	73,5 (750)	71,6 (730)	69,6 (710)	67,7 (690)	65,7 (670)	63,7 (650)	61,8 (630)	

3.1.8 Where the minimum thickness calculated by 3.1.6 or 3.1.7 is less than shown in Table 12.3.2, the minimum nominal thickness for the appropriate standard pipe size shown in the Table is to be used. No allowance is required for negative tolerance or reduction in thickness due to bending on this nominal thickness. For threaded pipes, where permitted, the minimum thickness is to be measured at the bottom of the thread.

**Table 12.3.2 Minimum thickness for copper and copper alloy pipes**

Standard pipe sizes (outside diameter), in mm			Minimum overriding nominal thickness, in mm	
			Copper	Copper alloy
8	to	10	1,0	0,8
12	to	20	1,2	1,0
25	to	44,5	1,5	1,2
50	to	76,1	2,0	1,5
88,9	to	108	2,5	2,0
133	to	159	3,0	2,5
193,7	to	267	3,5	3,0
273	to	457,2	4,0	3,5
		508	4,5	4,0

### 3.2 Heat treatment

3.2.1 Pipes which have been hardened by cold bending are to be suitably heat treated on completion of fabrication and prior to being tested by hydraulic pressure. Copper pipes are to be annealed and copper alloy pipes are to be either annealed or stress relief heat treated.

4.1.2 Spheroidal or nodular graphite iron castings for pipes, valves and fittings in Class II and Class III piping systems are to be made in a grade having a specified minimum elongation not less than 12 per cent on a gauge length of  $5,65\sqrt{S_0}$ , where  $S_0$  is the actual cross-sectional area of the test piece.

4.1.3 Castings for Class II systems, also for ship-side valves and fittings and valves on the collision bulkhead, are to be manufactured and tested in accordance with the requirements of Chapter 7 of the Rules for Materials.

4.1.4 Castings for Class III systems are to comply with the requirements of acceptable national specifications. A manufacturer's certificate will be accepted and is to be provided for each consignment of material for Class III systems, see also 1.6 and Ch 1,3.1.3(c) of the Rules for Materials.

4.1.5 Proposals for the use of this material in Class I piping systems will be specially considered, but in no case is the material to be used in systems where the design temperature exceeds 350°C.

4.1.6 Where the elongation is less than the minimum required by 4.1.2, the material is, in general, to be subject to the same limitations as grey cast iron.

### 4.2 Grey cast iron

4.2.1 Grey cast iron pipes, valves and fittings will, in general, be accepted in Class III piping systems except as stated in 4.2.3.

4.2.2 Grey cast iron is not to be used for pipes, valves and other fittings handling media having temperatures above 220°C or for piping subject to pressure shock, excessive strains or vibrations.

## Section 4 Cast iron

### 4.1 Spheroidal or nodular graphite cast iron

4.1.1 Spheroidal or nodular graphite iron may be accepted for bilge, ballast and cargo oil piping.

# Piping Design Requirements

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Sections 4 & 5

4.2.3 Grey cast iron is not to be used for the following:

- Pipes for steam systems and fire extinguishing systems.
- Pipes, valves and fittings for boiler blow-down systems and other piping systems subject to shock or vibration.
- Ship-side valves and fittings, see Ch 13,2.5.
- Valves fitted on the collision bulkhead, see Ch 13,3.5.
- Bilge lines in tanks.
- Pipes and fittings in flammable oil systems where the design pressure exceeds 7 bar or the design operating temperature is greater than 60°C.
- Valves fitted to tanks containing flammable oil under static pressure.
- Valve chests and fittings for starting air systems, see Ch 2,8.3.4.

4.2.4 Castings for Class III piping systems are to comply with acceptable National Specifications.

## Section 5 Plastics pipes

### 5.1 General

5.1.1 Proposals to use plastics pipes in shipboard piping systems will be considered in relation to the properties of the materials, the operating conditions, the intended service and location. Details are to be submitted for approval. Special consideration will be given to any proposed service for plastics pipes not mentioned in these Rules.

5.1.2 Attention is also to be given to the *Guidelines for the Application of Plastic Pipes on Ships* contained in IMO Resolution A.753(18).

5.1.3 Plastics pipes and fittings will, in general, be accepted in Class III piping systems. Proposals for the use of plastics in Class I and Class II piping systems will be specially considered.

5.1.4 For Class I, Class II and any Class III piping systems for which there are Rule requirements, the pipes are to be of a type which has been approved by LR.

5.1.5 For domestic and similar services where there are no Rule requirements, the pipes need not be of a type which has been approved by LR. However, the fire safety aspects as referenced in 5.4, are to be considered.

5.1.6 The use of plastics pipes may be restricted by statutory requirements of the National Authority of the country in which the ship is to be registered.

### 5.2 Design and performance criteria

5.2.1 Pipes and fittings are to be of robust construction and are to comply with a National or other established Standard, consistent with the intended use. Particulars of pipes, fittings and joints are to be submitted for consideration.

5.2.2 The design and performance criteria of all piping systems, independent of service or location, are to meet the requirements of 5.3.

5.2.3 Depending on the service and location, the fire safety aspects are to meet the requirements of 5.4.

5.2.4 Plastics piping, connections and fittings are to be electrically conductive when:

- carrying fluids capable of generating electrostatic charges.
- passing through hazardous zones and spaces, regardless of the fluid being conveyed.

Suitable precautions against the build up of electrostatic charges are to be provided in accordance with the requirements of 5.5, see also Pt 6, Ch 2,1.13.

### 5.3 Design strength

5.3.1 The strength of pipes is to be determined by hydrostatic pressure tests to failure on representative sizes of pipe. The strength of fittings is to be not less than the strength of the pipes.

5.3.2 The nominal internal pressure,  $pN_i$ , of the pipe is to be determined by the lesser of the following:

$$pN_i \leq \frac{p_{st}}{4}$$

$$pN_i \leq \frac{p_{lt}}{2,5}$$

where

$p_{st}$  = short term hydrostatic test failure pressure, in bar

$p_{lt}$  = long term hydrostatic test failure pressure (100 000 hours), in bar

Testing may be carried out over a reduced period of time using suitable Standards, such as ASTM D2837 and D1598.

5.3.3 The nominal external pressure,  $pN_e$ , of the pipe, defined as the maximum total of internal vacuum and external static pressure head to which the pipe may be subjected, is to be determined by the following:

$$pN_e \leq \frac{p_{col}}{3}$$

where

$p_{col}$  = pipe collapse pressure, in bar

The pipe collapse pressure is not to be less than 3 bar.

5.3.4 Piping is to meet these design requirements over the range of service temperature it will experience.

5.3.5 High temperature limits and pressure reductions relative to nominal pressures are to be according to a recognised standard, but in each case the maximum working temperature is to be at least 20°C lower than the minimum temperature of deflection under load of the resin or plastics material without reinforcement. The minimum heat distortion temperature is not to be less than 80°C, see also Ch 14,4 of the Rules for Materials.



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Section 5

**Table 12.5.1 Typical temperature and pressure limits for thermoplastic pipes**

Material	Nominal pressure, bar	Maximum permissible working pressure, bar						
		–20 to 0°C	30°C	40°C	50°C	60°C	70°C	80°C
PVC	10 16		7,5 12	6 9	6			
ABS	10 16	7,5 12	7,5 12	7 10,5	6 9	7,5	6	
HDPE	10 16	7,5 12	6 9,5	6				
Abbreviations PVC Polyvinyl chloride ABS Acrylonitrile – butadiene – styrene HDPE High density polyethylene								

**Table 12.5.2 Typical temperature and pressure limits for glassfibre reinforced epoxy (GRE) and polyester (GRP) pipes**

Minimum heat distortion temperature of resin	Nominal pressure, bar	Maximum permissible working pressure, bar							
		–50 to 30°C	40°C	50°C	60°C	70°C	80°C	90°C	95°C
80°C	10	10	9	7,5	6				
	16	16	14	12	9,5				
	25	16	16	16	15				
100°C	10	10	10	9,5	8,5	7	6		
	16	16	16	15	13,5	11	9,5		
	25	16	16	16	16	16	15		
135°C	10	10	10	10	10	9,5	8,5	7	6
	16	16	16	16	16	15	13,5	11	9,5
	25	16	16	16	16	16	16	16	15

5.3.6 Where it is proposed to use plastics piping in low temperature services, design strength testing is to be made at a temperature 10°C lower than the minimum working temperature.

5.3.7 For guidance, typical temperature and pressure limits are indicated in Tables 12.5.1 and 12.5.2. The Tables are related to water service only. Transport of chemicals or other media is to be considered on a case by case basis.

5.3.8 The selection of plastics materials for piping is to take account of other factors such as impact resistance, ageing, fatigue, erosion resistance, fluid absorption and material compatibility such that the design strength of the piping is not reduced below that required by these Rules.

5.3.9 Design strength values may be verified experimentally or by a combination of testing and calculation methods.

### 5.4 Fire performance criteria

5.4.1 Where plastics pipes are used in systems essential to the safe operation of the ship, or for containing combustible liquids or sea-water where leakage or failure could result in fire or in the flooding of watertight compartments, the pipes and fittings are to be of a type which have been fire endurance tested in accordance with the requirements of Table 12.5.3.

5.4.2 Where a fire protective coating of pipes and fittings is necessary for achieving the fire endurance standards required, the coating is to be resistant to products likely to come into contact with the piping and be suitable for the intended application.

### 5.5 Electrical conductivity

5.5.1 Where a piping system is required to be electrically conductive for the control of static electricity, the resistance per unit length of the pipe, bends, elbows, fabricated branch pieces, etc., is not to exceed 0,1 MΩ/m, see also 5.2.4.

5.5.2 Electrical continuity is to be maintained across the joints and fittings and the system is to be earthed, see also Pt 6, Ch 2, 1.13. The resistance to earth from any point in the piping system is not to exceed 1 MΩ.

### Table 12.5.3

	Location										
	A	B	C	D	E	F	G	H	I	J	K
Piping systems	Machinery spaces of Category A	Other machinery spaces and pump rooms	Cargo pump rooms	Ro-Ro cargo holds	Other dry cargo holds	Cargo tanks	Fuel oil tanks	Ballast water tanks	Cofferdams void spaces pipe tunnel and ducts	Accommodation service and control spaces	Open decks
CARGO (FLAMMABLE CARGOES f.p. ≤ 60°C)	N/A	N/A	L1	N/A	N/A	0	N/A	0 <sup>10</sup>	0	N/A	L1 <sup>2</sup>
	N/A	N/A	L1	N/A	N/A	0	N/A	0 <sup>10</sup>	0	N/A	L1 <sup>2</sup>
	N/A	N/A	N/A	N/A	N/A	0	N/A	0 <sup>10</sup>	0	N/A	X
INERT GAS											
4 Water seal effluent line	N/A	N/A	0 <sup>1</sup>	N/A	N/A	0 <sup>1</sup>	0 <sup>1</sup>	0 <sup>1</sup>	0 <sup>1</sup>	N/A	0
5 Scrubber effluent line	0 <sup>1</sup>	0 <sup>1</sup>	N/A	N/A	N/A	N/A	N/A	0 <sup>1</sup>	0 <sup>1</sup>	N/A	0
6 Main line	0	0	L1	N/A	N/A	N/A	N/A	N/A	0	N/A	L1 <sup>6</sup>
7 Distribution lines	N/A	N/A	L1	N/A	N/A	0	N/A	N/A	0	N/A	L1 <sup>2</sup>
FLAMMABLE LIQUIDS (f.p. > 60°C)											
8 Cargo lines	X	X	L1	X	X	N/A <sup>3</sup>	0	0 <sup>10</sup>	0	N/A	L1
9 Fuel oil	X	X	L1	X	X	N/A <sup>3</sup>	0	0	0	L1	L1
10 Lubricating oil	X	X	L1	X	X	N/A	N/A	N/A	0	L1	L1
11 Hydraulic oil	X	X	L1	X	X	0	0	0	0	L1	L1
SEA-WATER <sup>1</sup>											
12 Bilge main and branches	L1 <sup>7</sup>	L1 <sup>7</sup>	L1	X	X	N/A	0	0	0	N/A	L1
13 Fire main and water spray	L1	L1	L1	X	N/A	N/A	N/A	0	0	X	L1

# Piping Design Requirements

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Section 5

**Table 12.5.3 Fire endurance requirements** (continued)

	Location										
	A	B	C	D	E	F	G	H	I	J	K
Piping systems	Machinery spaces of Category A	Other machinery spaces and pump rooms	Cargo pump rooms	Ro-Ro cargo holds	Other dry cargo holds	Cargo tanks	Fuel oil tanks	Ballast water tanks	Cofferdams void spaces pipe tunnel and ducts	Accommodation service and control spaces	Open decks
14 Foam system	L1	L1	L1	N/A	N/A	N/A	N/A	N/A	0	L1	L1
15 Sprinkler system	L1	L1	L3	X	N/A	N/A	N/A	0	0	L3	L3
16 Ballast	L3	L3	L3	L3	X	0 <sup>10</sup>	0	0	0	L2	L2
17 Cooling water, essential services	L3	L3	N/A	N/A	N/A	N/A	N/A	0	0	N/A	L2
18 Tank cleaning services fixed machines	N/A	N/A	L3	N/A	N/A	0	N/A	0	0	N/A	L3 <sup>2</sup>
19 Non-essential systems	0	0	0	0	0	N/A	0	0	0	0	0
FRESH WATER											
20 Cooling water essential services	L3	L3	N/A	N/A	N/A	N/A	0	0	0	L3	L3
21 Condensate return	L3	L3	L3	0	0	N/A	N/A	N/A	0	0	0
22 Non-essential systems	0	0	0	0	0	N/A	0	0	0	0	0
SANITARY/DRAINS/SCUPPERS											
23 Deck drains (internal)	L1 <sup>4</sup>	L1 <sup>4</sup>	N/A	L1 <sup>4</sup>	0	N/A	0	0	0	0	0
24 Sanitary drains (internal)	0	0	N/A	0	0	N/A	0	0	0	0	0
25 Scuppers and discharges (overboard)	0 <sup>1,8</sup>	0 <sup>1,8</sup>	0 <sup>1,8</sup>	0 <sup>1,8</sup>	0 <sup>1,8</sup>	0	0	0	0	0 <sup>1,8</sup>	0
SOUNDING/AIR											
26 Water tanks/dry spaces	0	0	0	0	0	0 <sup>10</sup>	0	0	0	0	0 <sup>11</sup>

# Piping Design Requirements

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Section 5

**Table 12.5.3 Fire endurance requirements** (continued)

	Location										
	A	B	C	D	E	F	G	H	I	J	K
Piping systems	Machinery spaces of Category A	Other machinery spaces and pump rooms	Cargo pump rooms	Ro-Ro cargo holds	Other dry cargo holds	Cargo tanks	Fuel oil tanks	Ballast water tanks	Cofferdams void spaces pipe tunnel and ducts	Accommodation service and control spaces	Open decks
27 Oil tanks (f.p. > 60°C)	X	X	X	X	X	X <sup>3</sup>	0	0 <sup>10</sup>	0	X	X
MISCELLANEOUS											
28 Control air	L1 <sup>5</sup>	L1 <sup>5</sup>	L1 <sup>5</sup>	L1 <sup>5</sup>	L1 <sup>5</sup>	N/A	0	0	0	L1 <sup>5</sup>	L1 <sup>5</sup>
29 Service air (non-essential)	0	0	0	0	0	N/A	0	0	0	0	0
30 Brine	0	0	N/A	0	0	N/A	N/A	N/A	0	0	0
31 Auxiliary low pressure steam (≤ 7 bar)	L2	L2	0 <sup>9</sup>	0 <sup>9</sup>	0 <sup>9</sup>	0	0	0	0	0 <sup>9</sup>	0 <sup>9</sup>
LOCATION DEFINITIONS											
Location		Definition									
A	Machinery spaces of Category A	Machinery spaces of Category A as defined in SOLAS* regulation II-2/3.19.									
B	Other machinery spaces and pump rooms	Spaces, other than Category A machinery spaces and cargo pump rooms, containing propulsion machinery, boilers, steam and internal combustion engines, generators and major electrical machinery, pumps, oil filling stations, refrigerating, stabilising, ventilation and air-conditioning machinery, and similar spaces, and trunks to such spaces.									
C	Cargo pump rooms	Spaces containing cargo pumps and entrances and trunks to such spaces.									
D	Ro-Ro cargo holds	Ro-Ro cargo holds are Ro-Ro cargo spaces and special category spaces as defined in SOLAS* regulation II-2/3.14 and 3.18.									
E	Other dry cargo holds	All spaces other than Ro-Ro cargo holds used for non-liquid cargo and trunks to such spaces.									
F	Cargo tanks	All spaces used for liquid cargo and trunks to such spaces.									
G	Fuel oil tanks	All spaces used for oil fuel (excluding cargo tanks) and trunks to such spaces.									
H	Ballast water tanks	All spaces used for ballast water and trunks to such spaces.									
I	Cofferdams, voids, etc.	Cofferdams and voids are those empty spaces between two bulkheads separating two adjacent compartments.									
J	Accommodation, service	Accommodation spaces, service spaces and control stations as defined in SOLAS* regulation II-2/3.10, 3.12, 3.22.									
K	Open decks	Open deck spaces, as defined in SOLAS* regulation II-2/26.2.2(5).									
*	SOLAS 74 as amended by the 1978 SOLAS Protocol and the 1981 and 1983 amendments (consolidated text).										
ABBREVIATIONS											
L1	Fire endurance test in dry conditions, 60 minutes, IMO Resolution A.753(18) Appendix 1.										
L2	Fire endurance test in dry conditions, 30 minutes, IMO Resolution A.753(18) Appendix 1.										
L3	Fire endurance test in wet conditions, 30 minutes, IMO Resolution A.753(18) Appendix 2.										
0	No fire endurance test required.										
N/A	Not applicable.										
X	Metallic materials having a melting point greater than 925°C.										

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**Table 12.5.3** Fire endurance requirements (conclusion)

NOTES	
1.	Where non-metallic piping is used, remotely controlled valves to be provided at ship's side (valve is to be controlled from outside space).
2.	Remote closing valves to be provided at the cargo tanks.
3.	When cargo tanks contain flammable liquids with f.p. > 60°C, 'O' may replace 'N/A' or 'X'.
4.	For drains serving only the space concerned, 'O' may replace 'L1'.
5.	When controlling functions are not required by the Rules or statutory requirements, 'O' may replace 'L1'.
6.	For pipe between machinery space and deck water seal, 'O' may replace 'L1'.
7.	For passenger vessels, 'X' is to replace 'L1'.
8.	Scuppers serving open decks in positions 1 and 2, as defined in regulation 13 of the <i>International Convention on Load Lines, 1966</i> , should be 'X' throughout unless fitted at the upper end with the means of closing capable of being operated from a position above the freeboard deck in order to prevent downflooding.
9.	For essential services, such as oil fuel tank heating and ship's whistle, 'X' is to replace 'O'.
10.	For tankers where compliance with MAPOL Annex I, Regulation 19.3.6 is required, 'N/A' is to replace 'O'.
11.	Air and sounding pipes on open deck are to be of substantial construction, see Ch 13, 10.2.2.

## 5.6 Manufacture and quality control

5.6.1 All materials for plastics pipes and fittings are to be approved by LR, and are in general to be tested in accordance with Ch 14,4 of the Rules for Materials. For pipes and fittings not employing hand lay up techniques, the hydrostatic pressure test required by Ch 14,4.9 of the Rules for Materials may be replaced by testing carried out in accordance with the requirements stipulated in a National or International Standard, consistent with the intended use for which the pipe or fittings are manufactured, provided there is an effective quality system in place complying with the requirements of Ch 14,4.4 of the Rules for Materials and the testing is completed to the satisfaction of the LR Surveyor.

5.6.2 The material manufacturer's test certificate, based on actual tested data, is to be provided for each batch of material.

5.6.3 Plastics pipes and fittings are to be manufactured at a works approved by LR in accordance with agreed quality control procedures which shall be capable of detecting at any stage (e.g., incoming material, production, finished article, etc.) deviations in the material, product or process.

5.6.4 Plastics pipes are to be manufactured and tested in accordance with Ch 14,4 of the Rules for Materials. For Class III piping systems the pipe manufacturer's test certificate may be accepted in lieu of an LR Certificate and is to be provided for each consignment of pipe.

## 5.7 Installation and construction

5.7.1 All pipes are to be adequately but freely supported. Suitable provision is to be made for expansion and contraction to take place without unduly straining the pipes.

5.7.2 Pipes may be joined by mechanical couplings or by bonding methods such as welding and laminating.

5.7.3 Where bonding systems are used, the manufacturer or installer shall provide a written procedure covering all aspects of installation, including temperature and humidity conditions. The bonding procedure is to be approved by LR.

5.7.4 The person carrying out the bonding is to be qualified. Records are to be available to the Surveyor for each qualified person showing the bonding procedure and performance qualification, together with dates and results of the qualification testing.

5.7.5 In the case of pipes intended for essential services each qualified person is, at the place of construction, to make at least one test joint, representative of each type of joint to be used. The joined pipe section is to be tested to an internal hydrostatic pressure of four times the design pressure of the pipe system and the pressure held for not less than one hour, with no leakage or separation of joints. The bonding procedure test is to be witnessed by the Surveyor.

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5.7.6 Conditions during installation, such as temperature and humidity, which may affect the strength of the finished joints, are to be in accordance with the agreed bonding procedure.

5.7.7 The required fire endurance level of the pipe is to be maintained in way of pipe supports, joints and fittings, including those between plastics and metallic pipes.

5.7.8 Where piping systems are arranged to pass through watertight bulkheads or decks, provision is to be made for maintaining the integrity of the bulkhead or deck by means of metallic bulkhead, or deck, pieces. The bulkhead pieces are to be protected against corrosion, and so constructed to be of a strength equivalent to the intact bulkhead; attention is drawn to 5.7.1, see *also* Ch 13,2.4.1. Details of the arrangements are to be submitted for approval.

5.7.9 Where a piping system is required to be electrically conductive, for the control of static electricity, continuity is to be maintained across the joints and fittings, and the system is to be earthed, see *also* Pt 6, Ch 2,1.13.

### 5.8 Testing

5.8.1 The hydraulic testing of pipes and fittings is to be in accordance with Section 8.

5.8.2 Where a piping system is required to be electrically conductive, tests are to be carried out to verify that the resistance to earth from any point in the system does not exceed 1 MΩ, see *also* Pt 6, Ch 2,2.1.2.3.

## Section 6 Valves

### 6.1 Design requirements

6.1.1 The design, construction and operational capability of valves is to be in accordance with an acceptable National or International Standard appropriate to the piping system. Where valves are not in accordance with an acceptable standard, details are to be submitted for consideration. Where valves are fitted, the requirements of 6.1.2 to 6.1.8 are to be satisfied.

6.1.2 Valves are to be made of steel, cast iron, copper alloy, or other approved material suitable for the intended purpose.

6.1.3 Valves having isolation or sealing components sensitive to heat are not to be used in spaces where leakage or failure caused by fire could result in fire spread, flooding or the loss of an essential service.

6.1.4 Where valves are required to be capable of being closed remotely in the event of fire, the valves, including their control gear, are to be of steel construction or of an acceptable fire tested design.

6.1.5 Valves are to be arranged for clockwise closing and are to be provided with indicators showing whether they are open or shut unless this is readily obvious. Legible nameplates are to be fitted.

6.1.6 Valves are to be so constructed as to prevent the possibility of valve covers or glands being slackened back or loosened when the valves are operated.

6.1.7 Valves are to be used within their specified pressure and temperature rating for all normal operating conditions, and are to be suitable for the intended purpose.

6.1.8 Valves intended for submerged installation are to be suitable for both internal and external media. Spindle sealing is to prevent ingress of external media at the maximum external pressure head expected in service.

## Section 7 Flexible hoses

### 7.1 General

7.1.1 A flexible hose assembly is a short length of metallic or non-metallic hose normally with prefabricated end fittings ready for installation.

7.1.2 For the purpose of approval for the applications in 7.2, details of the materials and construction of the hoses, and the method of attaching the end fittings together with evidence of satisfactory prototype testing, are to be submitted for consideration.

7.1.3 The use of hose clamps and similar types of end attachments are not to be used for flexible hoses in piping systems for steam, flammable media, starting air systems or for sea-water systems where failure may result in flooding. In other piping systems, the use of hose clamps may be accepted where the working pressure is less than 5 bar and provided that there are two clamps at each end connection.

7.1.4 Flexible hoses are to be limited to a length necessary to provide for relative movement between fixed and flexibly mounted items of machinery/equipment or systems.

7.1.5 Flexible hoses are not to be used to compensate for misalignment between sections of piping.

7.1.6 Flexible hose assemblies are not to be installed where they may be subjected to torsional deformation (twisting) under normal operating conditions.

7.1.7 The number of flexible hoses in piping systems mentioned in this Section is to be kept to a minimum and to be limited for the purpose stated in 7.2.1.

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7.1.8 Where flexible hoses are intended for conveying flammable fluids in piping systems that are in close proximity to hot surfaces, electrical installation or other sources of ignition, the risk of ignition due to failure of the hose assembly and subsequent release of fluids is to be mitigated as far as practicable by the use of screens or other suitable protection.

7.1.9 Flexible hoses are to be installed in clearly visible and readily accessible locations.

7.1.10 The installation of flexible hose assemblies is to be in accordance with the manufacturer's instructions and use limitations with particular attention to the following:

- (a) Orientation.
- (b) End connection support (where necessary).
- (c) Avoidance of hose contact that could cause rubbing and abrasion.
- (d) Minimum bend radii.

7.1.11 Flexible hoses are to be permanently marked by the manufacturer with the following details:

- (a) Hose manufacturer's name or trademark.
- (b) Date of manufacture (month/year).
- (c) Designation type reference.
- (d) Nominal diameter.
- (e) Pressure rating
- (f) Temperature rating.

Where a flexible hose assembly is made up of items from different manufacturers, the components are to be clearly identified and traceable to evidence of prototype testing.

### 7.2 Applications

7.2.1 Short joining lengths of flexible hoses complying with the requirements of this Section may be used, where necessary, to accommodate relative movement between various items of machinery connected to permanent piping systems. The requirements of this Section may also be applied to temporarily-connected flexible hoses or hoses of portable equipment.

7.2.2 Rubber or plastics hoses, with integral cotton or similar braid reinforcement, may be used in fresh and sea-water cooling systems. In the case of sea-water systems, where failure of the hoses could give rise to the danger of flooding, the hoses are to be suitably enclosed, as indicated in Ch 13,2.7.

7.2.3 Rubber hoses, with single, double or more closely woven integral wire braid or other suitable material reinforcement, or convoluted metal pipes with wire braid protection, may be used in bilge, ballast, compressed air, fresh water, sea-water, oil fuel, lubricating oil, Class III steam, hydraulic and thermal oil systems. Flexible hoses of plastics materials for the same purposes, such as Teflon or Nylon, which are unable to be reinforced by incorporating closely woven integral wire braid are to have suitable material reinforcement as far as practicable. Where rubber or plastics hoses are used for oil fuel supply to burners, the hoses are to have external wire braid protection in addition to the integral wire braid. Flexible hoses for use in steam systems are to be of metallic construction.

7.2.4 Flexible hoses are not to be used in high pressure fuel oil injection systems.

7.2.5 The requirements in this Section for flexible hose assemblies are not applicable to hoses intended to be used in fixed fire-extinguishing systems.

### 7.3 Design requirements

7.3.1 Flexible hose assemblies are to be designed and constructed in accordance with recognised National or International Standards acceptable to LR.

7.3.2 Flexible hoses are to be complete with approved end fittings in accordance with manufacturer's specification. End connections which do not have flanges are to comply with 2.12 as applicable and each type of hose/fitting combination is to be subject to prototype testing to the same standard as that required by the hose with particular reference to pressure and impulse tests.

7.3.3 Flexible hose assemblies intended for installation in piping systems where pressure pulses and/or high levels of vibration are expected to occur in service, are to be designed for the maximum expected impulse peak pressure and forces due to vibration. The tests required by 7.4 are to take into consideration the maximum anticipated in-service pressures, vibration frequencies and forces due to installation.

7.3.4 Flexible hose assemblies constructed of non-metallic materials intended for installation in piping systems for flammable media, and sea-water systems where failure may result in flooding, are to be of fire-resistant type. Fire resistance is to be demonstrated by testing to ISO 15540 and ISO 15541.

7.3.5 Flexible hose assemblies are to be suitable for the intended location and application, taking into consideration ambient conditions, compatibility with fluids under working pressure and temperature conditions consistent with the manufacturer's instructions and any other applicable requirements in the Rules.

### 7.4 Testing

7.4.1 Acceptance of flexible hose assemblies is subject to satisfactory prototype testing. Prototype test programmes for flexible hose assemblies are to be submitted by the manufacturer and are to be sufficiently detailed to demonstrate performance in accordance with the specified Standards.

7.4.2 For a particular hose type complete with end fittings, the tests, as applicable, are to be carried out on different nominal diameters for pressure, burst, impulse and fire resistance in accordance with the requirements of the relevant Standard. The following Standards are to be used as applicable:

- ISO 6802 – *Rubber and plastics hoses and hose assemblies with wire reinforcements – Hydraulic impulse test with flexing.*



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- ISO 6803 – *Rubber or plastics hoses and hose assemblies – Hydraulic-pressure impulse test without flexing.*
- ISO 15540 – *Ships and marine technology – Fire resistance of hose assemblies – Test methods.*
- ISO 15541 – *Ships and marine technology – Fire resistance of hose assemblies – Requirements for test bench.*
- ISO 10380 – *Pipework – Corrugated metal hoses and hose assemblies.*

Other Standards may be accepted where agreed by LR.

7.4.3 All flexible hose assemblies are to be satisfactorily prototype burst tested to an International Standard\* to demonstrate they are able to withstand a pressure of not less than four times the design pressure without indication of failure or leakage.

## NOTE

\* The International Standards, e.g., EN or SAE for burst testing of non-metallic hoses, require the pressure to be increased until burst without any holding period at 4 x Maximum Working Pressure.

## Section 8

### Hydraulic tests on pipes and fittings

#### 8.1 Hydraulic tests before installation on board

8.1.1 All Class I and II pipes and their associated fittings are to be tested by hydraulic pressure to the Surveyor's satisfaction. Further, all steam, feed, compressed air and oil fuel pipes, together with their fittings, are to be similarly tested where the design pressure is greater than 7,0 bar. The test is to be carried out after completion of manufacture and before installation on board and, where applicable, before insulating and coating.

8.1.2 Where the design temperature does not exceed 300°C, the test pressure is to be 1,5 times the design pressure, as defined in 1.3.

8.1.3 Where testing of systems or sub-systems following final assembly is specified, in addition to the requirements of 8.1.2 the lowest applicable pressure as defined in this sub-Section is to be used for testing.

8.1.4 For steel pipes and integral fittings for use in systems where the design temperature exceeds 300°C, the test pressure is to be as follows:

- For carbon and carbon-manganese steel pipes, the test pressure is to be twice the design pressure, as defined in 1.3.
- For alloy steel pipes, the test pressure is to be determined by the following formula, but need not exceed  $2p$ :

$$p_t = 1,5 \frac{\sigma_{100}}{\sigma} p \text{ bar (kgf/cm}^2\text{)}$$

where

$p_t$  and  $p$  are as defined in 1.2.1

$\sigma$  = permissible stress for the design temperature, in N/mm<sup>2</sup> (kgf/cm<sup>2</sup>), as stated in Table 12.2.2  
 $\sigma_{100}$  = permissible stress for 100°C, in N/mm<sup>2</sup> (kgf/cm<sup>2</sup>), as stated in Table 12.2.2.

8.1.5 Where alloy steels not included in Table 12.2.2 are used, the permissible stresses will be specially considered, as indicated in 2.2.2.

8.1.6 Consideration will be given to the reduction of the test pressure to not less than  $1,5p$ , where it is necessary to avoid excessive stress in way of bends, branches, etc.

8.1.7 Valves and fittings non-integral with the piping system, intended for Classes I and II, are to be tested in accordance with recognised standards, but to not less than 1,5 times the design pressure. Where design features are such that modifications to the test requirements are necessary, alternative proposals for hydraulic tests are to be submitted for special consideration.

8.1.8 For requirements relating to valves and cocks intended to be fitted on the ship's side below the load water line, see Ch 13,2.5.10.

8.1.9 In no case is the membrane stress to exceed 90 per cent of the yield stress at the testing temperature.

#### 8.2 Testing after assembly on board

8.2.1 Heating coils in tanks, gas fuel and oil fuel piping are to be tested by hydraulic pressure, after installation on board, to 1,5 times the design pressure but in no case to less than 4 bar (4,1 kgf/cm<sup>2</sup>).

8.2.2 Where pipes specified in 8.1.1 are butt welded together during assembly on board, they are to be tested by hydraulic pressure in accordance with the requirements of 8.1 after welding. The pipe lengths may be insulated, except in way of the joints made during installation and before the hydraulic test is carried out.

8.2.3 The hydraulic test required by 8.2.2 may be omitted provided non-destructive tests by ultrasonic or radiographic methods are carried out on the entire circumference of all butt welds with satisfactory results. Where ultrasonic tests have been carried out, the manufacturer is to provide the Surveyor with a signed statement confirming that ultrasonic examination has been carried out by an approved operator and that there were no indications of defects which could be expected to have a prejudicial effect on the service performance of the piping.

8.2.4 Where bilge pipes are accepted in way of double bottom tanks or deep tanks, see Ch 13,7.9 and 7.10, the pipes after fitting are to be tested by hydraulic pressure to the same pressure as the tanks through which they pass.

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## ■ Cross-reference

See also Ch 13,2.10 for testing after installation.

## ■ Section 9

### Piping for LPG/LNG carriers, gas fuelled ships and classed refrigeration systems

#### 9.1 Scope

9.1.1 This Section is applicable to piping systems installed in LPG/LNG carriers, gas fuelled ships and classed refrigeration systems for the following pipes and piping system components:

- (a) Pipework – stainless steel, carbon steel and copper.
- (b) Valves – normal and cryogenic service (below minus 55°C).
- (c) Bellows – normal and cryogenic service (below minus 55°C).
- (d) Pipe fittings – elbows, reducers, tee connections, etc.
- (e) Ancillary fittings – weldolets, threadolets, thermo-pockets.

9.1.2 The following piping systems are covered by this Section:

- (a) LPG/LNG cargo systems – normal cargo operations.
- (b) LPG/LNG cargo systems – cargo gas to reliquefaction system.
- (c) LNG cargo systems – gas burning and use of cargo as fuel.
- (d) LNG Regasification system – high and low pressure.
- (e) Cargo Reliquefaction system – nitrogen or mixed refrigerant.
- (f) Refrigeration – independent plant used in cascade systems.
- (g) Gas storage and supply systems for gas fuelled ships.

#### 9.2 Application

9.2.1 The requirements of this Section apply to pipes and piping system components, such as valves, elbows and bellows, which are to be used on gas carriers, gas fuelled ships or classed refrigeration/reliquefaction systems. The requirements are also applicable to other gas cargo services such as regasification systems and gas combustion units, and are in addition to those contained in both the Rules for Ships for Liquefied Gases and relevant Sections of this Chapter where appropriate.

#### 9.3 Classes of pipe

9.3.1 The material requirements for piping systems vary depending on the Class of the piping system. The Class of the piping system is dependent on the design pressure or temperature of the system and the pipe material used as shown in Table 12.1.1.

9.3.2 Table 12.1.1 piping systems containing LPG/LNG, cargo or fuel gas as the conveyed medium are to be treated as 'Flammable liquids'. These piping systems are to be categorised as Class II. Vapour lines are also to be categorised as Class II systems but the upper limit on pressure may be increased to 40 bar in accordance with the 'Other media'. Where higher design pressures are applied, such as in a regasification system, liquid lines above 16 bar and vapour lines above 40 bar are to be categorised as Class I. All open ended pipes, such as vent lines and pipes inside the cargo tanks may be categorised as Class III.

9.3.3 For reliquefaction and refrigeration systems Table 12.1.1 is to be applied. Nitrogen and non-toxic or non-flammable refrigerants are to be considered under the 'Other media' heading. Refrigeration systems containing ammonia are to be considered as Class I systems irrespective of the operational pressure.

#### 9.4 Materials

9.4.1 Stainless steel pipes, valves and fittings for welded fabrication are to be grades 304L, 316L, 321 or 347 in accordance with Ch 6,5 of the Rules for Materials. For non-welded fabrications the grades 304 and 316 may be accepted.

9.4.2 The materials used in Class I and Class II systems are to be produced at a works approved by LR. Testing is to be in accordance with the Rules for Materials and Tables 6.1 and 6.4 in chapter 6 of the Rules for Ships for Liquefied Gases.

9.4.3 For stainless steel pipes, valve castings and forgings intended for service temperatures down to minus 55°C, a LR materials certificate is required unless

- $DN < 50$  or
- $DN \leq 150$  and  $DN \times P < 2500$

where a manufacturer's material certificate is acceptable.

9.4.4 For pipe systems operating at cryogenic temperatures lower than minus 55°C, a LR materials certificate is required.

#### 9.5 Valves and piping components independent of temperature

9.5.1 For valves and piping components fitted in the cargo piping system of LPG/LNG gas carriers, each type of valve and piping component is to have evidence of satisfactory type testing.

#### 9.6 Valves for cryogenic temperature service

9.6.1 The tightness test required by 5.3.2.1 of the Rules for Ships for Liquefied Gases is to be conducted in accordance with a recognised National or International Code or Standard.

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#### 9.7 Valves for refrigeration service

9.7.1 For valves intended for installation in a refrigeration system with a nominal diameter equal to or less than 150 mm, a manufacturer's certificate is acceptable. The certificate is to include details of the maximum working pressure and test pressure, and sufficient information for the LR Surveyor to assess the suitability of the equipment for the intended use. Each size and type of valve is to be supplied with its own certificate and is to be signed by a responsible person in the manufacturer's quality control department.

9.7.2 Valves with nominal diameters above 150 mm are to be supplied with a LR materials certificate in accordance with the Rules for Materials.

9.7.3 Where valves are fitted to pressure vessels, the requirements of Chapters 10 and 11 are applicable for the Class of pressure vessel. Mountings for liquefied gas pressure vessels are to comply with the Rules for Ships for Liquefied Gases. Any acceptance of manufacturer's certification in other Sections of this Chapter is not applicable to the valves fitted to pressure vessels in chapters 10 and 11 of the Rules for Ships for Liquefied Gases.

9.7.4 Any valve fitted directly onto a pressure vessel is to be considered a mounting and is required to be hydraulically pressure tested to twice the approved design pressure. See Ch 11,10.2.1.

#### 9.8 Expansion bellows

9.8.1 The following plans and particulars are to be submitted:

- Dimensioned drawings of each type of bellows.
- Design calculations to show that the bellows are suitable for the intended design conditions, carried out to EJMA (Expansion Joint Manufacturers Association) standards (latest edition) or equivalent.
- A proposed prototype test program covering the tests detailed in 5.3.2.2 of the Rules for Ships for Liquefied Gases.
- Calculations to EJMA standards may be accepted, together with sample testing detailed above, in order to cover the entire size range for the type.

9.8.2 In accordance with 5.3 of the Rules for Ships for Liquefied Gases, the requirements for type testing in 9.8.3 to 9.8.7 are to be performed on each type of expansion bellows intended for use on LPG/LNG piping.

9.8.3 For each type of expansion bellows, an element of the bellows, not pre-compressed, is to be pressure tested at not less than five times the design pressure without bursting. This test is to be conducted at room temperature on each 'type' of element and need not be the complete bellows unit. A test on one element can cover other sized bellows with the same cross-sectional bellows form. The design pressure is to be at least 10 bar; bellows fitted to safety valves and vent lines may have a minimum design pressure of 5 bar in accordance with 5.2.3.3 of the Rules for Ships for Liquefied Gases. The required test duration is not to be less than 5 minutes.

9.8.4 A pressure test is to be performed on each type of expansion joint complete with all the accessories such as flanges, stays and articulations, at twice the design pressure at the extreme displacement conditions recommended by the manufacturer without permanent deformation. The test is to be undertaken at the minimum design temperature, unless the bellows material is stainless steel for which this test may be carried out at ambient temperature. The test duration is to be 30 minutes unless otherwise agreed with LR.

9.8.5 A cyclic thermal movement test, replicating the cooling down and warming up cycle which occurs during cargo loading and discharge, is to be performed on a complete expansion joint, by the application of representative external deflection resulting in bellow movement. This is to successfully withstand at least as many cycles, under the conditions of pressure, temperature, axial movement, rotational movement and transverse movement, as it will encounter in actual service. The number of cycles is to be estimated by the builder and depends on the ship's intended trading pattern and life expectancy. As a minimum, testing to 7000 cycles is to be carried out. The test is to be carried out at between 2-5 cycles per second. Testing at ambient temperature is permitted when this testing is at least as severe as testing at the service temperature. The maximum movements on the horizontal and vertical axis are to be provided by the builders and obtained from their stress analysis; however, the test can be extended to any value which is greater than that expected, or to the maximum deflection for which the bellows unit is suitable. Movements in the test need not be in both horizontal and vertical directions; but the horizontal-vertical box diagonal distance may be used. NDE testing is required after cyclic testing.

9.8.6 A cyclic fatigue test, representing ship deformation, is to be performed on a complete expansion joint, without internal pressure, by simulating the bellows movement corresponding to a compensated pipe length, for at least 2,000,000 cycles at a frequency not higher than 5 cycles per second. The test may be waived if the piping arrangement, experiences ship deformation loads. NDE is required after cyclic testing.

9.8.7 The cyclic thermal movement test and cyclic fatigue test may be waived by LR if satisfactory documentation is provided to establish the suitability of the expansion joints to withstand the expected working conditions. Where the maximum internal pressure exceeds 1,0 bar gauge, this documentation is to include sufficient test data to justify the design method used, with particular reference to correlation between calculation and test results.

#### 9.9 Pressure testing of piping and other piping components

9.9.1 Pressure testing is to be undertaken in accordance with specific Rule requirements relating to the system in which the component is to be located.

9.9.2 The duration for which pressure tests are to be held is to be in conjunction with an applicable and recognised code or standard acceptable to LR.

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## 9.10 Equipment documentation

**9.10.1** A certificate is required for each piping component supplied to be fitted in a Class I or Class II system. This certification is required for each size and type of equipment delivered. A single certificate may cover a number of valves, provided that they are of the same type and size, and serial numbers have been included on the certificate. If the piping components are part of a system fitted to a skid or packaged unit, then the complete skid may be supplied with a single certificate stating that the package has been constructed using approved materials, approved and tested in accordance with LR Rule requirements.

## 9.11 Relief valves for LPG/LNG cargo and deck tanks

**9.11.1** Relief valves fitted to cargo tanks and deck tanks are to be of a type tested design. Type testing is to include:

- flow or capacity verification to a recognised Standard acceptable to the Administration;
- cryogenic testing when operating at design temperatures colder than minus 55°C;
- seat tightness testing to a recognised Standard or manufacturers' procedure acceptable to the Administration; and
- pressure testing of pressure-containing parts to at least 1,5 times the design pressure.

**9.11.2** The materials used for construction of relief valves fitted to cargo tanks and deck tanks are to be produced in a works approved by LR and be provided with a Lloyd's Register Material Certificate

## Section 10 Austenitic stainless steels

### 10.1 Pipe thickness

**10.1.1** The minimum thickness of austenitic stainless steel pipes is to be determined from the formula given in 2.2.1 and either 2.2.3 or 2.2.4 using a corrosion allowance of 0,8 mm. Values of 1,0 per cent proof stress and tensile strength of the material for use in the formula in 2.2.1 may be obtained from Table 6.5.2 in Chapter 6 of the Rules for Materials.

**10.1.2** Where stainless steel is used in lubricating oil, hydraulic oil and refrigeration systems, the corrosion allowance may be reduced to 0 mm. For pipes passing through tanks, an additional corrosion allowance is to be added to take account of external corrosion; the addition will depend on the external medium and the value is to be in accordance with Table 12.2.3. Where the pipes are efficiently protected, the corrosion allowance may be reduced by not more than 50 per cent.

**10.1.3** In no case is the thickness of austenitic stainless steel pipes to be less than that shown in Table 12.10.1.

**Table 12.10.1 Minimum thickness for austenitic stainless steel pipes**

Standard pipe sizes (outside diameter) in mm	Min. thickness in mm
10,2 to 17,2	1,0
21,3 to 48,3	1,6
60,3 to 88,9	2,0
114,3 to 168,3	2,3
219,1	2,6
273,0	2,9
323,9 to 406,4	3,6
over 406,4	4,0

## APPENDIX

### Section 11 Guidance notes on metal pipes for water services

#### 11.1 General

**11.1.1** These guidance notes, except where it is specifically stated, apply to sea-water piping systems.

**11.1.2** In addition to the selection of suitable materials, careful attention should be given to the design details of the piping system and the workmanship in fabrication, construction and installation of the pipework in order to obtain maximum life in service.

#### 11.2 Materials

**11.2.1** Materials used in sea-water piping systems include:

- Galvanised steel.
- Steel pipes lined with rubber, plastics or stoved coatings.
- Copper.
- 90/10 copper-nickel-iron.
- 70/30 copper-nickel.
- Aluminium brass.

**11.2.2** Selection of materials should be based on:

- the ability to resist general and localised corrosion, such as pitting, impingement attack and cavitation throughout all the flow velocities likely to be encountered;
- compatibility with the other materials in the system, such as valve bodies and casings, (e.g., in order to minimise bimetallic corrosion);
- the ability to resist selective corrosion, e.g., dezincification of brass, dealuminification of aluminium brass and graphitisation of cast iron;
- the ability to resist stress corrosion and corrosion fatigue; and
- the amenability to fabrication by normal practices.

# Piping Design Requirements

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## 11.3 Steel pipes

11.3.1 Steel pipes should be protected against corrosion, and protective coatings should be applied on completion of all fabrication, i.e., bending, forming and welding of the steel pipes.

11.3.2 Welds should be free from lack of fusion and crevices. The surfaces should be dressed to remove slag and spatter and this should be done before coating. The coating should be continuous around the ends of the pipes and on the faces of flanges.

11.3.3 Galvanising the bores and flanges of steel pipes as protection against corrosion is common practice, and is recommended as the minimum protection for pipes in sea-water systems, including those for bilge and ballast service.

11.3.4 Austenitic stainless steel pipes are not recommended for salt-water services as they are prone to pitting, particularly in polluted waters.

11.3.5 Rubber lined pipes are effective against corrosion and suitable for higher water velocities. The rubber lining should be free from defects, e.g., discontinuities, pinholes, etc., and it is essential that the bonding of the rubber to the bore of the pipe and flange face is sound. Rubber linings should be applied by firms specialising in this form of protection.

11.3.6 The foregoing comments on rubber lined pipes also apply to pipes lined with plastics.

11.3.7 Stove coating of pipes as protection against corrosion should only be used where the pipes will be efficiently protected against mechanical damage.

## 11.4 Copper and copper alloy pipes

11.4.1 Copper pipes are particularly susceptible to perforation by corrosion/erosion and should only be used for low water velocities and where there is no excessive local turbulence.

11.4.2 Aluminium brass and copper-nickel-iron alloy pipes give good service in reasonably clean sea-water. For service with polluted river or harbour waters, copper-nickel-iron alloy pipes with at least 10 per cent nickel are preferable. Alpha-brasses, i.e., those containing 70 per cent or more copper, must be inhibited effectively against dezincification by suitable additions to the composition. Alpha beta-brasses, (i.e., those containing less than 70 per cent copper), should not be used for pipes and fittings.

11.4.3 New copper alloy pipes should not be exposed initially to polluted water. Clean sea-water should be used at first to allow the metals to develop protective films. If this is not available the system should be filled with inhibited town mains water.

## 11.5 Flanges

11.5.1 Where pipes are exposed to sea-water on both external and internal surfaces, flanges should be made, preferably, of the same material. Where sea-water is confined to the bores of pipes, flanges may be of the same material or of less noble metal than that of the pipe, see also 2.3.

11.5.2 Fixed or loose type flanges may be used. The fixed flanges should be attached to the pipes by fillet welds or by capillary silver brazing. Where welding is used, the fillet weld at the back should be a strength weld and that in the face, a seal weld.

11.5.3 Inert gas shielded arc welding is the preferred process but metal arc welding may be used on copper-nickel-iron alloy pipes.

11.5.4 Mild steel flanges may be attached by argon arc welding to copper-nickel-iron pipes and give satisfactory service, provided that no part of the steel is exposed to the sea-water.

11.5.5 Where silver brazing is used, strength should be obtained by means of the bond in a capillary space over the whole area of the mating surfaces. A fillet braze at the back of the flange or at the face is undesirable. The alloy used for silver brazing should contain not less than 49 per cent silver.

11.5.6 The use of a copper-zinc brazing alloy is not permitted.

## 11.6 Water velocity

11.6.1 Water velocities should be carefully assessed at the design stage and the materials of pipes, valves, etc., selected to suit the conditions.

11.6.2 The water velocity in copper pipes should not exceed 1 m/s.

11.6.3 The water velocity in the pipes of the materials below should normally be not less than about 1 m/s in order to avoid fouling and subsequent pitting, but should not be greater than the following:

- Galvanised steel 3,0 m/s
- Aluminium brass 3,0 m/s
- 90/10 copper-nickel-iron 3,5 m/s
- 70/30 copper-nickel 5,0 m/s

## 11.7 Fabrication and installation

11.7.1 Attention should be given to ensuring streamlined flow and reducing entrained air in the system to a minimum. Abrupt changes in the direction of flow, protrusions into the bores of pipes and other restrictions of flow should be avoided. Branches in continuous flow lines should be set at a shallow angle to the main pipe, and the junction should be smooth.

11.7.2 Pipe bores should be smooth and clean.



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11.7.3 Jointing should be flush with the bore surfaces of pipes and misalignment of adjacent flange faces should be reduced to a minimum.

11.7.4 Pipe bends should be of as large a radius as possible, and the bore surfaces should be smooth and free from puckering at these positions. Any carbonaceous films or deposits formed on the bore surfaces during the bending processes should be carefully removed. Organic substances are not recommended for the filling of pipes for bending purposes.

11.7.5 The position of supports should be given special consideration in order to minimise vibration and ensure that excessive bending moments are not imposed on the pipes.

11.7.6 Systems should not be left idle for long periods, especially where the water is polluted.

11.7.7 Strainers should be provided at the inlet to sea-water systems.

### 11.8 Metal pipes for fresh water services

11.8.1 Mild steel or copper pipes are normally satisfactory for service in fresh water applications. Hot fresh water, however, may promote corrosion in mild steel pipes unless the hardness and pH of the water are controlled.

11.8.2 Water with a slight salt content should not be left stagnant for long periods in mild steel pipes. Low salinity and the limited supply of oxygen in such conditions promote the formation of black iron oxide, and this may give rise to severe pitting. Where stagnant conditions are unavoidable, steel pipes should be galvanised, or pipes of suitable non-ferrous material used.

11.8.3 Copper alloy pipes should be treated to remove any carbonaceous films or deposits before the tubes are put into service.

11.8.4 Brass fittings and flanges in contact with water should be made of an alpha-brass effectively inhibited against dezincification by suitable additions to the composition.

11.8.5 Aluminium brass has been widely used as material for heat exchanger and condenser tubes, but its use in 'once through' systems is not recommended since, under certain conditions, it is prone to pitting and cracking.

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# Ship Piping Systems

# Part 5, Chapter 13

Section 1

## Section

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- 2 **Construction and installation**
- 3 **Drainage of compartments, other than machinery spaces**
- 4 **Bilge drainage of machinery spaces**
- 5 **Sizes of bilge suction pipes**
- 6 **Pumps on bilge service and their connections**
- 7 **Piping systems and their fittings**
- 8 **Additional requirements for bilge drainage and cross-flooding arrangements for passenger ships**
- 9 **Additional requirements relating to fixed pressure water spray fire-extinguishing systems**
- 10 **Drainage arrangements for ships not fitted with propelling machinery**
- 11 **Ballast system**
- 12 **Air, overflow and sounding pipes**
- 13 **Additional requirements for drainage and pumping arrangements for bulk carriers**
- 14 **Water ingress detection arrangements**

## ■ Section 1 General requirements

### 1.1 Application

1.1.1 The requirements of this Chapter apply to piping systems on all types of ship except where otherwise stated.

1.1.2 Whilst the requirements satisfy the relevant regulations of the *International Convention for the Safety of Life at Sea, 1974*, and applicable amendments, attention should be given to any relevant regulations of the International Convention for the Prevention of Pollution from Ships, 1973, and applicable amendments, where these impact the design or construction of piping systems. Attention should also be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

1.1.3 Consideration will be given to special cases or to arrangements which are equivalent to those required by these Rules. Consideration will also be given to the pumping arrangements of small ships and ships to be assigned class notations for restricted or special services.

1.1.4 Piping design is to comply with Chapter 12 as applicable.

### 1.2 Prevention of progressive flooding in damage condition

1.2.1 For ships to which subdivision and damage stability requirements apply, precautions are to be taken to prevent progressive flooding between compartments resulting from damage to piping systems. For this purpose, piping systems are to be located inboard of the assumed extent of damage applicable to the ship type.

1.2.2 Where it is not practicable to locate piping systems as required by 1.2.1, the following precautions are to be taken:

- (a) Bilge suction pipes are to be provided with non-return valves of approved type.
- (b) Other piping systems are to be provided with shut-off valves capable of being operated from positions accessible in the damage condition, or from above the bulkhead deck where required by the Rules.

These valves are to be located in the compartment containing the open end or in a suitable position such that the compartment may be isolated in the event of damage to the piping system.

1.2.3 Where subdivision and damage stability requirements apply and where penetration of watertight divisions by pipes, ducts, trunks or other penetrations is necessary, arrangements are to be made to maintain the watertight integrity.

### 1.3 Plans and particulars

1.3.1 The following plans (in diagrammatic form) and particulars are to be submitted for approval. Additional plans should not be submitted unless the arrangements are of a novel or special character affecting classification:

- (a) Arrangements of air pipes and closing devices for all tanks and enclosed spaces.
- (b) Sounding arrangements for all tanks, enclosed spaces and cargo holds.
- (c) Arrangements of level alarms fitted in tanks, cargo holds, machinery spaces, pump rooms and any other spaces.
- (d) Arrangements of any cross flooding or heeling tank systems.
- (e) Bilge drainage arrangements for all compartments which are to include details of location, number and capacity of pumping units on bilge service. In the case of passenger ships, the bilge pump numeral, as defined in the *International Convention for the Safety of Life at Sea, 1974*, and applicable amendments are to be stated, together with the number of flooded compartments which the ship is required to withstand under damage conditions.
- (f) Ballast filling and drainage arrangements: a schematic piping drawing showing connection of the ballast water treatment system to the ballast filling and drainage arrangement is to be submitted.
- (g) Oil fuel filling, transfer, relief and spill/drainage arrangements.
- (h) Tank overflow arrangements.
- (j) Blanking arrangements for bilge and ballast piping systems for bulk carriers having floodable holds.
- (k) Isolation arrangements for bilge systems where cargo holds are intended for the carriage of dangerous goods.

# Ship Piping Systems

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- (l) Details verifying compliance with the sizing of air pipes required by 12.8.
- (m) Arrangements of oil fuel piping in connection with oil burning installations and oil fired galleys.
- (n) Arrangements of oil fuel burning units for boilers and thermal fluid heaters.
- (o) Arrangement of boiler feed system.
- (p) Arrangements of thermal fluid circulation systems.
- (q) Arrangement of compressed air systems for main and auxiliary services.
- (r) Arrangements of lubricating oil systems.
- (s) Arrangements of flammable liquids used for control and heating systems.
- (t) Arrangements of power transmission systems for services essential for safety or for the operation of the ship at sea.
- (u) Arrangements of cooling water systems for main and auxiliary services.
- (v) Oil fuel settling service and other oil fuel tanks not forming part of the ship's structure and lubricating and hydraulic oil tanks with a capacity of 500 litres or more, not forming part of the ship's structure.
- (w) Arrangements and dimensions of all steam pipes where the design pressure or temperature exceeds 16,0 bar (16,3 kgf/cm<sup>2</sup>) or 300°C, respectively, and the outside diameter exceeds 76,1 mm, with details of flanges, bolts and weld attachments, and particulars of the material of pipes, flanges, bolts and electrodes.
- (x) Details verifying compliance with the capacity of the oil fuel treatment plant required by Ch 14,3.9.1.
- (y) Details verifying compliance of demands on low pressure air systems by supplying essential services as required by Ch 14,10.1.3.
- (z) For water ingress detection arrangements, see Section 14, plans and information in accordance with Pt 6, Ch 1,1.2 and, additionally, general arrangement plans showing the spaces provided with water ingress detectors, installed equipment locations and cable routes. Details of National Administration approvals are to be included.

2.1.4 Aluminium alloy pipes are not acceptable for fire extinguishing pipes unless they are suitably protected against the effect of heat. The proposed use of aluminium alloy with appropriate insulation will be considered when it has been demonstrated that the arrangements provide equivalent structural and integrity properties compared to steel. In open and exposed locations where the insulation material is likely to suffer from mechanical damage suitable protection is to be provided.

## 2.2 Pipe wall thickness

2.2.1 The minimum nominal wall thickness of steel, copper and copper alloy pipes are to be in accordance with Chapter 12.

2.2.2 Special consideration will be given to the wall thickness of pipes made of materials other than steel, copper and copper alloy.

## 2.3 Valves – Installation and control

2.3.1 Valves and cocks are to be fitted in places where they are at all times readily accessible, unless otherwise specifically mentioned in the Rules. Valves in cargo oil and ballast systems may be fitted inside tanks, subject to 2.3.2.

2.3.2 All valves which are provided with remote control are to be arranged for local manual operation, independent of the remote operating mechanism. For shipside valves and valves on the collision bulkhead, the means for local manual operation are to be permanently attached. For submerged valves in cargo oil and ballast systems, as permitted by 2.3.1, local manual operation may be by extended spindle or a portable hand pump. Where manual operation is by hand pump, the control lines to each submerged valve are to incorporate quick coupling connections, as close to the valve actuator as practicable, to allow easy connection of the hand pump. Not less than two hand pumps are to be provided.

2.3.3 In case of valves which are required by the Rules to be provided with remote control, opening and/or closing of the valves by local manual means are not to render the remote control system inoperable.

## 2.4 Attachment of valves to watertight plating

2.4.1 Valve chests, cocks, pipes or other fittings attached direct to the plating of tanks, and to bulkheads, flats or tunnels which are required to be of watertight construction, are to be secured by means of studs screwed through the plating or by tap bolts, and not by bolts passing through clearance holes. Alternatively, the studs or the bulkhead piece may be welded to the plating.

2.4.2 For requirements relating to valves on the collision bulkhead, see 3.5.4.

## Section 2

## Construction and installation

### 2.1 Materials

2.1.1 Except where otherwise stated in this Chapter, pipes, valves and fittings are to be made of steel, cast iron, copper, copper alloy, or other approved material suitable for the intended service.

2.1.2 Where applicable, the materials are to comply with the relevant requirements of Chapter 12.

2.1.3 Materials sensitive to heat, such as aluminium, lead or plastics, are not to be used in systems essential to the safe operation of the ship, or for containing combustible liquids or sea-water where leakage or failure could result in fire or in the flooding of watertight compartments, see Chapter 12 for plastics pipes.

# Ship Piping Systems

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### Section 2

#### 2.5 Ship-side valves and fittings (other than those on scuppers and sanitary discharges)

2.5.1 All sea inlet and overboard discharge pipes are to be fitted with valves or cocks secured direct to the shell plating, or to the plating of fabricated steel water boxes attached to the shell plating. These fittings are to be secured by bolts tapped into the plating and fitted with countersunk heads, or by studs screwed into heavy steel pads fitted to the plating. The stud holes are not to penetrate the plating.

2.5.2 Valves for ship-side applications are to be installed such that the section of piping immediately inboard of the valve can be removed without affecting the watertight integrity of the hull.

2.5.3 Distance pieces of short, rigid construction, and made of approved material, may be fitted between the valves and shell plating. Distance pieces of steel may be welded to the shell plating. Details of the welded connections and of fabricated steel water boxes are to be submitted.

2.5.4 Gratings are to be fitted at all openings in the ship's side for sea inlet valves and inlet water boxes. The net area through the gratings is to be not less than twice that of the valves connected to the sea inlets, and provision is to be made for clearing the gratings by use of low pressure steam or compressed air, see 2.5.9.

2.5.5 All suction and discharge valves and cocks secured direct to the shell plating of the ship are to be fitted with spigots passing through the plating, but the spigots on the valves or cocks may be omitted if these fittings are attached to pads or distance pieces which themselves form spigots in way of the shell plating. Blow-down valves or cocks are also to be fitted with a protection ring through which the spigot is to pass, the ring being on the outside of the shell plating. Where alternative forms of attachment are proposed, details are to be submitted for consideration.

2.5.6 Blow-down valves or cocks on the ship's side are to be fitted in accessible positions above the level of the working platform, and are to be provided with indicators showing whether they are open or shut. Cock handles are not to be capable of being removed unless the cocks are shut, and, if valves are fitted, the hand wheels are to be suitably retained on the spindle.

2.5.7 Sea inlet and overboard discharge valves and cocks are in all cases to be fitted in easily accessible positions and, so far as practicable, are to be readily visible. Indicators are to be provided local to the valves and cocks, showing whether they are open or shut. Provision is to be made for preventing any discharge of water into lifeboats. The valve spindles are to extend above the lower platform, and the hand wheels of the main cooling water sea inlet and emergency bilge suction valves are to be situated not less than 460 mm above this platform.

2.5.8 Ship-side valves and fittings, if made of steel or other approved material with low corrosion resistance, are to be suitably protected against wastage.

2.5.9 The scantlings of valves and valve stools fitted with steam or compressed air clearing connections are to be suitable for the maximum pressure to which the valves and stools may be subjected.

2.5.10 Valves, cocks and distance pieces, intended for installation on the ship's side below the load waterline, are to be tested by hydraulic pressure to not less than 5 bar.

2.5.11 For sea connections for ships having notation for ice navigation, see Pt 8, Ch 2,3.3, Pt 8, Ch 2,3.5 and Pt 8, Ch 2,11.21.

#### 2.6 Piping systems – Installation

2.6.1 Bilge, ballast and cooling water suction and discharge pipes are to be permanent pipes made in readily removable lengths with flanged joints, except as mentioned in 7.10, and are to be efficiently secured in position to prevent chafing or lateral movement. For joints in oil fuel piping systems, see Ch 14,4.5 and 4.6.

2.6.2 Where lack of space prevents the use of normal circular flanges, details of the alternative methods of joining the pipes are to be submitted.

2.6.3 Long or heavy lengths of pipes are to be supported by bearers so that no undue load is carried by the flanged connections of the pumps or fittings to which they are attached.

#### 2.7 Provision for expansion

2.7.1 Suitable provision for expansion is to be made, where necessary, in each range of pipes.

2.7.2 Where expansion pieces are fitted, they are to be of an approved type and are to be protected against over extension and compression. The adjoining pipes are to be suitably aligned, supported, guided and anchored. Where necessary, expansion pieces of the bellows type are to be protected against mechanical damage.

2.7.3 Expansion pieces of an approved type incorporating special quality oil resistant rubber or other suitable synthetic material may be used in cooling water lines in machinery spaces. Where fitted in sea- water lines, they are to be provided with guards which will effectively enclose, but not interfere with, the action of the expansion pieces and will reduce to the minimum practicable any flow of water into the machinery spaces in the event of failure of the flexible elements. Proposals to use such fittings in water lines for other services, including:

- ballast lines in machinery spaces, in duct keels and inside double bottom water ballast tanks, and
  - bilge lines inside duct keels only,
- will be specially considered when plans of the pumping systems are submitted for approval.

2.7.4 For requirements relating to flexible hoses, see Chapter 12.

# Ship Piping Systems

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Sections 2 & 3

## 2.8 Piping in way of refrigerated chambers

2.8.1 All pipes, including scupper pipes, air pipes and sounding pipes which pass through chambers intended for the carriage or storage of refrigerated produce are to be well insulated.

2.8.2 Where the pipes referred to in 2.8.1 pass through chambers intended for temperatures of 0°C or below, they are also to be insulated from the steel structure, except in positions where the temperature of the structure is mainly controlled by the external temperature and will normally be above freezing point. Pipes passing through a deckplate within the ship side insulation, where the deck is fully insulated below and has an insulation ribband on top, are to be attached to the deck plating. In the case of pipes adjacent to the shell plating, metallic contact between the pipes and the shell plating or frames is to be arranged so far as practicable.

2.8.3 The air refreshing pipes to and from refrigerated compartments need not, however, be insulated from the steel work.

## 2.9 Miscellaneous requirements

2.9.1 All pipes situated in cargo spaces, fish holds, chain lockers or other positions where they are liable to mechanical damage are to be efficiently protected.

2.9.2 Wash deck pipes and discharge pipes from the pumps to domestic water tanks are not to be led through cargo holds. Any proposed departure from this requirement is to be submitted for consideration.

2.9.3 So far as practicable, pipelines, including exhaust pipes from oil engines, are not to be led in the vicinity of switchboards or other electrical appliances in positions where the drip or escape of liquid, gas or steam from joints or fittings could cause damage to the electrical installation. Where it is not practicable to comply with these requirements, drip trays or shields are to be provided as found necessary. Short sounding pipes to tanks are not to terminate near electrical appliances, see 12.13.2.

## 2.10 Testing after installation

2.10.1 After installation on board, all steam, hydraulic, compressed air and other piping systems covered by 1.3.1, together with associated fittings which are under internal pressure, are to be subjected to a running test at the intended maximum working pressure.

## ■ Cross-reference

For guidance on metal pipes for water services, see Ch 12,11.

## ■ Section 3

## Drainage of compartments, other than machinery spaces

### 3.1 General

3.1.1 All ships are to be provided with efficient pumping plant having the suctions and means for drainage so arranged that any water within any compartment of the ship, or any watertight section of any compartment, can be pumped out through at least one suction when the ship is on an even keel and is either upright or has a list of not more than 5°. For this purpose, wing suctions will generally be necessary, except in short, narrow compartments where one suction can provide effective drainage under the above conditions.

3.1.2 In passenger ships, the pumping plant is to be capable of draining any watertight compartment under all practicable conditions after a casualty, whether the ship is upright or listed.

3.1.3 In the case of dry compartments, the suctions required by 3.1.1 are, except where otherwise stated, to be branch bilge suctions, i.e., suctions connected to a main bilge line.

3.1.4 For drainage arrangements of non-self-propelled ships, see Section 10.

3.1.5 For additional drainage arrangements on ferries and Roll on-Roll off ships, see Pt 4, Ch 2,9.9.

3.1.6 For a normally inaccessible small void compartment such as an echo sounding compartment, which is accessed from within a normally inaccessible space such as a forepeak tank, alternative drainage arrangements to those required by 3.1.1 may be considered. For such arrangements, a warning notice is to be located in a prominent position specifying the precautions to be taken prior to opening the manhole of the small void compartment. Means are to be provided to indicate flooding of the compartment without opening, such as fitting indicator plugs to the manhole. Drainage arrangements are to be submitted to LR for approval.

### 3.2 Cargo holds

3.2.1 In ships having only one hold, and this over 30 m in length, bilge suctions are to be fitted in suitable positions in the fore and after sections of the hold.

3.2.2 Where close ceiling or continuous gusset plates are fitted over the bilges, arrangements are to be made whereby water in a hold compartment may find its way to the suction pipes.

# Ship Piping Systems

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3.2.3 Where the inner bottom plating extends to the ship's side, the bilge suctions are to be led to wells placed at the wings. If the tank top plating has inverse camber, a well is also to be fitted at the centreline, but in the case of trawlers and fishing vessels, a single well fitted at the centre may be accepted. For capacity and construction of bilge wells, see 7.6.

3.2.4 For drainage arrangements from refrigerated cargo spaces, see Pt 6, Ch 3,4.19.

3.2.5 For cargo holds having non-weathertight hatch covers or where hatch covers have been omitted, drainage arrangements are to take into account the effects of additional water ingress into the hold(s). High level bilge alarms are to be provided in cargo holds having non-weathertight hatch covers or where hatch covers have been omitted, see also Pt 4, Ch 8,11.

3.2.6 Drainage arrangements of cargo holds intended for the carriage of flammable or toxic liquids are to be designed to prevent inadvertent drainage of such products through machinery space piping systems.

### 3.3 Holds and deep tanks for alternative carriage of liquid or dry cargo

3.3.1 Where holds and deep tanks are intended for the alternative carriage of liquid or dry cargo, the drainage arrangements are to be in accordance with the following:

- (a) For dry cargoes, 3.1 and 3.2.
- (b) For water ballast, oil fuel or cargo oil having a flash point of 60°C or above, 3.4.
- (c) For cargo oil having a flash point below 60°C, Chapter 15.

3.3.2 For blanking arrangements of filling and suction pipes, see 7.12.

### 3.4 Tanks and cofferdams

3.4.1 All tanks (including double bottom tanks), whether used for water ballast, oil fuel or liquid cargoes, are to be provided with suction pipes, led to suitable power pumps, from the after end of each tank.

3.4.2 In general, the drainage arrangements are to be in accordance with 3.1. However, where the tanks are divided by longitudinal watertight bulkheads or girders into two or more tanks, a single suction pipe, led to the after end of each tank, will normally be acceptable.

3.4.3 Similar drainage arrangements are to be provided for cofferdams, except that the suctions may be led to the main bilge line.

3.4.4 The pumping arrangements for tanks that are intended to carry cargo oil having a flash point of 60°C or above, are also to comply with the requirements of Chapter 14, Sections 2, 3 and 4, as far as they are applicable.

### 3.5 Fore and after peaks

3.5.1 Fuel oil, lubrication oil and other flammable liquids are not to be carried in forepeak tanks.

3.5.2 Where the peaks are used as tanks, a power pump suction is to be led to each tank, except in the case of small tanks used for the carriage of domestic fresh water, where hand pumps may be used.

3.5.3 Where the peaks are not used as tanks, and main bilge line suctions are not fitted, drainage of both peaks may be effected by hand pump suctions, provided that the suction lift is well within the capacity of the pumps and in no case exceeds 7,3 m. In the case of trawlers and fishing vessels, drainage of the after peak may be effected by means of a self-closing cock fitted in a well lighted and readily accessible position.

3.5.4 Except as permitted by 3.5.5, the collision bulkhead is not to be pierced below the bulkhead deck by more than one pipe for dealing with the contents of the fore peak. The pipe is to be provided with a screw-down valve capable of being operated from an accessible position above the bulkhead deck, the chest being secured to the bulkhead inside the fore peak. An indicator is to be provided to show whether the valve is open or closed. The valves may be fitted on the after side of the collision bulkhead, provided that the valve is readily accessible under all service conditions and the space in which it is located is not a cargo space.

3.5.5 Where the fore peak is divided into two compartments, the collision bulkhead may be pierced below the bulkhead deck by two pipes (i.e., one for each compartment) provided there is no practical alternative to the fitting of a second pipe. Each pipe is to be provided with a screw-down valve, fitted and controlled as in 3.5.4.

### 3.6 Spaces above fore peaks, after peaks and machinery spaces

3.6.1 Provision is to be made for the drainage of the chain locker and watertight compartments above the fore peak tank by hand or power pump suctions.

3.6.2 Steering gear compartments or other small enclosed spaces situated above the after peak tank are to be provided with suitable means of drainage, either by hand or power pump bilge suctions.

3.6.3 Subject to special approval of any applicable subdivision requirements, compartments referred to in 3.6.2 that are adequately isolated from the adjacent 'tween decks, may be drained by scuppers of not less than 38 mm bore, discharging to the tunnel (or machinery space in the case of ships with machinery aft) and fitted with self-closing cocks situated in well lighted and visible positions.

3.6.4 In case of trawlers and fishing vessels, accommodation spaces which overhang the machinery space, may also be drained as in 3.6.3.

3.6.5 For drainage of the fore and after peaks, see 3.5.



# Ship Piping Systems

## Part 5, Chapter 13

Sections 3 & 4

### 3.7 Maintenance of integrity of bulkheads

3.7.1 The intactness of the machinery space bulkheads, and of tunnel plating required to be of watertight construction, is not to be impaired by the fitting of scuppers discharging to machinery space or tunnels from adjacent compartments which are situated below the bulkhead deck. These scuppers may, however, be led into a strongly constructed scupper drain tank situated in the machinery space or tunnel, but closed to these spaces and drained by means of a suction of appropriate size led from the main bilge line through a screw-down non-return valve.

3.7.2 The scupper tank air pipe is to be led to above the bulkhead deck, and provision is to be made for ascertaining the level of water in the tank.

3.7.3 Where one tank is used for the drainage of several watertight compartments, the scupper pipes are to be provided with screw-down non-return valves.

3.7.4 No drain valve or cock is to be fitted to the collision bulkhead. Drain valves or cocks are not to be fitted to other watertight bulkheads if alternative means of drainage are practicable.

3.7.5 Where drain valves or cocks are fitted to bulkheads other than the collision bulkhead, as permitted by 3.7.4, the drain valves or cocks are to be at all times readily accessible and are to be capable of being shut off from positions above the bulkhead deck. Indicators are to be provided to show whether the drains are open or shut. These arrangements are not permissible in passenger ships.

3.7.6 Bilge drain valves or cocks may be used for draining accommodation spaces and the after dry peak of trawlers and fishing vessels as stated in 3.6.4 and 3.5.3.

3.7.7 For drainage of stern compartment, see 3.6.

### ■ Section 4 Bilge drainage of machinery spaces

#### 4.1 General

4.1.1 The bilge drainage arrangements in the machinery space are to comply with 3.1, except that the arrangements are to be such that any water which may enter this compartment can be pumped out through at least two bilge suction when the ship is on an even keel, and is either upright or has a list of not more than 5°. One of these suction is to be a branch bilge suction, i.e., a suction connected to the main bilge line, and the other is to be a direct bilge suction, i.e., a suction led direct to an independent power pump. Examples of the necessary arrangements are detailed in 4.2 and 4.3.

4.1.2 In passenger ships, the drainage arrangements are to be such that machinery spaces can be pumped out under all practical conditions after a casualty, whether the ship is upright or listed.

### 4.2 Machinery space with double bottom

4.2.1 Where the double bottom extends the full length of the machinery space and forms bilges at the wings, it will be necessary to provide one branch and one direct bilge suction at each side.

4.2.2 Where the double bottom plating extends the full length and breadth of the compartment, one branch bilge suction and one direct bilge suction are to be led to each of two bilge wells, situated one at each side.

4.2.3 For capacity and construction of bilge wells, see 7.6.

### 4.3 Machinery space without double bottom

4.3.1 Where there is no double bottom and the rise of floor is not less than 5°, one branch and one direct bilge suction are to be led to accessible positions as near the centreline as practicable.

4.3.2 In ships where the rise of floor is less than 5°, and in all passenger ships, additional bilge suction are to be provided at the wings.

### 4.4 Additional bilge suction

4.4.1 Additional bilge suction may be required for the drainage of depressions in the tank top formed by crankpits, or other recesses, by tank tops having inverse camber or by discontinuity of the double bottom.

4.4.2 In ships in which the propelling machinery is situated at the after end of the ship, it will generally be necessary for bilge suction to be fitted in the forward wings as well as in the after end of the machinery space, but each case will be dealt with according to the size and structural arrangements of the compartment.

4.4.3 In ships propelled by electrical machinery, special means are to be provided to prevent the accumulation of bilge water under the main propulsion generators and motors.

### 4.5 Separate machinery spaces

4.5.1 Where the machinery space is divided by watertight bulkheads to separate the boiler room(s), or auxiliary engine room(s) from the main engine room, the number and position of the branch bilge suction in the boiler room(s) or auxiliary engine room(s) are to be the same as for cargo holds.

4.5.2 In addition to the branch bilge suction, required by 4.5.1, at least one independent power pump direct bilge suction is to be fitted in each compartment. Similar provision is to be made in separate motor rooms of electrically propelled ships.

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4.5.3 In passenger ships, each independent bilge pump is to have a direct bilge suction from the space in which it is situated, but not more than two such suctions are required in any one space. Where two or more such suctions are provided, there is to be at least one suction on each side of the space.

## 4.6 Machinery space – Emergency bilge drainage

4.6.1 In addition to the bilge suctions detailed in 4.1 to 4.5, an emergency bilge suction is to be provided in each main machinery space. This suction is to be led to the main cooling water pump from a suitable low level in the machinery space and is to be fitted with a screw-down non-return valve having the spindle so extended that the hand wheel is not less than 460 mm above the bottom platform.

4.6.2 Where two or more cooling water pumps are provided, each capable of supplying cooling water for normal power, only one pump need be fitted with an emergency bilge suction.

4.6.3 In ships with steam propelling machinery, the suction is to have a diameter of at least two-thirds that of the pump suction. In other ships, the suction is to be the same size as the suction branch of the pump.

4.6.4 Where main cooling water pumps are not suitable for bilge pumping duties, the emergency bilge suction is to be led to the largest available power pump, which is not a bilge pump detailed in 6.1 and 6.2. This pump is to have a capacity not less than that required for a bilge pump and the bilge suction is to be the same size as that of the pump suction branch.

4.6.5 Where the pump to which the emergency bilge suction is connected is of the self-priming type, the direct bilge suction on the same side of the ship as the emergency suction may be omitted, except in passenger ships.

4.6.6 Emergency bilge suction valve nameplates are to be marked 'For emergency use only'.

4.6.7 Where **UMS** (Unattended Machinery Space) notation is to be assigned, the requirements of Pt 6, Ch 1,4.6.2 are not applicable for valves serving an emergency bilge system, provided that:

- (a) the emergency bilge valve is normally maintained in a closed position;
- (b) a non-return device is installed in the emergency bilge piping; and
- (c) the emergency bilge suction piping is located inboard of a shell valve that is fitted with the control arrangements complying with Pt 6, Ch 1,4.6.2.

## 4.7 Tunnel drainage

4.7.1 The tunnel well is to be drained by a suction from the main bilge line. In all ships, including passenger ships, this well may extend to the outer bottom.

4.7.2 Where the tank top in the tunnel slopes down from aft to forward, a bilge suction is to be provided at the forward end of the tunnel, in addition to the tunnel well suction required by 4.7.1.

## Section 5 Sizes of bilge suction pipes

### 5.1 Main bilge line

5.1.1 The diameter,  $d_m$ , of the main bilge line is to be not less than required by the following formula, to the nearest 5 mm, but in no case is the diameter to be less than that required for any branch bilge suction:

$$d_m = 1,68 \sqrt{L (B + D)} + 25 \text{ mm}$$

where

- $d_m$  = internal diameter of main bilge line, in mm
- $B$  = greatest moulded breadth of ship or maximum breadth of cargo hold for ore carriers, in metres
- $D$  = moulded depth to bulkhead deck, in metres
- $L$  = Rule length of ship as defined in Pt 3, Ch 1,6.1, in metres, for ships other than passenger ships
- = length between perpendiculars at the extremities of the deepest subdivision load line, in metres, for passenger ships.

### 5.2 Branch bilge suctions to cargo and machinery spaces

5.2.1 The diameter,  $d_b$ , of branch bilge suction pipes to cargo and machinery spaces is to be not less than required by the following formula, to the nearest 5 mm, but in no case is the diameter of any suction to be less than 50 mm:

$$d_b = 2,15 \sqrt{C (B + D)} + 25 \text{ mm}$$

where

- $d_b$  = internal diameter of branch bilge suction, in mm
- $C$  = length of compartment, in metres, and
- $B$  and  $D$  are as defined in 5.1.1.

### 5.3 Direct bilge suctions, other than emergency suctions

5.3.1 The direct bilge suctions in the main engine room, and the direct bilge suctions in large separate boiler rooms, motor rooms of electrically propelled ships and auxiliary engine rooms are not to be of a diameter less than that required for the main bilge line.

5.3.2 Where the separate machinery spaces are of small dimensions, the sizes of the direct bilge suctions to these spaces will be specially considered.

5.3.3 For sizes of emergency bilge suctions, see 4.6.



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### 5.4 Main bilge line – Tankers and similar ships

5.4.1 In oil tankers and similar ships, where the engine room pumps do not deal with bilge drainage outside the machinery space, the diameter of the main bilge line may be less than that required by the formula in 5.1.1, provided that the cross-sectional area is not less than twice that required for the branch bilge suction in the machinery space.

### 5.5 Distribution chest branch pipes

5.5.1 The area of each branch pipe connecting the bilge main to a distribution chest is to be not less than the sum of the areas required by the Rules for the two largest branch bilge suction pipes connected to that chest, but need not be greater than that required for the main bilge line.

### 5.6 Tunnel suction

5.6.1 The bilge suction pipe to the tunnel well is to be not less than 65 mm bore, except in ships not exceeding 60 m in length, in which case it may be 50 mm bore.

## Section 6 Pumps on bilge service and their connections

### 6.1 Number of pumps

6.1.1 For ships other than passenger ships, at least two power bilge pumping units are to be provided in the machinery space. In ships of 90 m in length and under, one of these units may be worked from the main engines and the other is to be independently driven. In larger ships both units are to be independently driven.

6.1.2 Each unit may consist of one or more pumps connected to the main bilge line, provided that their combined capacity is adequate.

6.1.3 In ships other than passenger ships, a bilge ejector in combination with a high pressure sea-water pump may be accepted as a substitute for an independent bilge pump as required by 6.1.1.

6.1.4 Special consideration will be given to the number of pumps for small ships and, in general, if there is a class notation restricting a small ship to harbour or river service, a hand pump may be accepted in lieu of one of the bilge pumping units.

6.1.5 For passenger ships, at least three power bilge pumps are to be provided, one of which may be operated from the main engines. Where the bilge pump numeral as derived from Regulation 35-1 of Chapter II-1 of the *International Convention for the Safety of Life at Sea, 1974*, and applicable amendments, is 30 or more, one additional independent power pump is to be provided.

6.1.6 For location of pumps on passenger ships, see 8.1.

### 6.2 General service pumps

6.2.1 The bilge pumping units, or pumps, required by 6.1 may also be used for ballast, fire or general service duties of an intermittent nature, but they are to be immediately available for bilge duty when required, see *also* SOLAS 1974 as amended Reg. II-2/C, 10, as applicable.

### 6.3 Capacity of pumps

6.3.1 Each bilge pumping unit, or bilge pump in the case of passenger ships, is to be connected to the main bilge line and is to be capable of giving a speed of water through the Rule size of main bilge pipe of not less than 122 m/min.

6.3.2 The capacity of each bilge pumping unit or bilge pump is to be not less than required by the following formula:

$$Q = \frac{5,75}{10^3} d_m^2$$

where

$d_m$  = Rule internal diameter of main bilge line, in mm

$Q$  = capacity, in m<sup>3</sup>/hour.

6.3.3 In ships other than passenger ships, where one bilge pumping unit is of slightly less than Rule capacity, the deficiency may be made good by an excess capacity of the other unit. In general, the deficiency is to be limited to 30 per cent.

### 6.4 Self-priming pumps

6.4.1 All power pumps which are essential for bilge services are to be of the self-priming type, unless an approved central priming system is provided for these pumps. Details of this system are to be submitted.

6.4.2 Cooling water pumps having emergency bilge suction need not be of the self-priming type.

6.4.3 For requirements regarding emergency bilge suction, see 4.6.

### 6.5 Pump connections

6.5.1 The connections at the bilge pumps are to be such that one unit may continue in operation when the other unit is being opened up for overhaul.

6.5.2 Pumps required for essential services are not to be connected to a common suction or discharge chest or pipe unless the arrangements are such that the working of any pumps so connected is unaffected by the other pumps being in operation at the same time.

# Ship Piping Systems

## Part 5, Chapter 13

Sections 6 &amp; 7

### 6.6 Direct bilge suction

6.6.1 The direct bilge suction in the machinery space(s) are to be led to independent power pump(s), and the arrangements are to be such that these direct suction can be used independently of the main bilge line suction.

## Section 7 Piping systems and their fittings

### 7.1 Main bilge line suction

7.1.1 Suctions from the main bilge line, i.e., branch bilge suction, are to be arranged to draw water from any hold, compartment, watertight section or machinery compartment of the ship, excepting small spaces such as those mentioned in 3.1.6, 3.5 and 3.6, where manual pump suction are accepted, and are not to be of smaller diameter than that required by the formula in 5.2.1, see also 7.4.1 and 7.5.1. For special arrangements for oil tankers, see Chapter 15.

7.1.2 Where passenger or cargo ships are of a design having enclosed car decks or cargo spaces located on the bulkhead deck or on the freeboard deck, special consideration will be given to the drainage arrangements where any fixed pressure water spray system is fitted, see also Pt 3, Ch 12,4.1 and 9.1.

### 7.2 Prevention of communication between compartments

7.2.1 The arrangement of valves, cocks and their connections is to be such as to prevent the possibility of one watertight compartment being placed in communication with another, or of dry cargo spaces, machinery spaces or other dry compartments being placed in communication with the sea or with tanks. For this purpose, screw-down non-return valves are to be provided in the following fittings:

- Bilge valve distribution chests.
- Bilge suction hose connections, whether fitted direct to the pump or on the main bilge line.
- Direct bilge suction and bilge pump connections to main bilge line.

### 7.3 Isolation of bilge system

7.3.1 Bilge pipes which are required for draining cargo or machinery spaces are to be entirely distinct from sea inlet pipes or from pipes which may be used for filling or emptying spaces where water or oil is carried. This does not, however, exclude a bilge ejection connection, a connecting pipe from a pump to its suction valve chest, or a deep tank suction pipe suitably connected through a changeover device to a bilge, ballast or oil line.

### 7.4 Machinery space suction – Mud boxes

7.4.1 Suctions for bilge drainage in machinery spaces and tunnels, other than emergency suction, are to be led from easily accessible mud boxes fitted with straight tail pipes to the bilges and having covers secured in such a manner as to permit their being expeditiously opened or closed. Strum boxes are not to be fitted to the lower ends of these tail pipes or to the emergency bilge suction.

### 7.5 Hold and other compartment suction – Strum boxes

7.5.1 The open ends of bilge suction in holds and other compartments outside machinery spaces and tunnels such as cofferdams and tanks other than those permanently arranged for the carriage of fresh water, water ballast, oil fuel or liquid cargo and for which other efficient means of pumping are provided, are to be enclosed in strum boxes having perforations of not more than 10 mm diameter, whose combined area is not less than twice that required for the suction pipe. The boxes are to be so constructed that they can be cleared without breaking any joint of the suction pipe.

### 7.6 Bilge wells

7.6.1 Bilge wells required by 3.2.3 and 4.2.2 are to be formed of steel plates and are to be not less than 0,15 m<sup>3</sup> capacity. In small compartments, steel bilge hats of reasonable capacity may be fitted.

7.6.2 In passenger ships, the depth of bilge wells in double bottom tanks will be specially considered.

7.6.3 Where access manholes to bilge wells are necessary, they are to be fitted as near to the suction strums as practicable.

### 7.7 Tail pipes

7.7.1 The distance between the foot of all bilge tail pipes and the bottom of the bilge well is to be adequate to allow a full flow of water and to facilitate cleaning.

### 7.8 Location of fittings

7.8.1 Bilge valves, cocks and mud boxes are to be fitted at, or above, the machinery space and tunnel platforms. Where it is not practicable to avoid the fittings being situated at the starting platform or in passageways, they may be situated just below the platform, provided readily removable traps or covers are fitted and nameplates indicate the presence of these fittings.

7.8.2 Where relief valves are fitted to pumps having sea connections, these valves are to be fitted in readily visible positions above the platform. The arrangements are to be such that any discharge from the relief valves will also be readily visible.

# Ship Piping Systems

## Part 5, Chapter 13

Sections 7 & 8

### 7.9 Bilge pipes in way of double bottom tanks

7.9.1 Bilge suction pipes are not to be led through double bottom tanks if it is possible to avoid doing so.

7.9.2 Bilge pipes which have to pass through these tanks are to have a wall thickness in accordance with Table 12.2.4 in Chapter 12. (The thickness of pipes made from material other than steel will be specially considered).

7.9.3 Expansion bends, not glands, are to be fitted to these pipes within the tanks, and the pipes are to be tested, after installation, to the same pressure as the tanks through which they pass.

### 7.10 Bilge pipes in way of deep tanks

7.10.1 In way of deep tanks, bilge pipes should preferably be led through pipe tunnels but, where this is not done, the pipes are to be of steel, having a wall thickness in accordance with Table 12.2.4 in Chapter 12, with welded joints or heavy flanged joints. The number of joints is to be kept to a minimum.

7.10.2 Expansion bends, not glands, are to be fitted to these pipes within the tanks, and the open ends of the bilge suction pipes in the holds are to be fitted with non-return valves of the special type approved for use in holds, see 7.11.1.

7.10.3 The pipes are to be tested, after installation, to a pressure not less than the maximum head to which the tanks can be subjected in service.

### 7.11 Hold bilge non-return valves

7.11.1 Where non-return valves are fitted to the open ends of bilge suction pipes in cargo holds in order to decrease the risk of flooding, they are to be of an approved type which does not offer undue obstruction to the flow of water.

### 7.12 Blanking arrangements

7.12.1 In case of deep tanks and cargo holds which may be used for either water ballast or dry cargo, provision is to be made for blank flanging the water ballast filling and suction pipes when the tank or hold is being used for the carriage of dry cargo, and for blank flanging the bilge suction pipes when the tank or hold is being used for the carriage of water ballast. Change-over devices may be used for this purpose.

7.12.2 For arrangements when oil fuel or cargo oil (having a flash point of 60°C or above) is carried in deep tanks, see Ch 14.4.14.

7.12.3 Where a ship is designed for the alternative carriage of dry cargo or oil having a flash point below 60°C, the blanking arrangements will be specially considered.

### Section 8

## Additional requirements for bilge drainage and cross-flooding arrangements for passenger ships

### 8.1 Location of bilge pumps and bilge main

8.1.1 In passenger ships, the power bilge pumps required by 6.1.5 are to be placed, if practicable, in separate watertight compartments which will not readily be flooded by the same damage. If the engines and boilers are in two or more watertight compartments, the bilge pumps are to be distributed throughout these compartments so far as is possible.

8.1.2 In passenger ships of 91,5 m or more in length, or having a bilge pump numeral of 30 or more (see 6.1.5), the arrangements are to be such that at least one power pump will be available for use in all ordinary circumstances in which the ship may be flooded at sea. This requirement will be satisfied if:

- one of the pumps is an emergency pump of a submersible type having a source of power situated above the bulk-head deck, or
- the pumps and their sources of power are so disposed throughout the length of the ship that, under any conditions of flooding which the ship is required by statutory regulation to withstand, at least one pump in an undamaged compartment will be available.

8.1.3 The bilge main is to be so arranged that no part is situated nearer the side of the ship than  $\frac{B}{5}$ , measured at right angles to the centreline at the level of the deepest subdivision load line, where  $B$  is the breadth of the ship.

8.1.4 Where any bilge pump or its pipe connection to the bilge main is situated outboard of the  $\frac{B}{5}$  line, then a non-return valve is to be provided in the pipe connection at the junction with the bilge main. The emergency bilge pump and its connections to the bilge main are to be so arranged that they are situated inboard of the  $\frac{B}{5}$  line.

### 8.2 Prevention of communication between compartments in the event of damage

8.2.1 Provision is to be made to prevent the compartment served by any bilge suction pipe being flooded, in the event of the pipe being severed, or otherwise damaged by collision or grounding in any other compartment. For this purpose, where the pipe is at any part situated nearer the side of the ship than  $\frac{B}{5}$  or in a duct keel, a non-return valve is to be fitted to the pipe in the compartment containing the open end.

# Ship Piping Systems

## Part 5, Chapter 13

Sections 8, 9 &amp; 10

### 8.3 Arrangement and control of bilge valves

8.3.1 All the distribution boxes, valves and cocks in connection with the bilge pumping arrangements are to be so arranged that, in the event of flooding, one of the bilge pumps may be operative on any compartment. If there is only one system of pipes common to all pumps, the necessary valves or cocks for controlling the bilge suctions must be capable of being operated from the bulkhead deck. Where, in addition to the main bilge pumping system, an emergency bilge pumping system is provided, it is to be independent of the main system and so arranged that a pump is capable of operating on any compartment under flooding conditions; in this case, only the valves and cocks necessary for the operation of the emergency system need be capable of being operated from above the bulkhead deck.

8.3.2 All valves and cocks mentioned in 8.3.1 which can be operated from above the bulkhead deck are to have their controls at their place of operation clearly marked and provided with means to indicate whether they are open or closed.

### 8.4 Cross-flooding arrangements

8.4.1 Where divided deep tanks or side tanks are provided with cross-flooding arrangements to limit the angle of heel after side damage, the arrangements are to be self-acting where practicable. In any case, where controls to cross-flooding fittings are provided, they are to be operable from above the bulkhead deck.

## Section 9 Additional requirements relating to fixed pressure water spray fire-extinguishing systems

### 9.1 Bilge drainage requirements

9.1.1 Where arrangements for cooling cargo, Ro-Ro or special category spaces below the bulk-head or freeboard deck, or fire-fighting by means of fixed spraying nozzles or by flooding of these spaces with water are provided, the following provisions are to apply, see also IMO guidelines (MSC.1/Circ.1320):

- The drainage system is to be sized to remove no less than 125 per cent of the combined capacity of both the water spraying system pumps and the required number of fire hose nozzles.
- The drainage system valves are to be operable from outside the protected space at a position in the vicinity of the extinguishing system controls.
- Adequately sized bilge wells are to be located at the side shell of the ship at a distance from each other of not more than 40 m in each watertight compartment, the bilge wells should be uniformly distributed fore and aft, see also Pt 3, Ch 12, 4.1.4 and Pt 4, Ch 2, 11.2. For cargo ships only, if this is not possible, the free surface effect on the ship's stability is to be determined and submitted to the Flag Administration for appraisal.

9.1.2 If drainage of vehicle or cargo spaces is by gravity, the drainage is to be led directly overboard or to a closed drain tank. If led overboard the scuppers are to comply with Pt 3, Ch 12, 4.1.3. If led to a closed drain tank, this tank is to be located outside the machinery spaces and provided with a vent pipe leading to a safe location on the open deck. See also Pt 4, Ch 2, 11.2.

9.1.3 Drainage from a cargo space into bilge wells in a lower space is only permitted if that space satisfies the same requirements as the cargo space above.

9.1.4 On ships with closed vehicle spaces, ro-ro spaces and special category spaces, means are to be provided to prevent the blockage of drainage systems from these spaces.

## Section 10 Drainage arrangements for ships not fitted with propelling machinery

### 10.1 Hand pumps

10.1.1 Where auxiliary power is not provided, hand pumps are to be fitted, in number and position, as may be required for the efficient drainage of the ship.

10.1.2 In general, one hand pump is to be provided for each compartment. Alternatively, two pumps connected to a bilge main, having at least one branch to each compartment, are to be provided.

10.1.3 The pumps are to be capable of being worked from the upper deck or from positions above the load waterline which are at all times readily accessible. The suction lift is not to exceed 7,3 m and is to be well within the capacity of the pump.

10.1.4 The sizes of the hand pumps are to be not less than those given in Table 13.10.1. Where the ship is closely subdivided into small watertight compartments, 50 mm bore suctions will be accepted.

**Table 13.10.1 Sizes of hand pumps**

Tonnage under upper deck	Diameter of barrel of bucket pump mm	Bore of suction pipe of bucket pumps and semi-rotary pumps mm
Not exceeding 500 tons	100	50
Above 500 tons but not exceeding 1000 tons	115	57
Above 1000 tons but not exceeding 2000 tons	125	65
Above 2000 tons	140	70

# Ship Piping Systems

## Part 5, Chapter 13

Sections 10, 11 & 12

### 10.2 Ships with auxiliary power

**10.2.1** In ships in which auxiliary power is available on board, power pump suction is to be provided for dealing with the drainage of tanks and of the bilges of the principal compartments.

**10.2.2** The pumping arrangements are to be as required for self-propelled ships, so far as these requirements are applicable, duly modified to suit the size and service of the ship.

**10.2.3** Details of the pumping arrangements are to be submitted for special consideration.

## Section 11 Ballast system

### 11.1 Stand-by arrangements for ballast pumping

**11.1.1** Where ballasting/de-ballasting is required for ship operation or trading purposes stand-by ballast pumping arrangements are to be provided, see also 6.2.1 and Ch 15,2.4.4.

### 11.2 Integrated cargo and ballast systems

**11.2.1** Where ballast and cargo systems share power supplies and/or control engineering systems, the additional requirements of this sub-Section apply.

**11.2.2** A failure is not to prevent operation of the ballast system by other means.

**11.2.3** Controls to stop the cargo system, including normal controls and emergency stop and safety shut-downs, are not to prevent operation of the ballast system.

### 11.3 Ballast water treatment system installations

**11.3.1** Failure of a ballast water treatment system is not to impair or restrict ballasting or de-ballasting operations.

**11.3.2** Failure of a ballast water treatment system shall not impair or restrict any other essential system as defined by Pt 6, Ch 2,1.5.

**11.3.3** Ballast water treatment systems are to be installed on a by-pass arrangement, designed to ensure that the treatment system can be efficiently isolated from the ballast water system without impairing ballast water flow.

**11.3.4** Pipe work associated with ballast water treatment systems units is to meet the requirements of Table 12.5.3 in Chapter 12.

**11.3.5** Valves are to comply with the requirements of Ch 12,6.

**11.3.6** All electrical equipment forming part of ballast water treatment units is to meet the applicable requirements of Pt 6, Ch 2. Hazardous areas associated with ballast water treatment system installations are to be determined in accordance with the requirements of Pt 6, Ch 2,14.

**11.3.7** Any deck and bulkhead penetrations are to meet the requirements of Section 1.

**11.3.8** Arrangements for transferring ballast water from non-hazardous to hazardous areas is only permitted where:

- There is no ballast water supply from hazardous areas to non-hazardous areas.
- Ballast water from the non-hazardous area is discharged to a hazardous area with the piping provided with two non-return valves installed in series.
- All pipe penetrations from the non-hazardous area to the hazardous area are led above main deck level.
- Engine room and pump-room bulkheads are not to be penetrated.

## Section 12 Air, overflow and sounding pipes

### 12.1 Definitions

**12.1.1** Reference to cargo oil in this Section is to be taken to mean cargo oil which has a flash point 60°C or above (closed cup test).

### 12.2 Materials

**12.2.1** Air, overflow and sounding pipes are to be made of steel or other approved material. For use of plastics pipes of approved type, see Chapter 12.

**12.2.2** The portions of air, overflow and sounding pipes fitted above the weather deck are to be of steel or equivalent material.

### 12.3 Nameplates

**12.3.1** Nameplates are to be affixed to the upper ends of all air and sounding pipes.

### 12.4 Air pipes

**12.4.1** Air pipes are to be fitted to all tanks, cofferdams, tunnels and other compartments which are not fitted with alternative ventilation arrangements.

**12.4.2** The air pipes are to be fitted at the opposite end of the tank to that which the filling pipes are placed and/or at the highest part of the tank. Where the tank top is of unusual or irregular profile, special consideration will be given to the number and position of the air pipes.



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Section 12

12.4.3 For a normally inaccessible small void compartment such as an echo sounding compartment, which is accessed from within a normally inaccessible space such as a forepeak tank, alternative air pipe arrangements to those required by 12.4.1 may be considered. For such arrangements, a warning notice is to be located in a prominent position specifying the precautions to be taken prior opening the manhole and entering the small void compartment. Ventilation arrangements are to be submitted to LR for approval.

### 12.5 Termination of air pipes

12.5.1 Air pipes to double bottom tanks, deep tanks extending to the shell plating, or tanks which can be run up from the sea are to be led to above the bulkhead deck. Air pipes to oil fuel and cargo oil tanks, cofferdams and all tanks which can be pumped up are to be led to the open. For height of air pipes above deck, see Pt 3, Ch 12,3.

12.5.2 Air pipes from storage tanks containing lubricating or hydraulic oil may terminate in the machinery space, provided that the open ends are so situated that issuing oil cannot come into contact with electrical equipment or heated surfaces. Air pipes from heated lubricating oil tanks are to be led to the open.

12.5.3 The open ends of air pipes to oil fuel and cargo oil tanks are to be situated where no danger will be incurred from issuing oil vapour when the tank is being filled.

12.5.4 The location and arrangement of air pipes for oil fuel service, settling and lubricating oil tanks are to be such that in the event of a broken vent pipe, this does not directly lead to the risk of ingress of sea-water or rainwater.

12.5.5 For special requirements for the termination of air pipes on ferries, see Pt 3, Ch 12,3 and Pt 4, Ch 2,11.

### 12.6 Gauze diaphragms

12.6.1 The open ends of air pipes to oil fuel and cargo oil tanks are to be furnished with a wire gauze diaphragm of incorrodible material which can be readily removed for cleaning or renewal.

12.6.2 Where wire gauze diaphragms are fitted at air pipe openings, the area of the opening through the gauze is to be not less than the cross-sectional area required for the pipe, see 12.8.

### 12.7 Air pipe closing appliances

12.7.1 The closing appliances fitted to tank air pipes in accordance with Pt 3, Ch 12,3 are to be of an automatic opening type which will allow the free passage of air or liquid to prevent the tanks being subjected to a pressure or vacuum greater than that for which they are designed.

12.7.2 Air pipe closing devices are to be of a type acceptable to Lloyd's Register (hereinafter referred to as 'LR') and are to be tested in accordance with a National or International Standard recognised by LR. The flow characteristic of the closing device is to be determined using water, see 12.8.1 and 12.8.2.

12.7.3 Wood plugs and other devices which can be secured closed are not to be fitted at the outlets.

12.7.4 Air pipe automatic closing devices shall be so designed that they will withstand both ambient conditions as indicated in Pt 5, Ch 1,3.5 and 3.6 and designed working conditions, and be suitable for use at inclinations up to and including  $\pm 40^\circ$ .

12.7.5 Air pipe automatic closing devices shall be constructed to allow inspection of the closure and the inside of the casing as well as changing the seals.

12.7.6 Efficient ball or float seating arrangements are to be provided for the closures. Bars, cages or other devices are to be provided to prevent the ball or float from contacting the inner chamber in its normal state, and made in such a way that the ball or float is not damaged when subjected to liquid impact due to a tank being overfilled.

12.7.7 Air pipe automatic closing devices are to be self-draining.

12.7.8 The clear area through an air pipe closing device in the open position shall be at least equal to the area of the inlet.

12.7.9 In the case of air pipe closing devices of the float type, suitable guides are to be provided to ensure unobstructed operation under all working conditions of heel and trim.

12.7.10 The maximum allowable tolerances for wall thickness of floats shall not exceed  $\pm 10$  per cent of thickness.

12.7.11 The inner and the outer chambers of an automatic air pipe head are to be of a minimum thickness of 6 mm.

12.7.12 Casings of air pipe closing devices are to be of approved metallic materials, adequately protected against corrosion.

12.7.13 For galvanised steel air pipe heads, the zinc coating is to be applied by the hot method and the thickness is to be 70 to 100 microns.

12.7.14 For areas of the head susceptible to erosion (e.g., those parts directly subjected to ballast water impact when the tank is being pressed up, such as the inner chamber area above the air pipe plus an overlap of  $10^\circ$  or more either side) an additional harder coating should be applied. This is to be an aluminium-bearing epoxy, or other equivalent coating, applied over the zinc.



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12.7.15 Closures and seats made of non-metallic materials are to be compatible with the media intended to be carried in the tank and to sea-water, and suitable for operating at ambient temperatures between  $-25^{\circ}\text{C}$  and  $85^{\circ}\text{C}$ .

## 12.8 Size of air pipes

12.8.1 For every tank which can be filled by the ship's pumps, the total cross-sectional area of the air pipes and the design of the air pipe closing devices are to be such that when the tank is overflowing at the maximum pumping capacity available for the tank, it will not be subjected to a pressure greater than that for which it is designed.

12.8.2 In all cases, whether a tank is filled by ship's pumps or other means, the total cross-sectional area of the air pipes is to be not less than 25 per cent greater than the effective area of the respective filling pipe.

12.8.3 Where tanks are fitted with cross flooding connections, the air pipes are to be of adequate area for these connections.

12.8.4 Air pipes are to be not less than 50 mm bore.

## 12.9 Overflow pipes

12.9.1 For all tanks which can be filled by the ship's pumps or by shore pumps, overflow pipes are to be fitted where:

- (a) The total cross-sectional area of the air pipe is less than that required by 12.8.
- (b) The pressure head corresponding to the height of the air pipe is greater than that for which the tank is designed.

12.9.2 In the case of oil fuel and lubricating oil tanks, the overflow pipe is to be led to an overflow tank of adequate capacity or to a storage tank having a space reserved for overflow purposes. Suitable means are to be provided to indicate when overflow is occurring, or when the contents reach a predetermined level in the tanks.

12.9.3 Overflow pipes are to be self draining under normal conditions of trim.

12.9.4 Where overflow sight glasses are provided, they are to be in a vertically dropping line and designed such that the oil does not impinge on the glass. The glass is to be of heat resisting quality, adequately protected from mechanical damage and well lit.

## 12.10 Air and overflow systems

12.10.1 Where a combined air or overflow system is fitted, the arrangement is to be such that in the event of any one of the tanks being bilged, tanks situated in other watertight compartments of the ship cannot be flooded from the sea through combined air pipes or the overflow main. For this purpose, it will normally be necessary to lead the overflow pipe to a point close to the bulkhead deck.

12.10.2 In the case of trawlers and fishing vessels, the arrangement is to be such that in the event of any one of the tanks being bilged, the other tanks cannot be flooded from the sea through the combined air pipes or the overflow main.

12.10.3 Where overflow from tanks which are used for the alternative carriage of oil and water ballast is connected to an overflow system, arrangements are to be made to prevent water ballast overflowing into tanks containing oil, see *also* Ch 14.4.14.

12.10.4 Where a common overflow main is provided, the main is to be sized to allow any two tanks connected to that main to overflow simultaneously.

## 12.11 Sounding arrangements

12.11.1 Provision is to be made for sounding all tanks and the bilges of those compartments which are not at all times readily accessible. The soundings are to be taken as near the suction pipes as practicable.

12.11.2 Bilges of compartments which are not at all times readily accessible are to be provided with sounding pipes.

12.11.3 Where fitted, sounding pipes are to be as straight as practicable, and if curved to suit the structure of the ship, the curvature must be sufficiently easy to permit the ready passage of the sounding rod or chain.

12.11.4 Sounding devices of approved type may be used in lieu of sounding pipes for sounding tanks. These devices are to be tested, after fitting on board, to the satisfaction of the Surveyors.

12.11.5 Where gauge glasses are used for indicating the level of liquid in tanks containing lubricating oil, oil fuel or other flammable liquid, the glasses are to be of the flat type of heat-resisting quality, adequately protected from mechanical damage, and fitted with self-closing valves at the lower ends and at the top ends if these are connected to the tanks below the maximum liquid level.

12.11.6 If means of sounding, other than a sounding pipe, is fitted in any ship for indicating the level of liquid in tanks containing oil fuel, lubricating oil or other flammable liquid, failure of such means or over filling of the tank should not result in the release of tank contents.

12.11.7 In passenger ships, sounding devices for oil fuel tanks, lubricating oil tanks and other tanks which may contain flammable liquids are to be of a type which does not require penetration below the top of the tank.

12.11.8 For a normally inaccessible small void compartment such as an echo sounding compartment, which is accessed from within a normally inaccessible space such as a forepeak tank, alternative sounding arrangements to those required by 12.11.1 may be considered. For such arrangements, a warning notice is to be located in a prominent position specifying precautions to be taken prior opening the manhole of the small void compartment. Means are to be provided to indicate flooding of the compartment without

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opening, such as fitting indicator plugs to the manhole. Sounding arrangements are to be submitted to LR for approval.

### 12.12 Termination of sounding pipes

12.12.1 Sounding pipes are to be led to positions above the bulkhead deck which are at all times accessible and, in the case of oil fuel tanks, cargo oil tanks, lubricating oil tanks and tanks containing other flammable oils, the sounding pipes are to be led to safe positions on the open deck.

12.12.2 For closing requirements, *see also* Pt 3, Ch 12,3.

### 12.13 Short sounding pipes

12.13.1 In machinery spaces and tunnels, in circumstances where it is not practicable to extend the sounding pipes as mentioned in 12.12, short sounding pipes extending to well lighted readily accessible positions above the platform may be fitted to double bottom tanks. Where such pipes serve tanks containing oil fuel or other flammable liquid, an additional sounding device of approved type is to be fitted. An additional sounding device is not required for lubricating oil tanks. Any proposal to terminate in the machinery space, sounding pipes to tanks, other than double bottom tanks, will be the subject of special consideration.

12.13.2 Short sounding pipes to oil fuel, cargo oil (flash point not less than 60°C), lubricating oil tanks and other flammable oil tanks (flash point not less than 60°C) are to be fitted with cocks having parallel plugs with permanently attached handles, so loaded that, on being released, they automatically close the cocks. In addition, a small diameter self-closing test cock is to be fitted below the cock mentioned above in order to ensure that the sounding pipe is not under a pressure of oil before opening-up the sounding cock. Provision is to be made to ensure that discharge of oil through this test cock does not present an ignition hazard. An additional small diameter self-closing test cock is not required for lubricating oil tanks.

12.13.3 As a further precaution against fire, such sounding pipes are to be located in positions as far removed as possible from any heated surface or electrical equipment and, where necessary, effective shielding is to be provided in way of such surfaces and/or equipment.

12.13.4 In ships that are required to be provided with a double bottom, short sounding pipes, where fitted to double bottom tanks, are in all cases to be provided with self-closing cocks as described in 12.13.2.

12.13.5 Where a double bottom is not required to be fitted, short sounding pipes to tanks other than oil tanks are to be fitted with shut-off cocks or with screw caps attached to the pipes by chains.

12.13.6 In passenger ships, short sounding pipes are permissible only for sounding cofferdams and double bottom tanks situated in a machinery space, and are in all cases to be fitted with self-closing cocks as described in 12.13.2.

### 12.14 Elbow sounding pipes

12.14.1 Elbow sounding pipes are not to be used for deep tanks unless the elbows and pipes are situated within closed cofferdams or within tanks containing similar liquids. They may, however, be fitted to other tanks and may be used for sounding bilges, provided that it is not practicable to lead them direct to the tanks or compartments, and subject to any subdivision and damage stability requirements that may apply, *see* 1.2.1.

12.14.2 The elbows are to be of heavy construction and adequately supported.

12.14.3 In passenger ships, elbow sounding pipes are not permissible.

### 12.15 Striking plates

12.15.1 Striking plates of adequate thickness and size are to be fitted under open-ended sounding pipes.

12.15.2 Where slotted sounding pipes having closed ends are employed, the closing plugs are to be of substantial construction.

### 12.16 Sizes of sounding pipes

12.16.1 Sounding pipes are to be not less than 32 mm bore.

12.16.2 All sounding pipes, whether for compartments or tanks, which pass through refrigerated spaces or the insulation thereof, in which the temperatures contemplated are 0°C or below, are to be not less than 65 mm bore, *see also* 2.8.1 for insulation.

## Cross-references

For 'Ice Class' requirements, *see* Part 8.

For venting and gauging equipment for cargo tanks in oil tankers, *see* Ch 15,4 and Ch 15,5.

For control engineering equipment, *see* Pt 6, Ch 1.

For requirements relating to scuppers and sanitary discharges, *see* Pt 3, Ch 12.

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## Section 13 Additional requirements for drainage and pumping arrangements for bulk carriers

### 13.1 General requirements

13.1.1 Arrangements for drainage and pumping are to be in accordance with the requirements of SOLAS 1974 as amended, Chapter XII, Regulation 13.

13.1.2 On bulk carriers, the means for draining and pumping ballast tanks forward of the collision bulkhead and bilges of dry spaces any part of which extends forward of the foremost cargo hold are to be capable of being brought into operation from a readily accessible enclosed space, the location of which is accessible from the navigation bridge or propulsion machinery control positions without traversing exposed free-board or superstructure decks. Where pipes serving such tanks or bilges pierce the collision bulkhead, valve operation by means of remotely operated actuators may be accepted, as an alternative to the valve control specified in 3.5.4, provided that the location of such valve controls complies with this requirement.

### 13.2 Dewatering capability

13.2.1 The dewatering system for ballast tanks located forward of the collision bulkhead, and for bilges of dry spaces any part of which extends forward of the foremost cargo hold, is to be designed to remove water from the forward spaces at a rate of not less than  $320A \text{ m}^3/\text{h}$ , where  $A$  is the cross-sectional area in  $\text{m}^2$  of the largest air pipe or ventilator pipe connected from the exposed deck to a closed forward space that is required to be dewatered by these arrangements.

## Section 14 Water ingress detection arrangements

### 14.1 General requirements

14.1.1 Equipment for detecting the ingress of water in bulk carriers is to be fitted in accordance with the requirements of SOLAS 1974 as amended, Chapter XII, Regulation 12.

14.1.2 Equipment for detecting the ingress of water in single hold cargo ships is to be fitted in accordance with the requirements of SOLAS 1974 as amended, Chapter II-1, Regulation 25.

14.1.3 Flooding detection systems in passenger ships carrying 36 persons or more are to be fitted in accordance with the requirements of SOLAS 1974 as amended, Chapter II-1, Regulation 22-1.

14.1.4 Alarm and indicators specified in 14.2 to 14.4 are to be provided on the navigation bridge and, for passenger ships, additionally in the safety centre if located in a separate space from the navigation bridge.

14.1.5 Equipment required by 14.1.2 to 14.1.4 is to satisfy the applicable requirements of Pt 6, Ch 1.

14.1.6 Pt 6, Ch 1, 1.3.1 details applicable requirements for Survey at the manufacturer's works. At the initial installation and during each subsequent Complete Survey of Machinery alarm systems or Special Survey, the operation of the ingress detection arrangements is to be demonstrated to the satisfaction of the LR Surveyor.

14.1.7 Where alternative arrangements to those required by 14.1.2 to 14.1.4 are proposed, evidence is to be submitted for consideration by LR that demonstrates:

- water ingress will be detected in all areas considered necessary to reliably detect flooding of watertight spaces;
- responsible personnel will be effectively notified in the event of water ingress to allow for planned response; and
- acceptance by the National Administration with which the ship is registered.

### 14.2 Water ingress detection arrangements in bulk carriers

14.2.1 Bulk carriers are to be fitted with water level detectors:

- (a) in each cargo hold, giving audible and visual alarms, one when the water level above the inner bottom in any hold reaches a height of 0,5 m and another at a height not less than 15 per cent of the depth of the cargo hold but not more than 2 m. The water level detectors are to be fitted in the aft end of each cargo hold. For cargo holds which are used for water ballast, an alarm overriding device may be installed. The visual alarms are to clearly discriminate between the two different water levels detected in each hold;
- (b) in any ballast tank forward of the collision bulkhead required by Pt 3, Ch 3,4, giving an audible and visual alarm when the liquid in the tank reaches a level not exceeding 10 per cent of the tank capacity. An alarm overriding device may be installed to be activated when the tank is in use; and
- (c) in any dry or void space other than a chain cable locker, any part of which extends forward of the foremost cargo hold, giving an audible and visual alarm at a water level of 0,1 m above the deck. Such alarms need not be provided in enclosed spaces the volume of which does not exceed 0,1 per cent of the ship's maximum displacement volume.

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Section 14

### 14.3 Water ingress detection arrangements in single hold cargo ships

14.3.1 Ships having a length,  $L$ , of less than 80 m and a single cargo hold below the freeboard deck or cargo holds below the freeboard deck which are not separated by at least one bulkhead made watertight up to that deck, are to be fitted in such space or spaces with water level detectors.

14.3.2 The water level detectors required by 14.3.1 are to:

- (a) give an audible and visual alarm when the water level above the inner bottom in the cargo hold reaches a height of not less than 0,3 m, and another when such level reaches not more than 15 per cent of the mean depth of the cargo hold; and
- (b) be fitted at the aft end of the hold, or above its lowest part where the inner bottom is not parallel to the designed waterline. Where webs or partial watertight bulkheads are fitted above the inner bottom, the installation of additional detectors is to be considered.

14.3.3 The water level detectors required by 14.3.1 need not be fitted in ships complying with 14.2, or in ships having watertight side compartments each side of the cargo hold length which extend vertically at least from inner bottom to freeboard deck.

### 14.4 Flooding detection systems in passenger ships

14.4.1 Passenger ships for 36 persons or more are to be provided with a flooding detection system for watertight spaces below the bulkhead deck.

14.4.2 The flooding detection system required by 14.4.1 is to be fitted in all watertight spaces below the bulkhead deck that:

- (a) have a volume, in cubic metres, that is more than the ship's moulded displacement per centimetre immersion at deepest subdivision draught; or
- (b) have a volume more than 30 cubic metres, whichever is the greater.

14.4.3 Any watertight spaces that are individually equipped with a liquid level monitoring system (such as fresh water, ballast water, fuel, etc.), including an indicator panel or other means of monitoring at the navigation bridge, and the safety centre if located in a separate space from the navigation bridge, are excluded from the requirements of this sub-Section.

14.4.4 The number and location of flooding detection sensors is to be sufficient to ensure that any substantial water ingress into a watertight space requiring a flooding detection system is detected under reasonable angles of trim and heel. To accomplish this, flooding detection sensors are to be installed as indicated below:

- (a) **Vertical location** – sensors are to be installed as low as practical in the watertight space;

- (b) **Longitudinal location** – in watertight spaces located forward of the mid-length sensors are generally to be installed at the forward end of the space; and in watertight spaces located aft of the mid-length, sensors are generally to be installed at the aft end of the space. For watertight spaces located in the vicinity of the mid-length, consideration is to be given to the appropriate longitudinal location of the sensor. In addition, any watertight space of length more than 20 per cent of the ship's subdivision length or with arrangements that would seriously restrict the longitudinal flow of water is to be provided with sensors at both the forward and aft ends; and
- (c) **Transverse location** – sensors are generally to be installed at the centreline of the space (or alternatively at both the port and starboard sides). In addition, any watertight space that extends the full breadth of the ship or with arrangements that would seriously restrict the transverse flow of water is to be provided with sensors at both the port and starboard sides.

14.4.5 Where a watertight space extends in height over more than one deck, there is to be at least one flooding detection sensor at each deck level. This provision is not applicable in cases where a continuous flood level monitoring system is installed.

14.4.6 Consideration may be given to the number and location of flooding detection sensors in watertight spaces with unusual arrangements or in other cases where these requirements would not achieve the intended purpose, see 14.1.7.



# Machinery Piping Systems

# Part 5, Chapter 14

Sections 1 & 2

## Section

- 1 **General requirements**
- 2 **Oil fuel – General requirements**
- 3 **Oil fuel burning arrangements**
- 4 **Oil fuel pumps, pipes, fittings, tanks, etc.**
- 5 **Steam piping systems**
- 6 **Boiler feed water, condensate and thermal fluid circulation systems**
- 7 **Engine cooling water systems**
- 8 **Lubricating oil systems**
- 9 **Hydraulic systems**
- 10 **Low pressure compressed air systems**
- 11 **Multi-engined ships**
- 12 **Control, supervision and monitoring of machinery**

## ■ Section 1 General requirements

### 1.1 General

1.1.1 In addition to the requirements detailed in this Chapter, the requirements of Ch 13,1 and 2 are to be complied with, where applicable.

1.1.2 The requirements of Ch 13,3 are also to be complied with, so far as they are applicable, for the drainage of tanks, oily bilges and cofferdams, etc.

1.1.3 The requirements of Sections 2 and 4 are to be complied with, as far as they are applicable, for all flammable liquids.

## ■ Section 2 Oil fuel – General requirements

### 2.1 Flash point

2.1.1 The flash point (closed-cup test) of oil fuel for use in ships classed for unrestricted service is, in general, to be not less than 60°C. For emergency generator engines a flash point of not less than 43°C is permissible.

2.1.2 The use of oil fuel having a flash point of less than 60° but not less than 43° may be permitted for emergency generators, emergency fire pumps, engines and auxiliary machines which are not located in machinery spaces subject to the requirements of 4.19.

2.1.3 The use of fuel having a lower flash point than specified in 2.1.1 or 2.1.2 may be permitted in cargo ships provided that such fuel is not stored in any machinery space and the arrangements for the complete installation are specially approved.

2.1.4 Oil fuel in storage tanks is not to be heated to a temperature exceeding 10°C below its flash point. Higher temperatures will be considered for oil fuel stored in settling and service tanks where:

- (a) The tanks are vented to a safe position outside the engine room and, as in the case of all oil fuel tanks, the ends of the ventilation pipes are fitted with gauze diaphragms.
- (b) Openings in the drainage systems of tanks containing heated oil fuel are located in spaces where no accumulation of oil vapours at temperatures close to the flash point can occur.
- (c) The length of vent pipes from such tanks and/or a cooling device is sufficient for cooling oil vapours to below 60°C, or the outlet of the vent pipes is located at least 3 m from sources of ignition.
- (d) There is no source of ignition in the vicinity of openings in the drainage systems.
- (e) There are no openings from the vapour space of the fuel tanks into machinery spaces other than bolted manhole covers.
- (f) Enclosed spaces are not located directly over such fuel tanks, except for vented cofferdams.
- (g) Electrical equipment is not fitted in the vapour space of tanks unless it meets the requirements of Pt 6, Ch 2,14.2.4 for electrical equipment in zone 0 explosive atmospheres.

2.1.5 The temperature of any heating medium is not to exceed 220°C.

### 2.2 Special fuels

2.2.1 When it is desired to carry a quantity of fuel having a flash point below 43°C for special services, e.g. aviation spirit for use in helicopters, full particulars of the proposed arrangements are to be submitted for special consideration. For helicopter refuelling, as a minimum, the requirements of SOLAS 1974 as amended II-2/G, 18-7 will apply.

2.2.2 For the burning of methane gas in methane tankers, see the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk* (hereinafter referred to as the Rules for Ships for Liquefied Gases).

2.2.3 Where it is proposed to use gaseous fuels for main or auxiliary engines in ships other than LNG carriers, the relevant requirements of the *Rules for the Classification of Natural Gas Fuelled Ships* are to be complied with. Full particulars of the proposed arrangements are to be submitted for special consideration. Attention is to be given to any relevant statutory requirements of the National Authority of the country in which the ships are to be registered.



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# Part 5, Chapter 14

Section 2

## 2.3 Oil fuel sampling

2.3.1 Sampling points are to be provided at locations within the oil fuel system that enable samples of oil fuel to be taken in a safe manner.

2.3.2 The position of a sampling point is to be such that the sample of the oil fuel is representative of the oil fuel quality at that location within the system.

NOTE:

Samples taken from sounding pipes are not considered to be representative of the tank's contents.

2.3.3 The sampling arrangements within the machinery space are to be capable of safely providing samples when machinery is running and are to be provided with isolating valves and cocks of the self-closing type. The sampling points are to be located in positions as far removed as possible from any heated surface or electrical equipment so as to preclude impingement of oil fuel onto such surfaces on equipment under all operating conditions, see Ch 1,3.7.

## 2.4 Ventilation

2.4.1 The spaces in which the oil fuel burning appliances and the oil fuel settling and service tanks are fitted are to be well ventilated and easy of access.

## 2.5 Boiler insulation and air circulation in boiler room

2.5.1 The boilers are to be suitably lagged. The clearance spaces between the boilers and tops of the double bottom tanks, and between the boilers and the sides of the storage tanks in which oil fuel and cargo oil is carried, are to be adequate for the free circulation of the air necessary to keep the temperature of the stored oil sufficiently below its flash point.

2.5.2 Where water tube boilers are installed, there is to be a space of at least 760 mm between the tank top and the underside of the pans forming the bottom of the combustion spaces.

2.5.3 Smoke-box doors are to be shielded and well fitting, and the uptake joints made gastight. Where the surface temperature of the uptakes may exceed 220°C, they are to be efficiently lagged to minimise the risk of fire and to prevent damage by heat. Where lagging covering the uptakes, including flanges, is oil-absorbing or may permit penetration of oil, the lagging is to be encased in sheet metal or equivalent. In locations where the Surveyor is satisfied that oil impingement could not occur, the lagging need not be encased.

## 2.6 Funnel dampers

2.6.1 Dampers which are capable of completely closing the gas passages are not to be fitted to inner funnels of ships equipped for burning oil fuel only. In ships burning oil or coal alternatively, dampers may be retained, if they are provided with a suitable device whereby they may be securely locked in the fully open position.

## 2.7 Heating arrangements

2.7.1 Where steam is used for heating oil fuel, cargo oil or lubricating oil, in bunkers, tanks, heaters or separators, the exhaust drains are to discharge the condensate into an observation tank in a well lighted and accessible position where it can be readily seen whether or not it is free from oil, see Ch 15,6.4.

2.7.2 Where hot water is used for heating, means are to be provided for detecting the presence of oil in the return lines from the heating coils.

2.7.3 Where it is proposed to use any heating medium other than steam or hot water, full particulars of the proposed arrangements are to be submitted for special consideration.

2.7.4 The heating pipes in contact with oil are to be of iron, steel, approved aluminium alloy or approved copper alloy, and, after being fitted on board, are to be tested by hydraulic pressure in accordance with the requirements of Ch 12,8.1.

2.7.5 Where electric heating elements are fitted means are to be provided to ensure that all elements are submerged at all times when electric current is flowing and that their surface temperature cannot exceed 220°C.

## 2.8 Temperature indication

2.8.1 Tanks and heaters in which oil is heated are to be provided with suitable means for ascertaining the temperature of the oil. Where thermometers or temperature sensing devices are not fitted in blind pockets, a warning notice, in raised letters, is to be affixed adjacent to the fittings stating 'Do not remove unless tank/heater is drained'.

2.8.2 Controls are to be fitted to limit oil temperatures in oil storage and service tanks in accordance with 2.1.4 and in oil heaters to the maximum approved operating temperature, see Pt 6, Ch 1.

## 2.9 Precautions against fire

2.9.1 Oil fuel tanks and oil fuel filters are not to be situated immediately above boilers or other highly heated surfaces, see *also* Ch 1,4.5.

2.9.2 Oil fuel pipes are not to be installed above or near high temperature equipment. Oil fuel pipes should also be installed and screened or otherwise suitably protected to avoid oil spray or oil leakages onto hot surfaces, into machinery air intakes, or other sources of ignition such as electrical equipment. Pipe joints are to be kept to a minimum, and where provided are to be of a type acceptable to LR. Pipes are to be led in well lit and readily visible positions, see *also* Ch 2,8.

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Sections 2 & 3

**2.9.3** Pumps, filters and heaters are to be located to avoid oil spray or oil leakages onto hot surfaces or other sources of ignition, or onto rotating machinery parts. Where necessary, shielding is to be provided and the arrangements are to allow easy access for routine maintenance. The design of filter and strainer arrangements is to be such as to avoid the possibility of them being opened inadvertently when under pressure. This may be achieved by either mechanically preventing the pressurised filter from being opened or by providing pressure gauges which clearly indicate which filter is under pressure. In either case, suitable means for pressure release are to be provided, with drain pipes led to a safe location.

**2.9.4** The arrangement and location of short sounding pipes to oil tanks are to be in accordance with Ch 13,12.13. For alternative sounding arrangements, see Ch 13,12.11.

**2.9.5** Water service pipes and hoses are to be fitted in order that the floor plates and tank top or shell plating in way of boilers, oil fuel apparatus or deep storage tanks in the engine and boiler spaces can at any time be flushed with sea-water.

**2.9.6** So far as is practicable, the use of wood is to be avoided in the engine rooms, boiler rooms and tunnels of ships burning oil fuel.

**2.9.7** Drip trays are to be fitted at the furnace mouths to intercept oil escaping from the burners, and under all other oil fuel appliances which are required to be opened up frequently for cleaning or adjustment.

**2.9.8** Oil-tight drip trays of ample size having suitable drainage arrangements are to be provided at pipes, pumps, valves and other fittings where there is a possibility of leakage. Valves should be located in well lighted and readily visible positions. Drip trays will not be required where pumps, valves and other fittings are placed in special compartments either inside or outside the machinery space with approved overall drainage arrangements or for valves which are so positioned that any leakage will drain directly into the bilges see 2.9.2.

**2.9.9** Where drainage arrangements are provided from collected leakages, they are to be led to a suitable oil drain tank not forming part of an overflow system.

**2.9.10** Separate oil fuel tanks are to be placed in an oil-tight spill tray of ample size having drainage arrangements leading to a drain tank of suitable size, see 4.17.

**2.9.11** Where level switches are used below the tank top, they are to be contained in a steel enclosure or other enclosures which provide equivalent protection against fire.

## 2.10 Oil fuel contamination

**2.10.1** The materials and/or their surface treatment used for the storage and distribution of oil fuel are to be selected such that they do not introduce contamination or modify the properties of the fuel. The use of copper or zinc compounds in oil fuel distribution and utilisation piping is not permitted except for small diameter pipes in low pressure systems, see 4.6.1.

**2.10.2** For prevention of ingress of water into oil fuel tanks via air pipes, see Ch 13,10.5.4.

**2.10.3** The piping arrangements for oil fuel are to be separate and distinct from those intended for lubricating oil systems to prevent contamination of fuel oil by lubricating oil.

**2.10.4** Piping arrangements or alternative means are to be provided to ensure that distillates (i.e. gas oils/diesel grades) are to be kept separate and distinct from residual grades, up to the service tanks required by 4.18, in order to prevent cross-contamination. Cross-connection is permitted between separate arrangements in the event of failure of a designated item of equipment.

## 2.11 Tanks and cofferdams

**2.11.1** Tanks containing oil fuel are to be separated from passenger, crew and baggage compartments by a gastight and watertight boundary or a cofferdam which is suitably ventilated and drained.

## ■ Cross-reference

For requirements regarding refrigerated cargo spaces in way of oil storage tanks, see Pt 6, Ch 3,4.

## ■ Section 3

## Oil fuel burning arrangements

### 3.1 Oil burning units

**3.1.1** All oil burning equipment is to be capable of operating at defined power/rating levels where specified by the Owner/Operator. Confirmation by the manufacturer of this capability is to be provided to LR including the specified power/rating parameters, and operating and maintenance regimes. See also Pt 5, Ch 1,3.1.2

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**3.1.2** Where steam is required for the main propelling engines, or where steam or thermal oil is required for auxiliary machinery for essential services, or for heating of heavy oil fuel and is generated by burning oil fuel under pressure, there are to be not less than two oil burning units. For auxiliary boilers, a single oil burning unit may be accepted, provided that alternative means, such as an exhaust gas boiler or composite boiler, are available for supply of essential services. Where the oil burning unit is not of the monobloc type (i.e., separate register and oil supply unit), each oil burning unit is to comprise a pressure pump, suction filter, discharge filter and, when required, a heater.

**3.1.3** In installations consisting of two or more oil burning units, the number, arrangement and capacity of such units is to be capable of supplying sufficient fuel to allow the steam to be generated or thermal oil heated, as applicable to provide essential services with any one unit out of action.

**3.1.4** Unit pressure pumps are to be entirely separate from the feed, bilge or ballast systems.

**3.1.5** In dual oil fuel burning systems for boilers which are primarily designed for operation with residual fuel oil grades, arrangements are to be such that atomising steam cannot be used in combination with distillate fuel oil grades where the burner arrangements have not been designed for such use.

**3.1.6** In all dual oil fuel burning systems for boilers, the manufacturer of the combustion equipment is to ensure that the full system, including control and monitoring systems, is capable of continuous operation in all conditions for each fuel grade.

**3.1.7** Whenever the oil fuel burning units are stopped, shut-off arrangements for oil fuel to the units are to be provided as follows:

- (a) If the supply oil fuel is under pressure during shut-off to oil burning units, duplicated shut-off valves in series are to be fitted. Arrangements are to be such to allow manual testing for leakage from each of the valves in the installed condition, the test arrangement is to be such to prevent inadvertent operation, and any discharges are to be led to a safe position to ensure that discharge of leakage oil does not present an ignition hazard.
- (b) If arrangements are such that oil fuel pressure is released through drainage during oil fuel shut-off to oil burning units, a single shut-off device may be accepted subject to approval by LR.

**3.1.8** When combined air and fuel/steam/air combustion systems are used for multiple boiler installations, they are to be such that single boiler operation will not be adversely affected by the operation of another boiler system at any time.

**3.1.9** Arrangements are to be such that furnace pre-purging is completed prior to any burner ignition sequence. The purge time is to be based on a minimum of 4 air changes of the combustion chamber, furnace and uptake spaces. The purge timing is to take account of the air flow rate and the sequence is not to commence until all air registers and dampers, as applicable, are fully open and the forced draft fans are operating.

**3.1.10** The effect of multiple light-off failures is to be assessed and the need to lock out further ignition sequences established. The manufacturer's recommended procedures are to be followed before further attempts to ignite the boiler are made. These procedures are to be displayed at the ignition control positions and included in the warning notice required by 3.1.11.

**3.1.11** Means are to be provided so that, in the event of flame failure, the oil fuel supply to the burner(s) is shut-off automatically, and an alarm is given, see Pt 5, Ch 10,18.3, Ch 14,12.2 and Ch14,12.3, as applicable.

**3.1.12** It is to be demonstrated to the Surveyor's satisfaction during trials that burner shut-off times due to flame failure comply with the following requirements, and details of the procedures and means used to set this time interval are to be submitted for consideration:

- (a) The time interval at burner start up between the burner oil fuel valve(s) being opened and then closed in the event of flame failure is to be long enough to allow a stable flame to be established and detected under normal operational circumstances, but is to be set to minimise the quantity of oil fuel delivered to the furnace and the possibility of subsequent damage as a result of unintended ignition.
- (b) The time interval between flame failure detection and closing of burner oil fuel valve(s) is to be long enough to prevent shutdown due to incorrect detection of a flame failure under normal operational circumstances, but is to be set to minimise the quantity of unburned oil fuel delivered to the furnace and the possibility of subsequent damage as a result of unintended ignition.

**3.1.13** A warning notice is to be fitted in a prominent position at every oil burning unit local manual control station which specifies that burners operated with manual or local overrides in use are only to be ignited after sufficient purging of the furnace and of any additional precautions required when operating in this condition.

## 3.2 Gravity feed

**3.2.1** In systems where oil is fed to the burners by gravity, duplex filters are to be fitted in the supply pipeline to the burners and so arranged that one filter can be opened up when the other is in use.

## 3.3 Starting-up unit

**3.3.1** A starting-up oil fuel unit, including an auxiliary heater and hand pump, or other suitable starting-up device, which does not require power from shore, is to be provided.

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3.3.2 Alternatively, where auxiliary machinery requiring compressed air or electric power is used to bring the boiler plant into operation, the arrangements for starting such machinery are to comply with Ch 2,9.1.

## 3.4 Steam connections to burners

3.4.1 Where burners are provided with steam purging and/or atomising connections, the arrangements are to be such that oil fuel cannot find its way into the steam system in the event of valve leakage.

## 3.5 Burner arrangements

3.5.1 The burner arrangements are to be such that a burner cannot be withdrawn unless the oil fuel supply to that burner is shut off, and that the oil cannot be turned on unless the burner has been correctly coupled to the supply line.

## 3.6 Quick-closing valve

3.6.1 A quick-closing master valve is to be fitted to the oil supply to each boiler manifold, suitably located so that the valve can be readily operated in an emergency, either directly or by means of remote control, having regard to the machinery arrangements and location of controls.

## 3.7 Spill arrangements

3.7.1 Provision is to be made, by suitable non-return arrangements, to prevent oil from spill systems being returned to the burners when the oil supply to these burners has been shut off.

## 3.8 Alternately-fired furnaces

3.8.1 For alternately-fired furnaces of boilers using exhaust gases and oil fuel, the exhaust gas inlet pipe is to be provided with an isolating device and interlocking arrangements whereby oil fuel can only be supplied to the burners when the isolating device is closed to the boiler.

## 3.9 Oil fuel treatment for supply to main and auxiliary oil engines and gas turbines

3.9.1 A suitable fuel treatment plant that may include filtration, centrifuging and/or coalescing is to be provided to reduce the level of water and particulate contamination of the oil fuel to within the engine or gas turbine manufacturer's limits for inlet to the combustion system. The capacity and arrangements of the treatment plant is to be suitable for ensuring availability of treated oil fuel for the maximum continuous demand of the propulsion and electrical generating plant.

3.9.2 Two or more treatment systems are to be provided as part of the fuel treatment plant such that failure of one system will not render the other system(s) inoperative. Arrangements are to ensure that the failure of a treatment system will not interrupt the supply of clean oil fuel to oil engines or gas turbines used for propulsion and electrical generating purposes where treatment plant is installed between oil fuel service tanks and the inlet to the combustion system. Any treatment equipment in the system is to be capable of being cleaned without interrupting the flow of treated fuel to supply the combustion system.

3.9.3 Centrifuges used for oil fuel treatment are to be type tested for their intended usage when installed on board a ship in accordance with a standard acceptable to LR.

3.9.4 Where heating of the oil fuel is required for the efficient functioning of the oil fuel treatment plant, a minimum of two heating units are to be provided. Each heating unit is to be of sufficient capacity to raise and maintain the required temperature of the oil fuel for the required delivery flow rate.

3.9.5 Heating units may be in circuit with separate treatment systems or provided with connections such that any heating unit can be connected to any treatment system.

3.9.6 Where heating of the oil fuel is required for combustion, not less than two pre-heaters are to be provided, each with sufficient capacity to raise the temperature of the fuel to provide a viscosity suitable for combustion.

3.9.7 Filters and/or coalescers are to be fitted in the oil fuel supply lines to each oil engine and gas turbine to ensure that only suitably filtered oil is fed to the combustion system. The arrangements are to be such that any unit can be cleaned without interrupting the supply of filtered oil to the combustion system.

## 3.10 Booster pumps

3.10.1 Where an oil fuel booster pump is fitted, which is essential to the operation of the main engine, a standby pump is to be provided.

3.10.2 The standby pump is to be connected ready for immediate use but where two or more main engines are fitted, each with its own pump, a complete spare pump may be accepted provided that it is readily accessible and can easily be installed.

## 3.11 Booster pumps when operating in emissions control areas

3.11.1 Ships intending to use Heavy Fuel Oil (HFO) or Marine Diesel Oil (MDO) when operating outside emissions control areas and marine fuels with a sulphur content not exceeding 0,1 per cent m/m and minimum viscosity of 2 cSt when operating inside emission control areas are to meet the requirements of 3.11.2. or 3.11.3.

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**3.11.2** The booster pumps which are fitted in compliance with 3.10 are acceptable for use in emissions control areas where these pumps are each suitable for marine fuels with a sulphur content not exceeding 0,1 per cent m/m and minimum viscosity of 2 cSt operation at the required capacity for normal operation of propulsion machinery.

**3.11.3** When the booster pumps which are fitted in compliance with 3.10 are suitable to operate on marine fuels with a sulphur content not exceeding 0,1 per cent m/m and minimum viscosity of 2 cSt, but one pump alone is not capable of delivering marine fuels with a sulphur content not exceeding 0,1 per cent m/m and minimum viscosity of 2 cSt at the required capacity, two booster pumps may operate in parallel to achieve the required capacity for normal operation of propulsion machinery. In this case, one additional fuel oil pump is to be provided. The additional booster pump shall, when operating in parallel with one of the booster pumps in 3.10, be suitable for and capable of delivering marine fuels with a sulphur content not exceeding 0,1 per cent m/m and minimum viscosity of 2 cSt at the required capacity for normal operation of the propulsion machinery.

## 3.12 Fuel valve cooling pumps

**3.12.1** Where pumps are provided for fuel valve cooling, the arrangements are to be in accordance with 3.10.

## 3.13 Oil-fired galleys

**3.13.1** The oil fuel tank is to be located outside the galley and is to be fitted with approved means of filling and venting.

**3.13.2** The fuel supply to the burners is to be controlled from a position which will always be accessible in the event of a fire occurring in the galley.

**3.13.3** The galley is to be well ventilated.

**3.13.4** When liquefied petroleum gas is used, bottles are to be stored on the open deck or in a well ventilated space which only opens to the open deck.

## Section 4 Oil fuel pumps, pipes, fittings, tanks, etc.

### 4.1 Transfer pumps

**4.1.1** Where a power driven pump is necessary for transferring oil fuel, a standby pump is to be provided and connected ready for use, or, alternatively, emergency connections may be made to one of the unit pumps or to another suitable power driven pump.

### 4.2 Control of pumps

**4.2.1** The power supply to all independently driven oil fuel transfer and pressure pumps is to be capable of being stopped from a position outside the space which will always be accessible in the event of fire occurring in the compartment in which they are situated, as well as from the compartment itself.

### 4.3 Relief valves on pumps

**4.3.1** All pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with relief valves. Each relief valve is to be in closed circuit, i.e. arranged to discharge back to the suction side of the pump and to effectively limit the pump discharge pressure to the design pressure of the system.

### 4.4 Pump connections

**4.4.1** Valves or cocks are to be interposed between the pumps and the suction and discharge pipes, in order that any pump may be shut off for opening up and overhauling.

### 4.5 Pipes conveying oil

**4.5.1** Pipes conveying oil under pressure are to be of seamless steel or other approved material having flanged or welded joints, and are to be placed in sight above the platform in well lighted and readily accessible parts of the machinery spaces. The number of flanged joints is to be kept to a minimum.

**4.5.2** Where pipes convey heated oil under pressure the flanges are to be machined, and the jointing material, which is to be impervious to oil heated to 150°C, is to be the thinnest possible, so that flanges are practically metal to metal. The scantlings of the pipes and their flanges are to be suitable for a pressure of at least 13,7 bar (14 kgf/cm<sup>2</sup>) or for the design pressure, whichever is the greater.

**4.5.3** The short joining lengths of pipes to the burners from the control valves at the boiler may have cone unions, provided these are of specially robust construction.

**4.5.4** Flexible hoses of approved material and design may be used for the burner pipes, provided that spare lengths, complete with couplings, are carried on board.

**4.5.5** For requirements relating to flexible hoses, see Ch 12.7.



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### 4.6 Low pressure pipes

4.6.1 Transfer, suction and other low pressure oil pipes and all pipes passing through oil storage tanks are to be made of cast iron or steel, having flanged joints suitable for a working pressure of not less than 6,9 bar (7 kgf/cm<sup>2</sup>). The flanges are to be machined and the jointing material is to be impervious to oil. Where the pipes are 25 mm bore or less, they may be of seamless copper or copper alloy, except those which pass through oil storage tanks. Oil pipes within the engine and boiler spaces are to be fitted where they can be readily inspected and repaired.

4.6.2 For requirements regarding bilge pipes in way of double bottom tanks and deep tanks, see Ch 13, 7.9 and 7.10.

### 4.7 Valves and cocks

4.7.1 Valves, cocks and their pipe connections are to be so arranged that oil cannot be admitted into tanks which are not structurally suitable for the carriage of oil or into tanks which can be used for the carriage of fresh water.

4.7.2 All valves and cocks forming part of the oil fuel installation are to be capable of being controlled from readily accessible positions which, in the engine and boiler spaces, are to be above the working platform, see also Ch 13, 2.3.

4.7.3 Every oil fuel suction pipe from a double bottom tank is to be fitted with a valve or cock.

### 4.8 Valves on deep tanks and their control arrangements

4.8.1 Every oil fuel suction pipe from a storage, settling and daily service tank situated above the double bottom, and every oil fuel levelling pipe within the boiler room or engine room, is to be fitted with a valve or cock secured to the tank.

4.8.2 The valves and cocks mentioned in 4.8.1 are to be capable of being closed locally and from positions outside the space in which the tank is located. The remote controls are to be accessible in the event of fire occurring in the deep tank's space. Instructions for closing the valves or cocks are to be indicated at the valves and cocks and at the remote control positions.

4.8.3 The control for remote operation of the valve on the emergency generator fuel tank is to be in a separate location from the controls for the remote operation of other valves for tanks located in machinery spaces.

4.8.4 In the case of tanks of less than 500 litres capacity, consideration will be given to the omission of remote controls.

4.8.5 Every oil fuel suction pipe which is led into the engine and boiler spaces, from a tank situated above the double bottom outside these spaces, is to be fitted in the machinery space with a valve controlled as in 4.8.2, except where the valve on the tank is already capable of being closed from an accessible position above the bulkhead deck.

4.8.6 Where the filling pipes to deep oil tanks are not connected to the tanks near the top, they are to be provided with non-return valves at the tanks or with valves or cocks fitted and controlled as in 4.8.2.

### 4.9 Water drainage from settling tanks

4.9.1 Settling tanks are to be provided with means for draining water from the bottom of the tanks.

4.9.2 If settling tanks are not provided, the oil fuel bunkers or daily service tanks are to be fitted with water drains.

4.9.3 Open drains for removing the water from oil tanks are to be fitted with valves or cocks of self-closing type, and suitable provision is to be made for collecting the oily discharge.

### 4.10 Relief valves on oil heaters

4.10.1 Relief valves are to be fitted on the oil side of heaters and are to be adjusted to operate at a pressure of 3,4 bar (3,5 kgf/cm<sup>2</sup>) above that of the supply pump relief valve, see 4.3. The discharge from the relief valves is to be led to a safe position.

### 4.11 Filling arrangements

4.11.1 Filling stations are to be isolated from other spaces and are to be efficiently drained and ventilated.

4.11.2 Provision is to be made against over-pressure in the filling pipelines, and any relief valve fitted for this purpose is to discharge to an overflow tank or other safe position.

### 4.12 Transfer arrangements – Passenger ships

4.12.1 In passenger ships, provision is to be made for the transfer of oil fuel from any oil fuel storage or settling tank to any other oil fuel storage or settling tank in the event of fire or damage.

### 4.13 Alternative carriage of oil fuel and water ballast

4.13.1 Where it is intended to carry oil fuel and water ballast in the same compartments alternatively, the valves or cocks connecting the suction pipes of these compartments with the ballast pump and those connecting them with the oil fuel transfer pump are to be so arranged that the oil may be pumped from any one compartment by the oil fuel pump at the same time as the ballast pump is being used on any other compartment. In passenger ships the arrangement will require to be specially approved.

4.13.2 Where settling or service tanks are fitted, each having a capacity sufficient to permit 12 hours normal service without replenishment, the above requirement may be dispensed with.



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4.13.3 Attention is drawn to the statutory regulations issued by National Authorities in connection with the *International Convention for the Prevention of Pollution of the Sea by Oil, 1973/78*.

## 4.14 Deep tanks for the alternative carriage of oil, water ballast or dry cargo

4.14.1 In the case of deep tanks which can be used for the carriage of oil fuel, cargo oil, water ballast or dry cargo, provision is to be made for blank flanging the oil and water ballast filling and suction pipes, also the steam heating coils if retained in place, when the tank is used for dry cargo, and for blank flanging the bilge suction pipes when the tanks are used for oil or water ballast.

4.14.2 If the deep tanks are connected to an overflow system, the arrangements are to be such that liquid or vapour from other tanks cannot enter the deep tanks when dry cargo is carried in them.

## 4.15 Separation of cargo oils from oil fuel

4.15.1 Pipes conveying vegetable oils or similar cargo oils are not to be led through oil fuel tanks, nor are oil fuel pipes to be led through tanks containing these cargo oils. For requirements regarding provision of cofferdams between oil and water tanks, see Pt 3, Ch 3,4.7.

## 4.16 Fresh water piping

4.16.1 Pipes in connection with compartments used for storing fresh water are to be separate and distinct from any pipes which may be used for oil or oily water, and are not to be led through tanks which contain oil, nor are oil pipes to be led through fresh water tanks.

## 4.17 Separate oil fuel tanks

4.17.1 Where separate oil fuel tanks are permitted, their construction is to be in accordance with the requirements of 4.17.2 to 4.17.6, see also SOLAS 1974 as amended Reg.II-2/B4.2.2.3.2.

4.17.2 In general, the minimum thickness of the plating of service, settling and other oil tanks, where they do not form part of the structure of the ship, is to be 5 mm, but in the case of very small tanks, the minimum thickness may be 3 mm.

4.17.3 For rectangular steel tanks of welded construction, the plate thicknesses are to be not less than those indicated in Table 14.4.1. The stiffeners are to be of approved dimensions.

4.17.4 The dimension given in Table 14.4.1 for the breadth of the panel is the maximum distance allowable between continuous lines of support, which may be stiffeners, wash-plates or the boundary of the tank.

**Table 14.4.1 Plate thickness of separate oil fuel tanks**

Thickness of plate, mm	Head from bottom of tank to top of overflow pipe, metres				
	2,5	3,0	3,7	4,3	4,9
Breadth of panel, mm					
5	585	525	—	—	—
6	725	645	590	—	—
7	860	770	700	650	—
8	1000	900	820	750	700
10	1280	1140	1040	960	900

4.17.5 Where necessary, stiffeners are to be provided, and if the length of the stiffener exceeds twice the breadth of the panel, transverse stiffeners are also to be fitted, or, alternatively, tie bars are to be provided between stiffeners on opposite sides of the tank.

4.17.6 On completion, the tanks are to be tested by a head of water equal to the maximum to which the tanks may be subjected, but not less than 2,5 m above the crown of the tank.

## 4.18 Oil fuel service tanks

4.18.1 An oil fuel service tank is an oil fuel tank which contains only the required quality of fuel ready for immediate use.

4.18.2 Two oil fuel service tanks, for each type of fuel used on board, necessary for propulsion and generator systems, are to be provided. Each tank is to have a capacity for at least eight hours' operation, at sea, at maximum continuous rating of the propulsion plant and/or generating plant associated with that tank.

4.18.3 The arrangement of oil fuel service tanks is to be such that one tank can continue to supply oil fuel when the other is being cleaned or opened up for repair.

4.18.4 For ships of less than 500 gross tonnage, the capacity of each oil fuel service tank required by 4.18.2 may be less than for eight hours operation, where the class notation includes a service restriction.

## 4.19 Arrangements for fuels with a flash point between 43° and 60°

4.19.1 Fuel oil tanks other than those in double bottom compartments shall be located outside 'Category A' machinery spaces, see also Pt 3, Ch 3,4.7.

4.19.2 Provisions are to be made for the measurement of oil fuel temperature at the pump suction pipe.

4.19.3 Stop valves are to be provided at the inlet and outlet side of oil fuel strainers.

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Sections 4, 5 & 6

4.19.4 Pipe joints shall be either welded or spherical type union joints.

## Section 5 Steam piping systems

### 5.1 Provision for expansion

5.1.1 In all steam piping systems, provision is to be made for expansion and contraction to take place without unduly straining the pipes.

5.1.2 Where expansion pieces are used, particulars are to be submitted.

5.1.3 For installation requirements regarding expansion pieces, see Ch 13,2.7.

### 5.2 Drainage

5.2.1 The slope of the pipes and the number and position of the drain valves or cocks are to be such that water can be efficiently drained from any portion of the steam piping system when the ship is in normal trim and is either upright or has a list of up to 5°.

5.2.2 Arrangements are to be made for ready access to the drain valves or cocks.

5.2.3 For the drainage of boiler and exhaust gas economiser safety valves, see Ch 10,15.2.8.

### 5.3 Soot cleaning drains

5.3.1 The capacity of the drains from exhaust gas economisers/boilers is to be sufficient to remove all wash water or condensate generated by installed washing systems and arrangements are to be such that engines and turbochargers are protected from wash water or condensate drainage from the washing system.

5.3.2 Adequate arrangements are to be made for the collection and disposal of the waste water generated during periodic water washing of the exhaust gas economiser/boiler. Details are to be submitted for approval.

### 5.4 Pipes in way of holds

5.4.1 In general, steam pipes are not to be led through spaces which may be used for cargo, but where it is impracticable to avoid this arrangement, plans are to be submitted for consideration. The pipes are to be efficiently secured and insulated, and well protected from mechanical damage. Pipe joints are to be as few as practicable and preferably butt welded.

5.4.2 If these pipes are led through shaft tunnels, pipe tunnels in way of cargo holds or through duct keels, they are to be efficiently secured and insulated.

### 5.5 Reduced pressure lines

5.5.1 Pipelines which are situated on the low pressure side of reducing valves, and which are not designed to withstand the full pressure at the source of supply, are to be fitted with pressure gauges and with relief valves having sufficient discharge capacity to protect the piping against excessive pressure.

### 5.6 Steam for fire-extinguishing in cargo holds

5.6.1 Where steam is used for fire-extinguishing in cargo holds provision is to be made to prevent damage to cargo by leakage of steam or by drip.

5.6.2 Details of the proposed precautionary measures are to be submitted.

## Cross-reference

For steam heating arrangements for oil fuel, cargo oil or lubricating oil, see 2.7.

## Section 6 Boiler feed water, condensate and thermal fluid circulation systems

### 6.1 Feed water piping

6.1.1 Two separate means of feed are to be provided for all main and auxiliary boilers which are required for essential services. In the case of steam/steam generators, one means of feed will be accepted provided steam for essential services is available simultaneously from another source.

### 6.2 Feed and circulation pumps

6.2.1 Two or more feed pumps are to be provided of sufficient capacity to supply the boilers under full load conditions with any one pump out of action.

6.2.2 Feed pumps may be worked from the main engines or may be independently driven, but at least one of the pumps required in 6.2.1 is to be independently driven.

6.2.3 In twin screw ships in which there is only one independent feed pump, each main engine is to be fitted with a feed pump. Where all the feed pumps are independently driven, the pumps are to be connected to deal with the condensate from both engines or from either engine.

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Sections 6 & 7

6.2.4 Independent feed pumps required for feeding the main boilers are to be fitted with automatic regulators for controlling their output.

6.2.5 The arrangement of forced water/thermal fluid circulation pumps for exhaust gas economisers/boilers/thermal heaters is to be such that where required, the flow through the exhaust gas economiser/boiler/thermal heater is to be established prior to engine start up. Where applicable, provision is to be made to allow for operation in the dry condition.

6.2.6 The forced circulation flow required by 6.2.5 is to be maintained on completion of engine shutdown for a sufficient duration in accordance with the exhaust gas economiser/boiler/thermal heater manufacturer's instructions. Details of arrangements are to be submitted for approval.

6.2.7 Where arrangements are such that exhaust gas economisers/boilers/thermal heaters require forced water/thermal fluid circulation, standby pumps are to be fitted, see Pt 5, Ch 4,8.8.3.

## 6.3 Harbour feed pumps

6.3.1 Where main-engine driven feed pumps are fitted and there is only one independent feed pump, a harbour feed pump or an injector is to be fitted to provide the second means of feed to the boilers which are in use when the main engines are not working. This requirement need not be complied with in the case of trawlers and fishing vessels.

6.3.2 The harbour feed pump required by 6.3.1 may be used for general service, provided that it is not connected to tanks containing oil, or to tanks, cofferdams and bilges which may contain oily water.

6.3.3 The valves on the suction pipes from the hotwell or condenser and the feed drain tank or filter are to be of the non-return type.

## 6.4 Condensate pumps

6.4.1 Two or more extraction pumps are to be provided for dealing with the condensate from the main and auxiliary condensers, at least one of which is to be independently driven. Where one of the independent feed pumps is fitted with direct suctions from the condensers and a discharge to the feed tank, it may be accepted for this purpose.

## 6.5 Valves and cocks

6.5.1 Feed and condensate pumps are to be provided with valves or cocks, interposed between the pumps and the suction and the discharge pipes, so that any pump may be opened up for overhaul while the others continue in operation.

## 6.6 Reserve feed water

6.6.1 All ships fitted with boilers are to be provided with storage space for reserve feed water, the structural and piping arrangements being such that this water cannot be contaminated by oil or oily water, see Pt 3, Ch 3,4.7 for structural arrangements.

6.6.2 For main boilers, one or more evaporators, of adequate capacity, are also to be provided.

## ■ Cross-reference

For feed water level regulators for water tube boilers, see Ch 10,16.8.

## ■ Section 7 Engine cooling water systems

### 7.1 Main supply

7.1.1 Provision is to be made for an adequate supply of cooling water to the main propelling machinery and essential auxiliary engines, also to the lubricating oil and fresh water coolers and air coolers for electric propelling machinery, where these coolers are fitted. The cooling water pump(s) may be worked from the engines or be driven independently.

7.1.2 In the case of main steam turbine installations, a sea inlet scoop arrangement may replace the main sea-water circulating pump, subject to the conditions stated in 7.2.2(c).

### 7.2 Standby supply

7.2.1 Provision is also to be made for a separate supply of cooling water from a suitable independent pump of adequate capacity.

7.2.2 The following arrangements are acceptable depending on the purpose for which the cooling water is intended:

- Where only one main engine is fitted, the standby pump is to be connected ready for immediate use.
- Where more than one main engine is fitted, each with its own pump, a complete spare pump of each type may be accepted.
- Where a sea inlet scoop arrangement is fitted, and there is only one independent condenser circulating pump, a further pump, or a connection to the largest available pump suitable for circulation duties, is to be fitted to provide the second means of circulation when the ship is manoeuvring. The pump is to be connected ready for immediate use.
- Where fresh water cooling is employed for main and/or auxiliary engines, a standby fresh water pump need not be fitted if there are suitable emergency connections from a salt water system.

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Sections 7 &amp; 8

- (e) Where each auxiliary is fitted with a cooling water pump, standby means of cooling need not be provided. Where, however, a group of auxiliaries is supplied with cooling water from a common system, a standby cooling water pump is to be provided for this system. This pump is to be connected ready for immediate use and may be a suitable general service pump.

### 7.3 Selection of standby pumps

7.3.1 When selecting a pump for standby purposes, consideration is to be given to the maximum pressure which it can develop if the overboard discharge valve is partly or fully closed and, when necessary, condenser doors, water boxes, etc., are to be protected by an approved device against inadvertent over-pressure. See Ch 3,7.3 for the hydraulic test pressure which condensers are required to withstand.

### 7.4 Relief valves on main cooling water pumps

7.4.1 Where cooling water pumps can develop a pressure head greater than the design pressure of the system, they are to be provided with relief valves on the pump discharge to effectively limit the pump discharge pressure to the design pressure of the system. For location of relief valves, see Ch 13,7.8.

### 7.5 Sea inlets

7.5.1 Not less than two sea inlets are to be provided for the pumps supplying the sea-water cooling system, one for the main pump and one for the standby pump. Alternatively, the sea inlets may be connected to a suction line available to main and standby pumps.

7.5.2 Where standby pumps are not connected ready for immediate use, see 7.2.2(b), the main pump is to be connected to both sea inlets.

7.5.3 Cooling water pump sea inlets are to be low inlets and one of them may be the ballast pump or general service pump sea inlet.

7.5.4 The auxiliary cooling water sea inlets are preferably to be located one on each side of the ship.

### 7.6 Strainers

7.6.1 Where sea-water is used for the direct cooling of the main engines and essential auxiliary engines, the cooling water suction pipes are to be provided with strainers which can be cleaned without interruption to the cooling water supply.

## ■ Cross-reference

For guidance on metal pipes for water services, see Ch 12,11.

## ■ Section 8 Lubricating oil systems

### 8.1 General requirements

8.1.1 The arrangements for storage, distribution and utilisation of lubricating oils are to comply with the requirements of this Section.

### 8.2 Pumps

8.2.1 Where lubricating oil for the main engine(s) is circulated under pressure, a standby lubricating oil pump is to be provided where the following conditions apply:

- The lubricating oil pump is independently driven and the total output of the main engine(s) exceeds 370 kW (500 shp).
- One main engine with its own pump is fitted and the output of the engine exceeds 370 kW (500 shp).
- More than one main engine each with its own lubricating oil pump is fitted and the output of each engine exceeds 370 kW (500 shp).

8.2.2 The standby pump is to be of sufficient capacity to maintain the supply of oil for normal conditions with any one pump out of action. The pump is to be fitted and connected ready for immediate use, except that where the conditions referred to in 8.2.1(c) apply a complete spare pump may be accepted. In all cases satisfactory lubrication of the engines is to be ensured while starting and manoeuvring.

8.2.3 Similar provisions to those of 8.2.1 and 8.2.2 are to be made where separate lubricating oil systems are employed for piston cooling, reduction gears, oil operated couplings and controllable pitch propellers, unless approved alternative arrangements are provided.

8.2.4 Independently driven pumps of rotary type are to be fitted with a non-return valve on the discharge side of the pump.

### 8.3 Control of pumps

8.3.1 The power supply to all independently driven lubricating oil transfer and pressure pumps is to be capable of being stopped from a position outside the space, which will always be accessible in the event of fire occurring in the compartment in which they are situated, as well as from the compartment itself.

### 8.4 Relief valves on pumps

8.4.1 All lubricating oil pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with relief valves or equivalent. Each relief valve is to be in closed circuit, i.e., arranged to discharge back to the suction side of the pump, thereby limiting the pump discharge pressure to the design pressure of the system.

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## Part 5, Chapter 14

Section 8

8.4.2 Where centrifugal type lubricating oil pumps are fitted, pressure relief valves will not be required, provided that pipes, valves and fittings are suitable for the greater of the design pressure or pump non-delivery pressure.

### 8.5 Emergency supply for propulsion turbines and propulsion turbo-generators

8.5.1 A suitable emergency supply of lubricating oil is to be arranged to come automatically into use in the event of a failure of the supply from the pump.

8.5.2 The emergency supply may be obtained from a gravity tank containing sufficient oil to maintain adequate lubrication for not less than six minutes, and, in the case of propulsion turbo-generators, until the unloaded turbine comes to rest from its maximum rated running speed.

8.5.3 Alternatively, the supply may be provided by the standby pump or by an emergency pump. These pumps are to be so arranged that their availability is not affected by a failure in the power supply.

8.5.4 For automatic shutdown arrangements of main turbines in the event of failure of the lubrication system, see Ch 3,5.1 and Ch 4,8.

### 8.6 Maintenance of bearing lubrication

8.6.1 The arrangements for lubricating bearings and for draining crankcase and other oil sumps of main and auxiliary engines, gearcases, electric generators, motors, and other running machinery are to be so designed that lubrication will remain efficient with the ship inclined under the conditions as shown in Ch 1,3.7.

8.6.2 For details of the requirements relating to the lubrication of bearings of electric generators and motors, see Pt 6, Ch 2,1.10 and Section 8.

### 8.7 Filters

8.7.1 Where the lubricating oil for main propelling engines is circulated under pressure, provision is to be made for the efficient filtration of the oil. The filters are to be capable of being cleaned without stopping the engine or reducing the supply of filtered oil to the engine. Proposals for an automatic by-pass for emergency purposes in high speed engines are to be submitted for special consideration.

8.7.2 In the case of propulsion turbines and their gears, arrangements are to be made for the lubricating oil to pass through magnetic strainers and fine filters. Generally, the openings in the filter elements are to be not coarser than required by the manufacturer of the turbines, especially for the supply to turbine thrust bearings.

### 8.8 Filling arrangements

8.8.1 Filling stations are to be isolated from other spaces and are to be efficiently drained and ventilated.

8.8.2 Provision is to be made against over-pressure in the filling pipelines, and any relief valve fitted for this purpose is to discharge to an overflow tank or other safe position, or an equivalent arrangement is to be provided, except filling by means of loose hose.

### 8.9 Cleanliness of pipes and fittings

8.9.1 Extreme care is to be taken to ensure that lubricating oil pipes and fittings, before installation, are free from scale, sand, metal particles and other foreign matter.

### 8.10 Pipes conveying oil

8.10.1 Pipes conveying lubricating oil under pressure are to be of seamless steel or other approved material having flanged or welded joints, and are to be placed in sight above the platform in well lit and readily accessible parts of the machinery spaces. The number of flanged joints is to be kept to a minimum.

8.10.2 For requirements relating to flexible hoses, see Ch 12,7.

### 8.11 Lubricating oil drain tank

8.11.1 Where an engine lubricating oil drain tank extends to the bottom shell plating in ships that are required to be provided with a double bottom, a shut-off valve is to be fitted in the drainpipe between the engine casing and the double bottom tank. This valve is to be capable of being closed from an accessible position above the level of the lower platform.

### 8.12 Lubricating oil contamination

8.12.1 The materials used in the storage and distribution of lubricating oil are to be selected such that they do not introduce contaminants or modify the properties of the oil. The use of cadmium or zinc in lubricating oil systems where they may normally come into contact with the oil is not permitted.

8.12.2 Arrangements are to be made for each forced lubrication system, renovation system, ready to use tank(s) and their associated rundown lines to drain tanks to be flushed after system installation and prior to running of machinery. The flushing arrangements are to be in accordance with the equipment manufacturer's procedures and recommendations.

8.12.3 For prevention of ingress of water into lubricating oil tanks via air pipes, see Ch 13,12.5.4.



# Machinery Piping Systems

## Part 5, Chapter 14

Sections 8 &amp; 9

8.12.4 The design and construction of engine and gear box piping arrangements are to prevent contamination of engine lubricating oil systems by leakage of cooling water or from bilge water where engines or gearboxes are partly installed below the lower platform. Where flexibility is required to accommodate movement between the engine and sump tank, any flexible joint assembly is to be of an approved type suitable for its intended application.

8.12.5 Where there is a permanently attached oil filling pipe and cap provided for an engine or other item of machinery, provision is to be made for the topping up oil to safely pass through a suitable strainer to prevent unwanted matter getting into the lubricating oil system. The caps are to be capable of being secured in the closed position.

8.12.6 Sampling points are to be provided that enable samples of lubricating oil to be taken in a safe manner. The sampling arrangements are to have the capability to provide samples when machinery is running and are to be provided with valves and cocks of the self-closing type and located in positions as far removed as possible from any heated surface or electrical equipment.

### 8.13 Deep tank valves and their control arrangements

8.13.1 The requirements for remote operation of valves on deep tank suction pipes may be waived where the valves are closed during normal operation.

8.13.2 Remotely operated valves on lubricating oil deep tank suctions should not be of the quick-closing type where inadvertent use would endanger the safe operation of the main propulsion and essential auxiliary machinery.

8.13.3 Every lubricating oil suction pipe from a storage, settling and service tank situated above the double bottom, and every oil levelling pipe within the engine room, is to be fitted with a valve or cock secured to the tank.

8.13.4 Valves and cocks are to be capable of being closed locally and from positions outside the space in which the tank is located. The remote controls are to be accessible in the event of fire occurring in the deep tank's space. Instructions for closing the valves or cocks are to be indicated at the valves and cocks and at the remote control positions.

8.13.5 In the case of tanks of less than 500 litres, capacity, consideration will be given to the omission of remote controls.

8.13.6 Every lubricating oil suction pipe which is led into the engine space from a tank situated above the double bottom outside this space is to be fitted in the machinery space with a valve controlled as in 8.13.4, except where the valve on the tank is already capable of being closed from an accessible position above the bulkhead deck.

8.13.7 Where the filling pipes to deep lubricating oil tanks are not connected to the tanks near the top, they are to be provided with non-return valves at the tanks or with valves or cocks, fitted and controlled as in 8.13.4.

### 8.14 Separate oil tanks

8.14.1 On completion, the tanks are to be tested by a head of water equal to the maximum to which the tanks may be subjected.

### 8.15 Precautions against fire

8.15.1 Lubricating oil tanks and filters are not to be situated immediately above boilers or other highly heated surfaces.

8.15.2 Lubricating oil pipes are not to be installed above or near high-temperature equipment. Lubricating oil pipes should also be installed and screened or otherwise suitably protected, to avoid oil spray or oil leakages on to hot surfaces, into machinery air intakes, or other sources of ignition such as electrical equipment. Pipe joints are to be kept to a minimum and where provided are to be of a type acceptable to LR. Pipes are to be led in well lit and readily visible positions.

8.15.3 Pumps, filters and heaters are to be located to avoid lubricating oil spray or leakage on to hot surfaces or other sources of ignition, or on to rotating machinery parts. Where necessary, shielding is to be provided and the arrangements are to allow easy access for routine maintenance. The design of filter and strainer arrangements is to be such as to avoid the possibility of them being opened inadvertently when under pressure. This may be achieved either by mechanically preventing the pressurised filter from being opened or by providing pressure gauges which clearly indicate which filter is under pressure. In either case, suitable means for pressure release are to be provided, with drain pipes led to a safe location.

## Cross-references

For air, sounding pipes and gauge glasses, see Ch 13,12. For separation of lubricating oil tanks from fuel tanks, see Pt 3, Ch 3,4.7.

## Section 9 Hydraulic systems

### 9.1 General

9.1.1 The requirements of this Section are applicable to flammable oils employed under pressure in power transmission, control, actuating and heating systems, and hydraulic media in systems which are providing essential services.

9.1.2 The arrangements for storage, distribution and utilisation of hydraulic and flammable oils employed in the systems defined in 9.1.1 are to comply with the requirements of this Section.



# Machinery Piping Systems

# Part 5, Chapter 14

Sections 9 & 10

## 9.2 System arrangements

9.2.1 Hydraulic fluids are to be suitable for the intended purpose under all operating service conditions.

9.2.2 Materials used for all parts of hydraulic seals are to be compatible with the working fluid at the appropriate working temperature and pressure.

9.2.3 Provision is to be made for hand operation of the systems in an emergency, unless an acceptable alternative is available.

9.2.4 Where hydraulic securing arrangements are applied, the system is to be capable of being locked in the closed position so that in the event of hydraulic system failure the securing arrangements will remain locked.

9.2.5 Where pilot operated non-return valves are fitted to hydraulic cylinders for locking purposes, the valves are to be connected directly to the actuating cylinder(s) without intermediate pipes or hoses.

9.2.6 Hydraulic circuits for securing and locking of bow, inner, stern or shell doors are to be arranged such that they are isolated from other hydraulic circuits when securing and locking devices are in the closed position. For requirements relating to hydraulic steering gear arrangements see Ch 19,3.

9.2.7 Suitable oil collecting arrangements for leaks shall be fitted below hydraulic valves and cylinders.

## 9.3 Relief valves on pumps

9.3.1 All pumps which are capable of developing a pressure exceeding the design pressure of the system are to be provided with relief valves. Each relief valve is to be in closed circuit, i.e., arranged to discharge back to the suction side of the pump and effectively to limit the pump discharge pressure to the design pressure of the system.

## 9.4 Pipes conveying oil

9.4.1 Pipes conveying hydraulic oil under pressure are to be of seamless steel or other approved material having flanged or welded joints, and are to be placed in sight above the platform in well lit and readily accessible parts of the machinery spaces. The number of flanged joints is to be kept to a minimum.

9.4.2 For requirements relating to flexible hoses, see Ch 12,7.

## 9.5 Filling arrangements

9.5.1 Filling stations are to be isolated from other spaces and are to be efficiently drained and ventilated.

9.5.2 Provision is to be made against over-pressure in the filling pipelines, and any relief valve fitted for this purpose is to discharge to an overflow tank or other safe position, or an equivalent arrangement is to be provided, except filling by means of a loose hose.

## 9.6 Separate oil tanks

9.6.1 On completion, the tanks are to be tested by a head of water equal to the maximum to which the tanks may be subjected.

## 9.7 Precaution against fire

9.7.1 Hydraulic oil tanks and filters are not to be situated immediately above boilers or other highly heated surfaces.

9.7.2 Hydraulic oil pipes are not to be installed above or near high-temperature equipment. Hydraulic oil pipes should also be installed and screened or otherwise suitably protected, to avoid oil spray or oil leakages on to hot surfaces, into machinery air intakes, or other sources of ignition such as electrical equipment. Pipe joints are to be kept to a minimum and where provided are to be of a type acceptable to LR. Pipes are to be led in well lit and readily visible positions.

9.7.3 Pumps, filters and heaters are to be located to avoid hydraulic oil spray or leakage on to hot surfaces or other sources of ignition or on to rotating machinery parts. Where necessary, shielding is to be provided and the arrangements are to allow easy access for routine maintenance. The design of filter and strainer arrangements is to be such as to avoid the possibility of them being opened inadvertently when under pressure. This may be achieved either by mechanically preventing the pressurised filter from being opened or by providing pressure gauges which clearly indicate which filter is under pressure. In either case, suitable means for pressure release are to be provided, with drain pipes led to a safe location.

## Section 10 Low pressure compressed air systems

### 10.1 General

10.1.1 The requirements of this Section are applicable to low pressure (LP) compressed air systems intended for essential pneumatic control and instrumentation purposes. The documentation required by Ch 13,1.3.1 is to provide information to demonstrate compliance with 10.1.2 to 10.1.5.

10.1.2 Low pressure compressed air systems are to produce and distribute cooled compressed air throughout the ship to supply all pneumatic control and instrumentation systems where the air pressure requirements are typically 3 to 10 bar. LP compressed air systems may include air compressors, oil/water separators, filters, dryers, distribution lines and air receivers.

# Machinery Piping Systems

## Part 5, Chapter 14

Section 10

**10.1.3** The design of LP compressed air systems is to be capable of providing a continuous flow of air to meet the demands of all essential services under all ambient conditions. This demand may include the use of intermittently used equipment that is part of the ship's equipment, such as power tools for machinery maintenance, testing equipment and line cleaning. Compressed air systems used for diesel engine or gas turbine starting are to comply with the requirements of Ch 2,16 and Ch 4,6 as applicable.

**10.1.4** User equipment requirements for the quality of compressed air in terms of dewpoint (dryness), oil content and solid particle count are to be recognised in the selection and configuration of compressors, equipment, filters and dryers which are included in the system.

**10.1.5** Configuration arrangements of LP compressed air systems may consist of:

- (a) Dedicated LP air compressors and LP air receivers with a distribution system for LP users; or
- (b) Supply from the starting air system to dedicated air pressure reducing valves/cross-over stations feeding into a distribution system for LP users.

### 10.2 Compressors and reducing valves/stations

**10.2.1** Where LP air is not derived from the starting air system, at least two LP air compressors are to be provided. The output of any one compressor is to match the total demand of all essential users. The system is to be arranged for auto-start of the compressors and means are to be provided to indicate if any compressor is operating longer and more frequently than the manufacturer's recommended operating periods.

**10.2.2** If only one LP air compressor is to be provided, a cross connection to the starting air system is to be made via a reducing valve/cross-connection station.

**10.2.3** Where LP air is derived only from the starting air system, at least two means of supplying air to the LP air system are to be provided. Each of the two means of supplying air is to have sufficient capability of supplying the total demand on the LP air system with one of the means out of action.

**10.2.4** Where the starting air system is fitted with an auxiliary compressor it is to be capable of continuous running and to be capable of maintaining the stored capacity of starting compressed air in the air receivers as required by Ch 2,16 and Ch 4,6 whilst also supplying essential LP services.

**10.2.5** Where the starting air system is designed to maintain sufficient compressed air for LP services and engine starting arrangements, an additional auxiliary compressor will not be required.

### 10.3 Air receivers

**10.3.1** The LP air system and any associated air receivers are to be configured to provide sufficient stored energy to supply LP compressed air without the pressure in the system falling below a level that is insufficient for the operation of all essential users. See also Pt 6, Ch 1,2.5.8.

**10.3.2** All air receivers are to comply with the requirements of Chapter 11 as applicable.

**10.3.3** Stop valves on air receivers are to permit slow opening to avoid sudden pressure rises in the piping system.

### 10.4 Distribution system

**10.4.1** Drain pots with drain valves are to be provided throughout the distribution system at all low points.

**10.4.2** Pipelines that are situated on the low pressure side of reducing valves/stations and that are not designed to withstand the full pressure of the source supply, are to be provided with pressure gauges and with relief valves having sufficient capacity to protect the piping against excessive pressure.

**10.4.3** In-line filters capable of being cleaned/changed without interrupting the flow of filtered air are to be fitted in the system.

### 10.5 Pneumatic remote control valves

**10.5.1** Where valves, which are required by the Rules to be capable of being closed from outside a machinery space, have pneumatic closing arrangements, a dedicated air receiver is to be fitted to supply compressed air to the valves. This air receiver is to be located outside the machinery space.

**10.5.2** The air receiver is to be maintained fully charged from the main LP air system via a non-return valve located at the air receiver inlet which is to be locked in the open position.

**10.5.3** In the case of passenger ships, a permanently attached hand-operated air compressor capable of charging the air receiver is to be provided in the space in which the air receiver is located.

**10.5.4** The capacity of the air receiver is to be sufficient to operate all valves and any other essential supplies such as ventilation flaps without replenishment.

### 10.6 Control arrangements

**10.6.1** The control, alarm and monitoring systems are to comply with Pt 6, Ch 1.

# Machinery Piping Systems

## Part 5, Chapter 14

Sections 11 &amp; 12

### Section 11

#### Multi-engined ships

##### 11.1 General

11.1.1 This Section is applicable to ships of less than 500 gross tons and which are not required to comply with the *International Convention for the Safety of Life at Sea, 1974*, as amended (SOLAS 74), and that have multi-engine installations for propulsion purposes.

11.1.2 For vessels in which the propulsion systems are independent and the propulsion system prime movers are also fully independent of each other such that in the event of the failure of one of the sources of propulsion power the vessels will retain the capability of safely manoeuvring under all conditions of service, the following may not be required:

- (a) Spare fuel oil booster pump stipulated in 3.10.2.
- (b) Spare lubricating oil pump stipulated in 8.2.1(c), 8.2.2 and 8.2.3.
- (c) Spare cooling water pump stipulated in 7.2.2(b).

### Section 12

#### Control, supervision and monitoring of machinery

##### 12.1 General

12.1.1 Where machinery is fitted with automatic or remote controls so that under normal operating conditions it does not require any manual intervention by the operators, it is to be provided with the alarms and safety arrangements required by 12.2 to 12.5, as appropriate. Alternative arrangements which provide equivalent safeguards will be considered.

12.1.2 Where machinery is arranged to start automatically or from a remote control station, interlocks are to be provided to prevent start-up under conditions which could hazard the machinery.

12.1.3 Where machinery specified in this Section is required to be provided with a standby pump, the standby pump is to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

12.1.4 Where a first stage alarm together with a second stage alarm and automatic shut-down of machinery are required in the relevant Tables of this Section, the sensors and circuits utilised for the second stage alarm and automatic shut-down are to be independent of those required for the first stage alarm.

##### 12.2 Thermal fluid heaters

12.2.1 Alarms and safeguards are indicated in 12.2.2 to 12.2.8 and Table 14.12.1.

12.2.2 The standby pumps for oil fuel and thermal fluid circulation are to start automatically when the discharge pressure from the working pump falls below a predetermined value. The standby pumps for thermal fluid circulation are to start before shut-off due to low thermal fluid pressure, see Table 14.12.1, is activated.

12.2.3 The following heater services are to be fitted with automatic controls so as to maintain steady state conditions throughout the operating range of the heater:

- (a) Combustion system.
- (b) Oil fuel supply temperature or viscosity (heavy oil only).
- (c) Thermal fluid temperature.

12.2.4 Burner controls are to be arranged such that light-off is only possible at the minimum firing rate compatible with flame establishment. If ignition is set to occur at a fuel rich condition then the burner is to revert to the correct operating air/fuel ratio on establishment of a stable flame.

12.2.5 Arrangements are to be such that burner oil fuel valve(s) do not open:

- (a) prior to completion of required warm up times for residual fuel oil; or
- (b) when the power supply to the igniter has failed, as applicable; or
- (c) until a pilot flame is established, as applicable; or
- (d) prior to the completion of furnace purging, see 3.1.7.

12.2.6 Arrangements for flame failure detection are to be provided with self-monitoring capabilities which ensure that the flame detector is not erroneously indicating the presence of a flame. In the event of failure being detected by these self-monitoring capabilities:

- an alarm is to be activated;
- In the event of loss of flame detection capability for a burner;
- oil fuel to the burner is to be shut off automatically; and
- an alarm is to be activated.

12.2.7 Where established as necessary by 3.1.8, means are to be provided to prevent starting of the ignition sequence following multiple flame failures until completion of the identified lock-out period.

12.2.8 Following burner shut-down, the furnace is to be purged automatically for at least the required pre-purging time. In event of shut-down due to activation of a required safeguard, this purging is to be manually initiated.

##### 12.3 Inert gas generators

12.3.1 Alarms and safeguards are indicated in 12.3.2 and Table 14.12.2.

12.3.2 Inert gas generators are to be fitted with an automatic combustion control system in order to maintain steady state conditions throughout the operating range of the generator.

12.3.3 For the requirements of flue gas inert gas systems, see Ch 15,7.

# Machinery Piping Systems

## Part 5, Chapter 14

Section 12

**Table 14.12.1 Thermal fluid heaters: Alarms and safeguards**

Item	Alarm	Note
Expansion tank level*	Low	Oil fuel burners to be shut off automatically
Thermal fluid flow	Low	Oil fuel burners to be shut off automatically, see Note 5
Thermal fluid pressure	Low	Oil fuel burners to be shut off automatically
Thermal fluid outlet temperature*	1st stage high 2nd stage high	— Oil fuel burners to be shut off automatically, see 12.1.4
Combustion air pressure*	Low	Oil fuel burners to be shut off automatically in operation or not released during start-up, see Note 3. Purge sequence to be inhibited see 3.1.9
Oil fuel pressure*	Low	—
Oil fuel temperature or viscosity*	High and low	Heavy oil only
Oil fuel atomising steam/air pressure	Low	—
Burner flame*	Failure	Each burner to be monitored. Oil fuel to burner to be shut off automatically, see 3.1.11 to 3.1.12, and Note 3
Flame monitoring device(s)*	Failure	See 12.2.6 and Note 3
Igniter power supply*	Failure	Each igniter to be checked before oil fuel is supplied to burner(s), see 12.2.5 and Note 3
Forced draft fan*	Power failure	Oil fuel burners to be shut off automatically in operation or not released during start-up, see Note 3
Air register and dampers (including those in the uptake)*	Not fully open	Purge sequence to be inhibited, see 3.1.9
Control system*	Power failure	Oil fuel burners to be shut off automatically. Control using alternative arrangement is to remain available, see Pt 6, Ch 1, 2.5.8
Uptake temperature	High	To monitor for soot fires. Oil fuel to the burner is to be shut off, see Notes 4 and 6
<b>NOTES</b> 1. Special consideration may be given to the requirements for oil-fired hot water heaters. 2. For heaters not supplying thermal oil for services essential for the safety or the operation of the ship at sea, only the items marked* are required. 3. These safeguards are to remain operative during automatic, manual and emergency operation. 4. Alarm and oil fuel shut-off is only required where exhaust gas economisers/boilers are fitted. 5. For exhaust gas economisers/boilers requiring thermal fluid forced circulation, the low flow alarm is to be fitted with provision to override the alarm if the exhaust gas economiser/boiler is to be operated in the dry condition. See also 6.2.5. 6. Alternatively, details of an appropriate fire detection system are to be submitted for consideration.		

### 12.4 Incinerators

12.4.1 Alarms and safeguards are indicated in 12.4.2, 12.4.3 and Table 14.12.3.

12.4.2 Where arrangements are provided to introduce solid waste into the furnace, these are to be such that there is no risk of a fire hazard.

12.4.3 The combustion temperature is to be controlled to ensure that all liquid and solid waste is efficiently burned without exceeding predetermined temperature limits.

### 12.5 Miscellaneous machinery

12.5.1 Alarms and safeguards are indicated in 12.5.2 to 12.5.6 and Table 14.12.4.

12.5.2 **Dual fuel systems.** Oil and gas dual-fired systems for boilers and engines are to be provided with indication to show which fuel is in use.

12.5.3 **Lifts.** For details of alarms and safeguards for lifts classed by LR, reference is to be made to LR's *Code for Lifting Appliances in a Marine Environment*.

12.5.4 **Oil heaters.** Oil fuel or lubricating oil heaters are to be fitted with a high temperature alarm which may be incorporated in the temperature control system. In addition to the temperature control system, an independent sensor with manual reset is to be fitted, which will automatically cut off the heating supply in the event of excessively high temperatures or loss of flow, except where the maximum temperature of the heating medium remains limited to a value below 220°C.

# Machinery Piping Systems

## Part 5, Chapter 14

Section 12

**Table 14.12.2 Inert gas generators: Alarms and safeguards**

Item	Alarm	Note
Inert gas outlet temperature	High	Oil fuel burners to be shut off automatically
Combustion air pressure	Low	Oil fuel burners to be shut off automatically
Oil fuel pressure	Low	—
Oil fuel temperature or viscosity	High and low	Heavy oil only
Burner flame and ignition	Failure	Oil fuel to burner to be shut off automatically, see Note 1
Cooling water pressure or flow	Low	Oil fuel to burner to be shut off automatically
Cooling water temperature	High	—
Combustion space cooling water level (where continuous circulation is required)	High	Cooling water pump and oil fuel to burner are to be shut off automatically
Oil fuel supply	Insufficient	
Power supply to inert gas generator	Failure	Gas regulating valve is to be shut down automatically
Automatic control system power supply	Failure	
NOTES		
1. Combustion spaces are to be purged automatically before re-ignition takes place in the event of a flame-out on all burners.		
2. See also Chapter 15.		

**Table 14.12.3 Incinerators: Alarms and safeguards**

Item	Alarm	Note
Oil fuel temperature or viscosity	High and low	Heavy oil and sludge
Oil fuel pressure	Low	—
Combustion air pressure	Low	Oil fuel and/or sludge to burners to be shut off automatically
Burner flame and ignition	Failure	Oil fuel and/or sludge to burners to be shut off automatically, see Note
Furnace temperature	High	Oil fuel and/or sludge to burners to be shut off automatically
Furnace temperature	Low	If applicable
Exhaust temperature	High	—
NOTE		
Combustion spaces are to be purged automatically before re-ignition takes place in the event of a flame-out on all burners.		

**12.5.5 Oil tank electric heating.** Oil fuel and lubricating oil tanks that are provided with electric heating elements are to be fitted with a high temperature alarm, which may be incorporated in the temperature control system, a low level alarm and an additional low level sensor to cut off the power supply at a level above that at which the heating element would be exposed.

**12.5.6 Oil fuel tanks.** Means are to be provided to eliminate the possibility of overflow from oil fuel service tanks into the machinery space and to safeguard against overflow of oil from oil fuel service tanks through the air pipe. See Chapter 13 regarding the termination of air pipes.

# Machinery Piping Systems

## Part 5, Chapter 14

Section 12

**Table 14.12.4    Miscellaneous machinery: Alarms and safeguards**

Item	Alarm	Note
Stern tube lubricating oil tank level	Low	—
Stern tube bearing temperature (oil lubricated)	High	—
Coolant tanks level	Low	—
Oil fuel service tanks level	High and low	Where a common overflow tank is fitted, a high level alarm in the common overflow tank may be accepted
Oil fuel service tanks temperature	High	Where heating arrangements are fitted
Oil fuel settling tanks temperature	High	Where heating arrangements are fitted
Sludge tanks level	High	—
Feed water tanks level	Low	Service tank only
Purifier water seal broken	Fault	—
Purifier oil inlet temperature	High	—
Air compressor lubricating oil	Failure	Automatic shut-down
Air compressor discharge air temperature	High	—
Hydraulic control system pressure	Low	—
Pneumatic control system pressure	Low	—
Oil heater temperature	High	—
Control environmental conditions	Abnormal	See also Pt 6, Ch 1, 1.3.3





# Piping Systems for Oil Tankers

## Part 5, Chapter 15

Section 1

### Section

- 1 **General requirements**
- 2 **Piping systems for bilge, ballast, oil fuel, etc.**
- 3 **Cargo handling system**
- 4 **Cargo tank venting, purging and gas-freeing**
- 5 **Cargo tank level gauging equipment**
- 6 **Cargo heating arrangements**
- 7 **Inert gas systems**

### ■ Section 1 General requirements

#### 1.1 Application

1.1.1 The requirements of this Chapter are additional to those of Chapter 13 and are applicable to ships which are intended for the carriage of oil in bulk.

1.1.2 The requirements are based on the assumption that the ships are of normal tanker type having the main propelling machinery aft. Departures from this arrangement will require special consideration.

1.1.3 The requirements are primarily intended for ships which are to carry flammable liquids having a flash point not exceeding 60°C (closed-cup test).

1.1.4 Where ships are intended to carry specific cargoes which are non-flammable or which have a flash point exceeding 60°C, the requirements will be modified, where necessary, to take account of the lesser hazards associated with the cargoes.

1.1.5 For a list of cargoes which can be carried in oil tankers, see Table 9.1.2 in Pt 4, Ch 9.

#### 1.2 Plans and particulars

1.2.1 In addition to the plans and particulars required in Chapter 13, the following plans (in a diagrammatic form) are to be submitted for consideration:

- Pumping arrangement at the fore and aft ends and drainage of cofferdams and pump-rooms.
- General arrangement of cargo piping in tanks and on deck.
- General arrangement of cargo tank vents. The plan is to indicate the type and position of the vent outlets from any superstructure, erection, air intake, etc.
- Arrangement of inert gas piping system together with details of inert gas generating plant including all control and monitoring devices.
- Piping arrangements for cargo oil (F.P. 60°C or above, closed-cup test).

- Ventilation arrangements of cargo and/or ballast pump-rooms and other enclosed spaces which contain cargo handling equipment.
- Arrangements for venting, purging and gas measurement for double hull and double bottom spaces.
- Details of alarms and safety arrangements required by 1.6, see also Pt 6, Ch 1,2.

#### 1.3 Materials

1.3.1 All materials used in the cargo pumping and piping systems are to be suitable for use with the intended cargoes and, where applicable, they are to comply with the requirements of Chapter 12.

1.3.2 The requirements of 1.3.1 are also applicable to other piping systems which may come into contact with cargo.

#### 1.4 Design

1.4.1 All piping, valves and fittings are to be suitable for the maximum pressure to which the system can be subjected.

1.4.2 Piping subject to pressure is to be of seamless or other approved type, and is to comply with the requirements of Chapter 12.

#### 1.5 Hazardous zones and spaces

1.5.1 Oil engines, or any other equipment which could constitute a possible source of ignition, are not to be situated within cargo tanks, pump-rooms, cofferdams or other spaces liable to contain petroleum or other explosive vapours, or in spaces or zones immediately adjacent to cargo oil or slop tanks. The temperature of steam, or other fluid, in pipes (or heating coils) in these spaces is not to exceed 220°C. On gas tankers and chemical tankers, the maximum temperature is not to exceed that of the required temperature class of electrical equipment in the cargo area.

1.5.2 For definition of hazardous zones and spaces and requirements for electrical equipment within such spaces, see Pt 6, Ch 2,14.5.

1.5.3 For the requirements for earthing and bonding of pipework for the control of static electricity, see Pt 6, Ch 2,1.13.

#### 1.6 Cargo pump-room

1.6.1 Control engineering systems are to be in accordance with the requirements of Pt 6, Ch 1.

1.6.2 Cargo pump-rooms are to be totally enclosed and are to have no direct communication with machinery spaces. For bilge drainage arrangements in pump-room, see 2.2.

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1.6.3 Pump-rooms are to be situated within, or adjacent to the cargo tank area and are to be provided with ready means of access from the open deck, see also Pt 4, Ch 9, 13.

1.6.4 In cargo pump-rooms any drain pipes from steam or exhaust pipes from the steam cylinders of the pumps are to terminate well above the level of the bilges.

1.6.5 Alarms and safety arrangements are to be provided as indicated in 1.6.6 and Table 15.1.1. These requirements are applicable to pump-rooms where pumps for cargo, such as cargo pumps, stripping pumps, pumps for slop tanks, pumps for COW or similar pumps are provided and not for pump-rooms intended solely for ballast transfer. See also 1.6.7.

**Table 15.1.1 Alarms and safety arrangements**

Item	Alarm	Note
Temperature sensing of bulkhead shaft glands, bearings and pump casings	High see Note 1	Cargo, ballast and stripping pumps
Bilge level	High	—
Hydrocarbon concentration	High see Note 2	> 10% LEL
<b>NOTES</b> 1. The alarm signals shall trigger continuous visual and audible alarms in the cargo control room or the pump control station. 2. This alarm signal shall trigger a continuous audible and visual alarm in the pump-room, cargo control room, engine control room and bridge.		

1.6.6 A system for continuously monitoring the concentrations of hydrocarbon gases within the cargo pump-room is to be fitted. Monitoring points are to be located in positions where potentially dangerous concentrations may be readily detected. Gas analysing units with non-safe-type measuring equipment may be located outside cargo areas (e.g. in cargo control room, navigation bridge or engine room when mounted on the forward bulkhead) provided that:

- sampling lines do not pass through gas safe spaces, except where permitted by (e);
- the gas sampling pipes are fitted with flame arresters. Sample gas is to be led to the atmosphere with outlets arranged in a safe location, in the open atmosphere;
- bulkhead penetrations of sample pipes between safe and dangerous areas are of an approved type. A manual isolating valve is to be fitted in each of the sampling lines at the bulkhead in the safe area;
- the gas detection equipment including sampling piping, sampling pumps, solenoid valves and analysing units, are located in a fully enclosed steel cabinet, with a gasketed door, monitored by its own sampling point. At gas concentrations above 30 per cent LEL inside the steel cabinet, the entire gas-analysing unit is to be automatically shut down; and

- where the cabinet cannot be arranged on the bulkhead, sample pipes are to be of steel or other equivalent material and without detachable connections, except for the connection points for isolating valves at the bulkhead and analysing units. The sample pipes are to be led by their shortest route.

Sequential sampling is acceptable as long as it is dedicated for the pump-room only, including exhaust ducts, and the detection equipment is capable of monitoring from each sampling head location at intervals not exceeding 30 minutes.

1.6.7 Where items of equipment other than described in Table 15.1.1 are located in the pump-room and are driven by shafts passing through bulkheads, the potential risk of ignition of hydrocarbon gas is to be assessed and proposals for mitigation submitted to LR for consideration.

## 1.7 Arrangements for fixed hydrocarbon gas detection systems in double hull and double bottom spaces of oil tankers

1.7.1 In accordance with SOLAS 1974, as amended, Ch II-2/B, Reg. 4.5.7, double hull and double bottom spaces of oil tankers with a deadweight of 20 000 tonnes and above that are not provided with a constant operative inerting system are to be provided with a fixed hydrocarbon gas detection system.

1.7.2 Where a fixed hydrocarbon gas detection system is required by 1.7.1, it is to be of an approved type and it is to meet the requirements of Chapter 16 of the *International Code for Fire Safety Systems (FSS Code)*.

## 1.8 Cargo pump-room ventilation

1.8.1 Cargo pump-rooms and other closed spaces which contain cargo handling equipment, and to which regular access is required during cargo handling operations, are to be provided with permanent ventilation systems of the mechanical extraction type.

1.8.2 The ventilation system is to be capable of being operated from outside the compartment being ventilated and a notice to be fixed near the entrance stating that no person is to enter the space until the ventilation system has been in operation for at least 15 minutes.

1.8.3 The ventilation systems are to be capable of 20 air changes per hour, based on the gross volume of the pump-room or space.

1.8.4 The ventilation ducting is to be arranged to permit extraction from the vicinity of the pump-room bilges, immediately above the transverse floor plates or bottom longitudinals. An emergency intake is also to be arranged in the ducting at a height of 2 m above the pump-room lower platform and is to be provided with a damper capable of being opened or closed from the weather deck and lower platform level. An arrangement involving a specific ratio of areas of upper emergency and lower main ventilation openings, which can be shown to result in at least the required number of air changes through the lower inlets, can

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be accepted without the use of dampers. When the lower inlets are sealed off, owing to flooding of the bilges, then at least 75 per cent of the required number of air changes is to be obtainable through the upper inlets. Means are to be provided to ensure the free flow of gases through the lower platform to the duct intakes.

1.8.5 Protection screens of not more than 13 mm square mesh are to be fitted in outside openings of ventilation ducts, and ventilation intakes are to be so arranged as to minimise the possibility of re-cycling hazardous vapours from any ventilation discharge opening. Vent exits are to be arranged to discharge to a safe place on the open deck and comply with the requirements of 1.8.6.

1.8.6 The vent exits from pump-rooms are to discharge at least 3 m above deck, and from the nearest air intakes or openings to accommodation and enclosed working spaces, and from possible sources of ignition.

1.8.7 The ventilation is to be interlocked to the lighting system (except emergency lighting) such that the cargo pump-room lighting may only come on when the ventilation is in operation. Failure of the ventilation system shall not cause the lighting to go out.

### 1.9 Non-sparking fans for hazardous areas

1.9.1 The air gap between impeller and housing of the fan is to be not less than 0,1 of the impeller shaft bearing diameter or 2 mm whichever is the larger, subject also to compliance with 1.9.2(e). Generally, however, the air gap need be no more than 13 mm.

1.9.2 The following combinations of materials are permissible for the impeller and the housing in way of the impeller:

- (a) impellers and/or housings of non-metallic material, due regard being paid to the elimination of static electricity,
- (b) impellers and housings of non-ferrous metals,
- (c) impellers and housings of austenitic stainless steel,
- (d) impellers of aluminium alloys or magnesium alloys and a ferrous housing provided that a ring of suitable thickness of non-ferrous material is fitted in way of the impeller,
- (e) any combination of ferrous impellers and housings with not less than 13 mm tip clearance,
- (f) any combination of materials for the impeller and housing which are demonstrated as being spark proof by appropriate rubbing tests.

1.9.3 The following combinations of materials for impellers and housing are not considered spark proof and are not permitted:

- (a) impellers of an aluminium alloy or magnesium alloy and a ferrous housing, irrespective of tip clearance,
- (b) impellers of a ferrous material and housings made of an aluminium alloy, irrespective of tip clearance,
- (c) any combination of ferrous impeller and housing with less than 13 mm tip clearance, other than permitted by 1.9.2(c).

1.9.4 Electrostatic charges both in the rotating body and the casing are to be prevented by the use of antistatic materials (i.e. materials having an electrical resistance between  $5 \times 10^4$  ohms and  $10^8$  ohms), or special means are to be provided to avoid dangerous electrical charges on the surface of the material.

1.8.5 Type tests on the complete fan are to be carried out to the Surveyor's satisfaction.

1.9.6 Protection screens of not more than 13 mm square mesh are to be fitted in the inlet and outlet of ventilation ducts to prevent the entry of objects into the fan housing.

1.9.7 The installation of the ventilation units on board is to be such as to ensure the safe bonding to the hull of the units themselves.

### 1.10 Slop tanks

1.10.1 The requirements in 1.10.2 to 1.10.7 are applicable to ships intended for the carriage of ore or oil when oil residues are to be retained in the slop tanks and the ship is otherwise gas free, see *also* Pt 4, Ch 9,11.3.

1.10.2 Slop tanks are to be provided with an approved independent venting system, see Section 4.

1.10.3 At least two portable instruments are to be available on board for gas detection.

1.10.4 Means are to be provided for isolating the piping connecting the pump-room with the slop tanks. The means of isolation is to consist of a valve followed by a spectacle flange or a spool piece with appropriate blank flanges. This arrangement is to be located adjacent to the slop tanks, but where this is unreasonable or impracticable it may be located within the pump-room directly after the piping penetrates the bulkhead. A separate permanently installed pumping and piping arrangement is to be provided for discharging the contents of the slop tanks directly to the open deck for transfer to shore reception facilities when the ship is in the dry cargo mode. When this transfer system is used for slop transfer in dry cargo mode, it shall have no connection to other systems. Separation by means of removal of spool pieces may be accepted.

1.10.5 Adequate ventilation is to be provided for spaces surrounding slop tanks, see *also* Pt 4, Ch 9,11.3.

1.10.6 Warning notices are to be erected at suitable points detailing precautions to be observed prior to the ship loading or unloading, or when the ship is carrying dry cargo with liquid in the slop tanks.

1.10.7 In order to satisfy the requirements of certain National and/or Terminal Authorities, it may be necessary to provide an inert gas system for blanketing the slop tank contents.

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Sections 1 &amp; 2

### 1.11 Steam connections to cargo tanks

1.11.1 Where steaming out and/or fire-extinguishing connections are provided for cargo tanks or cargo pipe lines, they are to be fitted with valves of the screw-down non-return type. The main supply to these connections is to be fitted with a master valve placed in a readily accessible position clear of the cargo tanks.

### ■ Cross-reference

See Pt 6, Ch 1,3 for alarm system requirements.

## ■ Section 2

### Piping systems for bilge, ballast, oil fuel, etc.

#### 2.1 Pumping arrangements at ends of ship outside hazardous zones and spaces

2.1.1 The pumping arrangements in the machinery space and at the forward end of the ship are to comply with the requirements for general cargo ships, in so far as they are applicable, and with the special requirements detailed in this Section.

2.1.2 Bilge, ballast and oil fuel lines, etc., which are connected to pumps, tanks or compartments at the ends of the ship outside hazardous zones and spaces, are not to pass through cargo tanks or have any connections to cargo tanks, or cargo piping. No objection will be made to these lines being led through ballast tanks or void spaces within the range of the cargo tanks.

2.1.3 The oil fuel bunkering system is to be entirely separate from the cargo handling system.

2.1.4 Where non-permanent connections are required in piping systems between non-hazardous and hazardous spaces, two means of isolation are to be provided. One of these means is to provide positive separation by means of a removable spool piece or flexible hose, and blank flanges are to be fitted. The other is to be a non-return valve, or similar, in accordance with an acceptable National or International Standard that is appropriate for the design conditions of the piping system. The non-return valve and removable piece are to be located within the existing hazardous spaces. A notice is also to be provided located in a prominent position adjacent to the means of isolation, clearly indicating that the spool piece or flexible hose is to be removed, and blanking flanges are to be fitted, when the piping is not in use. The removable spool piece is to be clearly identified (labelled/painted in a distinctive colour) and stowed close to its working position.

### 2.2 Cargo pump-room drainage

2.2.1 Provision is to be made for the bilge drainage of the cargo pump-rooms by pump or bilge ejector suction. The cargo pumps or cargo stripping pumps may be used for this purpose, provided that the bilge suction is fitted with screw-down non-return valves and, in addition, an isolating valve or cock is fitted on the pump connection to the bilge chest. The pump-room bilges of small tankers may be drained by means of a hand pump having a 50 mm bore suction. Pump-room suction is not to enter machinery spaces.

### 2.3 Deep cofferdam drainage

2.3.1 Cofferdams, which are required to be provided at the fore and aft ends of the cargo spaces in accordance with Pt 4, Ch 9,1.2 are to be provided with suitable drainage arrangements. Examples of acceptable arrangements are detailed in 2.3.2 and 2.3.3.

2.3.2 Where deep cofferdams can be filled with water ballast, a ballast pump in the main engine room may be used for emptying the after cofferdam. Where fitted, a ballast pump in a forward pump-room may be used for emptying the forward cofferdam. In each case, the suction is to be led direct to the pump and not to a pipe system.

2.3.3 Where intended to be dry compartments, after cofferdams adjacent to the pump-room may be drained by a cargo pump, provided that isolating arrangements are fitted in the bilge system as required by 2.2.1; forward cofferdams may be drained by a bilge and ballast pump in a forward pump-room. Alternatively, cofferdams may be drained by bilge ejectors or, in the case of small ships, by hand pumps.

2.3.4 Cofferdams are not to have any direct connections to the cargo tanks or cargo lines.

### 2.4 Drainage of ballast tanks and void spaces within the range of the cargo tanks

2.4.1 Ballast tanks and void spaces within the range of the cargo tanks are not to be connected to cargo pumps, or have any connections to the cargo system. A separate ballast/bilge pump is to be provided for dealing with the contents of these spaces. This pump is to be located in the cargo pump-room or other suitable space within the range of the cargo tanks.

2.4.2 Ballast pumps shall be provided with suitable arrangements to ensure efficient suction from ballast tanks.

2.4.3 Where submerged water ballast pumps are fitted, they are to be located in separate compartments on opposite sides of the ship such that, in the event of hull damage due to grounding or collision, the risk of total loss of ballast pumping capability is minimised.

2.4.4 Ballast piping is not to pass through cargo tanks and is not to be connected to cargo oil piping. Provision may, however, be made for emergency discharge of water ballast by means of a portable spool connection to a cargo oil pump and where this is arranged, a non-return valve is to be fitted in the ballast suction to the cargo oil pump.

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Sections 2 &amp; 3

2.4.5 Consideration will be given to connecting double bottom and/or wing tanks, which are in the range of the cargo tanks, to pumps in the machinery space where the tanks are completely separated from the cargo tanks by cofferdams, heating ducts or containment spaces, etc.

### 2.5 Air and sounding pipes

2.5.1 Deep cofferdams at the fore and aft ends of the cargo spaces and other tanks or cofferdams within the range of the cargo tanks, which are not intended for cargo, are to be provided with air and sounding pipes led to the open deck. The air pipes are to be fitted with gauze diaphragms at their outlets.

2.5.2 The air and sounding pipes required by 2.5.1 are not to pass through cargo tanks.

2.5.3 On oil tankers of less than 5000 tonnes dead-weight, where wing ballast tanks or spaces are not required, the sounding and air pipes to double bottom spaces below cargo tanks may pass through the cargo tanks. However, the pipes are to be of heavy gauge steel, and are to be in continuous lengths or with welded joints.

### 2.6 Ballast piping in pump-room double bottoms

2.6.1 Ballast piping is permitted to be located within the cargo pump-room double bottom provided any damage to that piping does not render the ship's ballast and cargo pumps, located in the cargo pump-room, ineffective.

### 2.7 Fore peak ballast tank

2.7.1 The fore peak tank can be ballasted with the system serving other ballast tanks within the cargo area, provided that:

- (a) the fore peak tank is considered as a hazardous area;
- (b) the vent pipe openings are located on open deck at an appropriate distance from sources of ignition. In this respect, the hazardous zones distances are to be defined in accordance with Pt 6, Ch 2, 14.5;
- (c) means are provided, on the open deck, to allow measurement of flammable gas concentrations within the fore peak tank by a suitable portable instrument;
- (d) the sounding arrangement to the fore peak tank is direct from open deck; and
- (e) the access to the fore peak tank is direct from open deck; alternatively, indirect access from the open deck to the fore peak tank through an enclosed space may be accepted, provided that:
  - (i) in case the enclosed space is separated from the cargo tanks by cofferdams, the access is through a gas-tight bolted manhole located in the enclosed space and a warning sign is to be provided at the manhole, stating that the fore peak tank may only be opened after it has been proven to be gas free, or any electrical equipment which is not certified safe in the enclosed space is isolated.
  - (ii) where the enclosed space has a common boundary with the cargo tanks and is therefore a hazardous area, the enclosed space is to be well ventilated.

## Section 3 Cargo handling system

### 3.1 General

3.1.1 A complete system of piping and pumps is to be fitted for dealing with the cargo.

3.1.2 Standby means for pumping out each cargo tank are to be provided.

3.1.3 Where cargo tanks are provided with single deep well pumps, or submerged pumps, it will be necessary to provide alternative means for emptying the tanks in the event of the failure of a pump. Portable submersible pumps may be provided on board for this purpose, but the arrangements are to be such that a portable pump could be safely introduced into a full or part-full tank. Details of the arrangements are to be submitted.

3.1.4 Provision is to be made for the gas freeing of the cargo oil tanks when the cargo has been discharged, and for the ventilation and gas freeing of all compartments adjacent to cargo oil tanks. It is recommended that arrangements be provided to enable double bottom tanks situated below cargo tanks to be filled with water ballast to assist in the gas freeing of these tanks, see *also* 7.6.2.

3.1.5 At least two portable instruments are to be available on board for gas detection.

3.1.6 Cargo tank access hatches and all other openings to cargo tanks, such as ullage and tank cleaning openings and restricted sounding devices, see 5.2, are to be located on the weather deck.

### 3.2 Cargo pumps

3.2.1 Pumps for the purpose of filling or emptying the cargo oil tanks are to be used exclusively for this purpose, except as provided in 2.2.1. They are not to have any connections to compartments outside the range of cargo oil tanks.

3.2.2 Means are to be provided for stopping the cargo oil pumps from a position outside the pump-rooms, as well as at the pumps.

3.2.3 The pumps are to be provided with effective relief valves which are to be in closed circuit, i.e. discharging to the suction side of the pumps. Alternative proposals to safeguard against over-pressure on the discharge side of the pump will be specially considered.

3.2.4 Where cargo pumps are driven by shafting which passes through a pump-room bulkhead or deck, gastight glands are to be fitted to the shaft at the pump-room plating. The glands are to be efficiently lubricated from outside the pump-room. The seal parts of the glands are to be of materials that will not initiate sparks. The glands are to be of an approved type and are to be attached to the bulkhead in accordance with Ch 13, 2.4. Where a bellows piece is incorporated in the design, it is to be hydraulically tested to 3,4 bar (3,5 kgf/cm<sup>2</sup>) before fitting.



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Section 3

3.2.5 Where cargo pumps are driven by hydraulic motors which are located inside cargo tanks, the design is to be such that contamination of the operating medium with cargo liquid cannot take place under normal operating conditions. The arrangements are to comply with 3.7.7 and 3.7.8, in so far as they are applicable.

## 3.3 Cargo piping system

3.3.1 Cargo piping and similar piping to cargo tanks are not to pass through ballast tanks.

3.3.2 Cargo pipes are not to pass through tanks or compartments which are outside the cargo tank area.

3.3.3 Means are to be provided to enable the contents of the cargo lines pumps to be drained to a cargo tank or other suitable tank. Where drain tanks are fitted in pump-rooms, they are to be of the closed type with air and sounding pipes led to the open deck.

3.3.4 Expansion joints of approved type or bends are to be provided, where necessary, in the cargo pipe lines.

3.3.5 Expansion pieces of an approved type, incorporating oil resistant rubber or other suitable material, may be accepted in cargo piping, see *also* Ch 13,2.7.2.

3.3.6 In combination carriers where cargo wing tanks are provided, cargo oil lines below deck are to be installed inside these tanks. However, Lloyd's Register (hereinafter referred to as 'LR') may permit cargo oil lines to be placed in special ducts which are to be capable of being adequately cleaned and ventilated to the satisfaction of LR's Surveyors. Where cargo wing tanks are not provided cargo oil lines below deck are to be placed in special ducts.

3.3.7 Means are to be provided for keeping deck spills away from accommodation and service areas. This may be accomplished by means of a 300 mm coaming extending from side to side. Special consideration shall be given to the arrangements associated with stern loading.

## 3.4 Terminal fittings at cargo loading stations

3.4.1 Terminal pipes, valves and other fittings in the cargo loading and discharging lines to which shore installation hoses are directly connected, are to be of steel or approved ductile material. They are to be of robust construction and strongly supported, see *also* 1.3 and 1.4.

3.4.2 A manually operated shut-off valve is to be fitted to each shore loading/discharging connection.

3.4.3 Drip pans for collecting cargo residues in cargo lines and hoses are to be provided beneath pipe and hose connections in the manifold area.

## 3.5 Bow or stern loading and discharge arrangements

3.5.1 Where a ship is arranged for bow and/or stern loading and discharge of cargo outside the cargo tank area, the pipe lines and related piping and equipment forward and/or aft of the cargo area are to have only welded joints and are to be provided with spectacle flanges or removable spool pieces, where branched off from the main line, and a blank flange at the bow and/or stern end connections, irrespective of the number and type of valves in the line.

3.5.2 The spaces within 4,5 m of flanged connections to, or valves or drip trays associated with, discharge manifolds discharge manifolds are to be considered as hazardous spaces with regard to electrical or incensive equipment, see *also* Pt 6, Ch 2,14.10.

## 3.6 Connections to cargo tanks

3.6.1 Where cargo tanks are provided with direct filling connections, the loading pipes are to be led to as low a level as practicable inside the tank.

3.6.2 Where cargo suction and/or filling lines are led through cargo tanks, or through other spaces situated below the weather deck, the connection to each tank is to be provided with a valve situated inside the tank, and capable of being operated from the deck. In the case of cargo tanks which are located adjacent to below-deck pump-rooms, or pipe tunnels, the deck operated valves may be located in these spaces at the bulkhead. In any case, not less than two isolating shut-off valves are to be provided in the pipe lines between the tanks and the cargo pumps.

## 3.7 Remote control valves

3.7.1 Valves on deck and in pump-rooms which are provided with remote control, are, in general, to be arranged for local manual operation independent of the remote operating mechanism, see *also* Ch 13,2.3.2 and 2.3.3.

3.7.2 Where the valves and their actuators are located inside the cargo tanks, two separate suctions are to be provided in each tank, or alternative means of emptying the tank, in the event of a defective actuator, are to be provided.

3.7.3 All actuators are to be of a type which will prevent the valves from opening inadvertently in the event of the loss of pressure in the operating medium. Indication is to be provided at the remote control station showing whether the valve is open or shut.

3.7.4 Materials of construction of the actuators and piping inside the cargo tanks are to be suitable for use with the intended cargo.

3.7.5 Compressed air is not to be used for operating actuators inside cargo tanks.

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Sections 3 &amp; 4

3.7.6 The actuator operating medium in hydraulic systems is to have a flash point of 60°C or above (closed-cup test) and is to be compatible with the intended cargoes.

3.7.7 The design of the actuators is to be such that contamination of the operating medium with cargo liquid cannot take place under normal operating conditions.

3.7.8 Where the operating medium is oil, or other fluid, the supply tank is to be located as high as practicable above the level of the top of the cargo tanks, and all actuator supply lines are to enter the cargo tanks through the highest part of the tanks. Furthermore, the supply tank is to be of the closed type with an air pipe led to a safe space on the open deck and fitted with a flameproof wire gauze diaphragm at its open end. This tank is also to be fitted with a high and low level audible and visual alarm. The requirements of this paragraph need not be complied with if the actuators and piping are located external to the cargo tanks.

3.7.9 It is recommended that for remote control valves not arranged for manual operation, emergency means be provided for operating the valve actuators in the event of damage to the main hydraulic circuits on deck. In the case of valves located inside cargo tanks, this could be achieved by ensuring that the supply lines to the actuators are led vertically inside the tanks from deck, and that connections, with necessary isolating valves, are provided on deck for coupling to a portable pump carried on board.

### 3.8 Cargo handling controls

3.8.1 Electrical measuring, monitoring control and communication circuits located in hazardous spaces are to be in accordance with Pt 6, Ch 2, 14.2, appropriate to the defined hazardous zone.

3.8.2 The handling controls and instruments are to be arranged for safe and easy operation. They may be grouped at a number of control stations or at one main control station.

3.8.3 A satisfactory means of communication is to be provided between cargo handling stations, open deck, the bridge and the machinery space.

3.8.4 The cargo handling controls and instrumentation are, so far as possible, to be separate from the propulsion and auxiliary machinery controls and instrumentation.

### Section 4

## Cargo tank venting, purging and gas-freeing

### 4.1 Cargo tank venting

4.1.1 The venting systems of cargo tanks are to be entirely distinct from the air pipes of the other compartments of the ship. The arrangements and position of openings in the cargo tank deck from which emission of flammable vapours can occur are to be such as to minimise the possibility of flammable vapours being admitted to enclosed spaces containing a source of ignition, or collecting in the vicinity of deck machinery and equipment which may constitute an ignition hazard.

4.1.2 The venting arrangements are to be so designed and operated as to ensure that neither pressure nor vacuum in cargo tanks exceeds design parameters and are to be such as to provide for:

- (a) the flow of the small volumes of vapour, air or inert gas mixtures caused by thermal variations in a cargo tank in all cases through pressure/vacuum valves; and
- (b) the passage of large volumes of vapour, air or inert gas mixtures during cargo loading and ballasting, or during discharging.
- (c) a secondary means of allowing full flow relief of vapour, air or inert gas mixtures to prevent overpressure or underpressure in the event of failure of the arrangements in 4.1.2(b). Alternatively, pressure sensors may be fitted to monitor the pressure in each tank protected by the arrangement required in 4.1.2(b), with a monitoring system in the ship's cargo control room or the position from which cargo operations are normally carried out. Such monitoring equipment is also to provide an alarm facility which is activated by detection of over-pressure or under-pressure conditions within a tank.

4.1.3 The venting arrangements in each cargo tank may be independent or combined with other cargo tanks and may be incorporated into the inert gas piping.

4.1.4 Where the arrangements are combined with other cargo tanks either stop valves or other acceptable means are to be provided to isolate each cargo tank. Where stop valves are fitted, they are to be provided with locking arrangements which are to be under the control of the responsible ship's officer.

4.1.5 There is to be a clear visual indication of the operational status of the valves, or other acceptable means. Where tanks have been isolated, it is to be ensured that the relevant isolating valves are opened before cargo loading or ballasting or discharging of those tanks is commenced. Any isolation is to continue to permit the flow caused by thermal variations in a cargo tank in accordance with 4.1.2(a).

4.1.6 If cargo loading and ballasting or discharging of a cargo tank or cargo tank group, which is isolated from a common venting system is intended, that cargo tank or cargo tank group is to be fitted with a means for over-pressure or under-pressure protection as required in 4.1.2(c).

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4.1.7 The venting arrangements are to be connected to the top of each cargo tank and are to be self-draining to the cargo tanks under all normal conditions of trim and list of the ship. Where it may not be possible to provide self-draining lines permanent arrangements are to be provided to drain the vent lines to a cargo tank.

4.1.8 The venting system is to be provided with devices to prevent the passage of flame into the cargo tanks. The design, testing and locating of these devices are to comply with recognised International Standards.

4.1.9 Ullage openings are not to be used for pressure equalisation and they should be fitted with self-closing tightly sealing covers. Flame arrestors and screens are not permitted in these openings.

4.1.10 Provision is to be made to guard against liquid rising in the venting system to a height which would exceed the design head of cargo tanks. This is to be accomplished by overflow control systems, or other equivalent means, e.g., overflow alarms, together with gauging devices and cargo tank filling procedures but not spill valves which are not considered equivalent to an overflow system. The system for guarding against liquid rising to a height which would exceed the design head of cargo tanks is to be independent of the gauging devices.

4.1.11 Openings for pressure release required by 4.1.2(a) are to:

- (a) have as great a height as is practicable above the cargo tank deck to obtain maximum dispersal of flammable vapours but in no case less than 2 m above the cargo tank deck, and
- (b) be arranged at the furthest distance practicable but not less than 5 m from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery, chain locker openings and equipment which may constitute an ignition hazard.

4.1.12 Pressure/vacuum valves required by 4.1.2(a) may be provided with a by-pass arrangement when they are located in a vent main or masthead riser. Where such an arrangement is provided there are to be suitable indicators to show whether the by-pass is open or closed.

4.1.13 Vent outlets for cargo loading, discharging and ballasting required by 4.1.2(b) are to:

- (a) permit the free flow of vapour mixtures or alternatively, permit the throttling of the discharge of the vapour mixtures to achieve a velocity of not less than 30 m/sec;
- (b) be so arranged that the vapour mixture is discharged vertically upwards;
- (c) where the method is by free flow of vapour mixtures, be such that the outlet is not less than 6 m above the cargo tank deck or fore and aft gangway if situated within 4 m of the gangway and located not less than 10 m measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery, chain locker openings and equipment which may constitute an ignition hazard;

- (d) where the method is by high velocity discharge, be located at a height not less than 2 m above the cargo tank deck and not less than 10 m measured horizontally from the nearest air intakes and openings to enclosed spaces containing a source of ignition and from deck machinery, chain locker openings and equipment which may constitute an ignition hazard. These outlets are to be provided with high velocity devices of an approved type; and
- (e) be designed on the basis of the maximum designed loading rate multiplied by a factor of at least 1,25 to take account of gas evolution, in order to prevent the pressure in any cargo tank from exceeding the design pressure. The master is to be provided with information regarding the maximum permissible loading rate for each cargo tank and in the case of combined venting systems, for each group of cargo tanks.

4.1.14 Pressure/vacuum valves are to be set at a positive pressure of not more than 0,2 bar (0,2 kgf/cm<sup>2</sup>) above atmospheric and a negative pressure of not more than 0,07 bar (0,07 kgf/cm<sup>2</sup>) below atmospheric. Higher positive pressures not exceeding 0,7 bar (0,7 kgf/cm<sup>2</sup>) gauge may be permitted in specially designed integral tanks.

4.1.15 In combination carriers the arrangements to isolate slop tanks containing oil or residues from other cargo tanks are to consist of blank flanges which will remain in position at all times when cargoes other than liquid cargoes referred to in 7.5.16 are carried.

### 4.2 Cargo tank purging and/or gas-freeing

4.2.1 Arrangements for purging and/or gas-freeing are to be such as to minimise the hazards due to the dispersal of flammable vapours in the atmosphere and to flammable mixtures in cargo tank, thus the requirements of 4.2.2 to 4.2.4 are to be complied with, as applicable.

4.2.2 When the ship is provided with an inert gas system the cargo tanks are first to be purged in accordance with the provisions of 7.6.2 until the concentration of hydrocarbon vapours in the cargo tanks has been reduced to less than two per cent by volume. Thereafter gas freeing may take place at the cargo tank deck level.

4.2.3 When the ship is not provided with an inert gas system, the operation is to be such that the flammable vapour is initially discharged either:

- (a) through the vent outlets as specified in 4.1.13, or
- (b) through outlets at least 2 m above the cargo tank deck level with a vertical efflux velocity of at least 30 m/sec. maintained during gas freeing operation, or
- (c) through outlets at least 2 m above the cargo tank deck level with a vertical efflux velocity of at least 20 m/sec. and which are protected by suitable devices to prevent the passage of flame.

4.2.4 When the flammable vapour concentration at the outlet has been reduced to 30 per cent of the lower flammable limit, gas-freeing may thereafter be continued at the cargo tank deck level.

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### 4.3 Venting, purging and gas measurement of double hull and double bottom spaces

4.3.1 Double hull and double bottom spaces are to be fitted with suitable connections for the supply of air.

4.3.2 On tankers required to be fitted with inert gas systems:

- (a) double hull spaces are to be fitted with suitable connections for the supply of inert gas;
- (b) where such spaces are connected to a permanently fitted inert gas distribution system means are to be provided to prevent hydrocarbon gases from the cargo tanks entering the double hull spaces through the system;
- (c) where such spaces are not permanently connected to an inert gas distribution system, appropriate means are to be provided to allow connection to the inert gas main.

4.3.3 When selecting portable instruments for measuring oxygen and flammable vapour, due attention is to be given to their use in combination with the fixed gas sampling line systems referred to in 4.3.4.

4.3.4 Where the atmosphere in double hull spaces cannot be reliably measured using flexible gas sampling hoses, such spaces are to be fitted with permanent gas sampling lines. The configuration of such line systems is to be adapted to the design of such spaces.

4.3.5 The materials of construction and the dimensions of gas sampling lines are to be such as to prevent restriction. Where plastics materials are used, they are to be electrically conductive.

### 4.4 Gas measurement

4.4.1 All tankers are to be equipped with at least two portable instruments for measuring per cent LEL of hydrocarbon concentrations in air.

4.4.2 All tankers are to be equipped with at least two portable oxygen analysers.

4.4.3 For tankers fitted with an inert gas system two portable gas detectors capable of measuring flammable vapour concentrations in inerted atmospheres are to be provided, see 7.7.5.

4.4.4 Suitable means are to be provided for the calibration of gas measurement instruments.

### Section 5

## Cargo tank level gauging equipment

### 5.1 General

5.1.1 Each cargo tank is to be fitted with suitable means for ascertaining the liquid level in the tank in accordance with the requirements of 5.2 and 5.3.

### 5.2 Restricted sounding device

5.2.1 Sounding pipes or other approved devices, which may permit a limited amount of vapour to escape to atmosphere when being used, would be accepted for those tanks which are not required to be fitted with closed sounding devices, see 5.3. The devices are to be so designed as to minimise the sudden release of vapour or liquid under pressure and the possibility of liquid spillage on deck. Means are also to be provided for relieving tank pressure before the device is operated.

5.2.2 Separate ullage openings may be fitted as a reserve means for sounding cargo tanks.

5.2.3 Arrangements which permit the escape of vapour to the atmosphere are not to be fitted in enclosed spaces.

### 5.3 Closed sounding devices

5.3.1 In all tankers fitted with a fixed inert gas system, the cargo tanks are to be fitted with closed sounding devices of an approved type, which do not permit the escape of cargo to the atmosphere when being used.

5.3.2 Proposals to use indirect sounding or measuring devices which do not penetrate the tank plating will be specially considered.

### Section 6

## Cargo heating arrangements

### 6.1 General

6.1.1 Where heating systems are provided for the cargo tanks, the arrangements are to comply with the requirements of 6.2 to 6.5.

### 6.2 Blanking arrangements

6.2.1 Spectacle flanges of spool pieces are to be provided in the heating medium supply and return pipes to the cargo heating system, at a suitable position within the cargo area, so that lines can be blanked off in circumstances where the cargo does not require to be heated or where the heating coils have been removed from the tanks. Alternatively, blanking arrangements may be provided for each tank heating circuit.

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Sections 6 & 7

## 6.3 Heating medium

6.3.1 Where a combustible liquid is used as the heating medium it is to have a flash point of 60°C or above (closed-cup test).

6.3.2 In general, the temperature of the heating medium is not to exceed 220°C, see 1.5.

## 6.4 Heating circuits

6.4.1 The heating medium supply and return lines are not to penetrate the cargo tank plating, other than at the top of the tank, and the main supply lines are to be run above the weather deck.

6.4.2 Isolating shut-off valves or cocks are to be provided at the inlet and outlet connections to the heating circuit(s) of each tank, and means are to be provided for regulating the flow.

6.4.3 Where steam or water is employed in the heating circuits, the returns are to be led to an observation tank which is to be in a well ventilated and well lighted part of the machinery space remote from the boilers.

6.4.4 Where a thermal oil is employed in the heating circuits, the arrangements will be specially considered but, in any case, they are to be such that contamination of the thermal oil with cargo liquid cannot take place under normal operating conditions. In general, the arrangements are, at least, to comply with 3.7.8, in so far as they are applicable.

6.4.5 In any heating system, a higher pressure is to be maintained within the heating circuit than the maximum pressure head which can be exerted by the contents of the cargo tank on the circuit. Alternatively, when the heating circuit is not in use, it may be drained and blanked.

## 6.5 Temperature indication

6.5.1 Means are to be provided for measuring the cargo temperature. Where overheating could result in a dangerous condition, an alarm system which monitors the cargo temperature is to be provided.

## Section 7 Inert gas systems

### 7.1 General

7.1.1 The following requirements apply where an inert gas system, based on flue gas, is fitted on board ships intended for the carriage of oil in bulk having a flash point not exceeding 60°C (closed-cup test). For inert gas systems utilising nitrogen, additional requirements contained in 7.9 are to be applied.

7.1.2 Ships complying with these requirements will be eligible for the additional notation **IGS** in the *Register Book*, see Pt 1, Ch 2.

7.1.3 Throughout this Section the term 'cargo tank' includes also 'slop tanks'. For definition of Machinery spaces of Category 'A', see SOLAS Reg. II-2/A.

7.1.4 The inert gas system is to comply with the requirements of Chapter 15 of the FSS Code, insofar as they are applicable, to new ships only. For the purposes of classification any use of the word 'Administration' in the Regulation is to be taken as meaning LR.

7.1.5 Those parts of scrubbers, blowers, non-return devices, scrubber effluent and other drain pipes which may be subjected to corrosive action by the gases and/or liquids, are to be either constructed of corrosion resistant material or lined with rubber, glass fibre epoxy resin or other equivalent coating material.

7.1.6 The compartment in which any oil fired inert gas generator is situated is to be treated as a machinery space of Category A with respect to fire protection, see also Ch 1, 4.8.

7.1.7 Arrangements are to be made to vent the inert gas from oil fired inert gas generators to the atmosphere when predetermined limits are reached, see 7.7.7(a) to (d), e.g., during start-up or in the event of equipment failure.

7.1.8 Automatic shut-down of the oil fuel supply to inert gas generators is to be arranged on predetermined limits being reached with respect to low water pressure or low water flow rate to the cooling and scrubbing arrangement and with respect to high gas temperature.

7.1.9 Automatic shut-down of the gas regulating valve is to be arranged with respect to failure of the power supply to the oil fired inert gas generators.

### 7.2 Gas supply

7.2.1 The inert gas may be treated flue gas from the main or auxiliary boiler(s), gas turbine(s), or from a separate inert gas generator. In all cases, automatic combustion control, capable of producing suitable inert gas under all service conditions, is to be fitted.

7.2.2 Two oil fuel pumps are to be fitted to the inert gas generator. One fuel pump only may be accepted provided sufficient spares for the oil fuel pump and its prime mover are carried on board to enable any failure of the oil fuel pump and its prime mover to be rectified by the ship's crew.

7.2.3 The inert gas system is to be capable of:

- (a) inerting empty cargo tanks by reducing the oxygen content of the atmosphere in each tank to a level at which combustion cannot be supported;
- (b) maintaining the atmosphere in any part of any cargo tank with an oxygen content not exceeding eight per cent by volume and at a positive pressure at all times in port and at sea except when it is necessary for such a tank to be gas free;



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- (c) eliminating the need for air to enter a tank during normal operations except when it is necessary for such a tank to be gas free;
- (d) purging empty cargo tanks of hydrocarbon gas, so that subsequent gas freeing operations will at no time create a flammable atmosphere within the tank.

7.2.4 The system is to be capable of delivering inert gas to the cargo tanks at a rate of at least 125 per cent of the maximum rate of discharge capacity of the ship expressed as a volume to time rate.

7.2.5 The system is to be capable of delivering inert gas with an oxygen content of not more than five per cent by volume in the inert gas supply main to the cargo tanks at any required rate of flow.

7.2.6 Flue gas isolating valves are to be fitted in the inert gas supply mains between the boiler uptakes and the flue gas scrubber. These valves are to be provided with indicators to show whether they are open or shut, and precautions are to be taken to maintain them gastight and keep the seatings clear of soot. Arrangements are to be made to ensure that boiler soot blowers cannot be operated when the corresponding flue gas valve is open.

### 7.3 Gas scrubber

7.3.1 A flue gas scrubber is to be fitted which will effectively cool the volume of gas specified in 7.2.4 and remove solids and sulphur combustion products. The cooling water arrangements are to be such that an adequate supply of water will always be available without interfering with any essential services on the ship. Provision is also to be made for alternative supply of cooling water.

7.3.2 Filters or equivalent devices are to be fitted to minimise the amount of water carried over to the inert gas blowers.

7.3.3 The scrubber is to be located aft of all cargo tanks, cargo pump-rooms and cofferdams separating these spaces from machinery spaces of Category A.

### 7.4 Gas blowers

7.4.1 At least two blowers are to be fitted which together are capable of delivering to the cargo tanks at least the volume of gas required by 7.2.4. In no case is one of these blowers to have a capacity less than one-third of the total capacity required. In a system with gas generators one blower only may be accepted if that system is capable of delivering the total volume of gas required by 7.2.4 to the protected cargo tanks, provided that sufficient spares for the blower and its prime mover are carried on board to enable any failure of the blower and its prime mover to be rectified by the ship's crew.

7.4.2 The inert gas system is to be so designed that the maximum pressure which it can exert on any cargo tank will not exceed the test pressure of any cargo tank. Suitable shut-off arrangements are to be provided on the suction and discharge connections of each blower. Arrangements are to be provided to enable the functioning of the inert gas plant to be stabilised before commencing cargo discharge. If the blowers are to be used for gas freeing, their air inlets are to be provided with blanking arrangements.

7.4.3 The blowers are to be located aft of all cargo tanks, cargo pump-rooms and cofferdams separating these spaces from machinery spaces of Category A.

### 7.5 Gas distribution lines

7.5.1 Special consideration is to be given to the design and location of scrubber and blowers with relevant piping and fittings in order to prevent flue gas leakages into enclosed spaces.

7.5.2 To permit safe maintenance, an additional water seal or other effective means of preventing flue gas leakage is to be fitted between the flue gas isolating valves and scrubber or incorporated in the gas entry to the scrubber.

7.5.3 A gas regulating valve is to be fitted in the inert gas supply main. This valve is to be automatically controlled to close as required in 7.7.9 and 7.7.10. It is also to be capable of automatically regulating the flow of inert gas to the cargo tanks unless means are provided to automatically control the speed of the inert gas blowers required in 7.4.1.

7.5.4 The valve referred to in 7.5.3 is to be located at the forward bulkhead of the forwardmost gas safe space through which the inert gas supply main passes.

7.5.5 At least two non-return devices, one of which is to be a water seal, are to be fitted in the inert gas supply main, in order to prevent the return of hydrocarbon vapour to the machinery space uptakes or to any gas safe spaces under all normal conditions of trim, list and motion of the ship. They are to be located between the automatic valve required by 7.5.3 and the aftermost connection to any cargo tank or cargo pipeline.

7.5.6 The devices referred to in 7.5.5 are to be located in the cargo area on deck.

7.5.7 The water seal referred to in 7.5.5 is to be capable of being supplied by two separate pumps, each of which is to be capable of maintaining an adequate supply at all times.

7.5.8 The arrangement of the seal and its associated fittings is to be such that it will prevent backflow of hydrocarbon vapours and will ensure the proper functioning of the seal under operating conditions.

7.5.9 Provision is to be made to ensure that the water seal is protected against freezing in such a way that the integrity of seal is not impaired by overheating.



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**7.5.10** A water loop or other approved arrangement is also to be fitted to each associated water supply and drain pipe and each venting or pressure-sensing pipe leading to gas safe spaces. Means are to be provided to prevent such loops from being emptied by vacuum.

**7.5.11** The deck water seal and all loop arrangements are to be capable of preventing return of hydrocarbon vapours at a pressure equal to the test pressure of the cargo tanks.

**7.5.12** The second non-return device is to be a non-return valve or equivalent capable of preventing the return of vapours or liquids and fitted forward of the deck water seal required in 7.5.5. It is to be provided with positive means of closure. As an alternative to positive means of closure, an additional valve having such means of closure may be provided forward of the non-return valve to isolate the deck water seal from the inert gas main to the cargo tanks.

**7.5.13** As an additional safeguard against the possible leakage of hydrocarbon liquids or vapours back from the deck main, means are to be provided to permit this section of the line between the valve having positive means of closure referred to in 7.5.12 and the valve referred to in 7.5.3 to be vented in a safe manner when the first of these valves is closed.

**7.5.14** The inert gas main may be divided into two or more branches forward of the non-return devices required by 7.5.5.

**7.5.15** The inert gas supply mains are to be fitted with branch piping leading to each cargo tank. Branch piping for inert gas is to be fitted with either stop valves or equivalent means of control for isolating each tank. Where stop valves are fitted, they are to be provided with locking arrangements, which are to be under the control of a responsible ship's officer. The method of control is to provide positive indication of the operational status of such valves.

**7.5.16** In combination carriers, the arrangement to isolate the slop tanks containing oil or oil residues from other tanks is to consist of blank flanges which will remain in position at all times other than when cargoes other than oil are being carried except as provided for in 1.9.

**7.5.17** Means are to be provided to protect cargo tanks against the effect of over-pressure or vacuum caused by thermal variations when the cargo tanks are isolated from the inert gas mains.

**7.5.18** Piping systems are to be so designed as to prevent the accumulation of cargo or water in the pipelines under all normal conditions.

**7.5.19** Arrangements are to be provided to enable the inert gas main to be connected to an external supply of inert gas. The arrangement is to consist of a 250 mm nominal size pipe bolted flange connection, isolated from the inert gas main by a valve and connected to the system forward of the non-return valve referred to in 7.5.12.

## 7.6 Venting arrangements

**7.6.1** The arrangements for the venting of all vapours displaced from the cargo tanks during loading and ballasting are to comply with Section 4 and are to consist of either one or more mast risers, or a number of high velocity vents. The inert gas supply mains may be used for such venting.

**7.6.2** The arrangements for inerting, purging or gas freeing of empty tanks as required in 7.2.3 are to be such that the accumulation of hydrocarbon vapours in pockets formed by the internal structural members in a tank is minimised and that:

- (a) on individual cargo tanks the gas outlet pipe, if fitted, is to be positioned as far as practicable from the inert gas/air inlet and in accordance with Section 4. The inlet of such outlet pipes may be located either at deck level or at not more than 1 m above the bottom of the tank;
- (b) the cross sectional area of such gas outlet pipes referred to in (a) is to be such that an exit velocity of at least 20 m/s can be maintained when any three tanks are being simultaneously supplied with inert gas. Their outlets are to extend not less than 2 m above deck level;
- (c) each gas outlet referred to in (b) is to be fitted with suitable blanking arrangements;
- (d) if a connection is fitted between the inert gas supply mains and the cargo piping system, arrangements are to be made to ensure an effective isolation having regard to the large pressure difference which may exist between the systems. This is to consist of two shut-off valves with an arrangement to vent the space between the valves in a safe manner or an arrangement consisting of a spool-piece with associated blanks. The valve separating the inert gas supply main from the cargo main and which is on the cargo main side is to be a non-return valve with a positive means of closure.

**7.6.3** One or more pressure-vacuum breaking devices are to be provided to prevent the cargo tanks from being subject to:

- (a) a positive pressure in excess of the test pressure of the cargo tank if the cargo were to be loaded at the maximum rated capacity and all other outlets were left shut; and
- (b) a negative pressure in excess of 700 mm water gauge if cargo were to be discharged at the maximum rated capacity of the cargo pumps and the inert gas blowers were to fail.

Such devices shall be installed on the inert gas main unless they are installed in the venting system required by Section 4 or on individual cargo tanks.

**7.6.4** The location and design of the devices referred to in 7.6.3 are to be in accordance with Section 4.

## 7.7 Instrumentation and alarms

**7.7.1** Means are to be provided for continuously indicating the temperature and pressure of the inert gas at the discharge side of the gas blowers, whenever the gas blowers are operating.

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7.7.2 Instrumentation is to be fitted for continuously indicating and permanently recording, when the inert gas is being supplied:

- (a) the pressure of the inert gas supply mains forward of the non-return devices required by 7.5.5; and
- (b) the oxygen content of the inert gas in the inert gas supply mains on the discharge side of the gas blowers.

7.7.3 The devices referred to in 7.7.2 are to be placed in the cargo control room where provided. But where no cargo control room is provided, they are to be placed in a position easily accessible to the officer in charge of cargo operations.

7.7.4 In addition to 7.7.2, meters are to be fitted:

- (a) in the navigating bridge to indicate at all times the pressure referred to in 7.7.2(a) and the pressure in the slop tanks of combination carriers, whenever those tanks are isolated from the inert gas supply main; and
- (b) in the machinery control room or in the machinery space to indicate the oxygen content referred to in 7.7.2(b).

7.7.5 Portable instruments for measuring oxygen and flammable vapour concentration are to be provided. In addition, suitable arrangement is to be made on each cargo tank such that the condition of the tank atmosphere can be determined using these portable instruments.

7.7.6 Suitable means are to be provided for the zero and span calibration of both fixed and portable gas concentration measurement instruments, referred to in 7.7.2, 7.7.4 and 7.7.5.

7.7.7 For inert gas systems of both flue gas type and the inert gas generator type audible and visual alarms are to be provided to indicate:

- (a) low water pressure or low water flow rate to the flue gas scrubber as referred to in 7.3.1;
- (b) high water level in the flue gas scrubber as referred to in 7.3.1;
- (c) high gas temperature as referred to in 7.7.1;
- (d) failure of the inert gas blowers referred to in 7.4;
- (e) oxygen content in excess of eight per cent by volume as referred to in 7.7.2(b);
- (f) failure of the power supply to the automatic control system for the gas regulating valve and to the indicating devices as referred to in 7.5.3 and 7.7.2;
- (g) low water level in the water seal as referred to in 7.5.5;
- (h) gas pressure less than 100 mm water gauge as referred to in 7.7.2(a). The alarm arrangements is to be such as to ensure that pressure in slop tanks in combination carriers can be monitored at all times; and
- (j) high gas pressure as referred to in 7.7.2(a).

7.7.8 For inert gas systems of the inert gas generator type additional audible and visual alarms are to be provided to indicate:

- (a) insufficient oil fuel supply,
- (b) failure of the power supply to the generator,
- (c) failure of the power supply to the automatic control system for the generator.

See also Pt 6, Ch 1 for requirements for control, alarm and safety systems, and additional requirements for unattended operation.

7.7.9 Automatic shutdown of the inert gas blowers and gas regulating valve is to be arranged on predetermined limits being reached in respect of (a), (b) and (c) of 7.7.7.

7.7.10 Automatic shut-down of the gas regulating valve is to be arranged in respect of 7.7.7(d).

7.7.11 In respect of 7.7.7(e), when the oxygen content of the inert gas exceeds eight per cent by volume, immediate action is to be taken to improve the gas quality. Unless the quality of the gas improves, all cargo tank operations are to be suspended so as to avoid air being drawn into the tanks and the isolation valve referred to in 7.5.12 is to be closed.

7.7.12 The alarms required in (e), (f) and (h) of 7.7.7 are to be fitted in the machinery space and cargo control room, where provided, but in each case in such a position that they are immediately received by responsible members of the crew.

7.7.13 In respect of 7.7.7(g), where a semi-dry or dry water seal is fitted, the arrangements are to be such that the maintenance of an adequate reserve of water will be ensured at all times and that the water seal will be automatically formed when the gas flow ceases. The audible and visual alarm on the low level of water in the water seal is to operate when the inert gas is not being supplied.

7.7.14 An audible alarm system independent of that required in 7.7.7(h) or automatic shut-down of cargo pumps is to be provided to operate on predetermined limits of low pressure in the inert gas mains being reached.

7.7.15 Detailed instruction manuals are to be provided on board, covering the operations, safety and maintenance requirements and occupational health hazards relevant to the inert gas system and its application to the cargo tank system. The manuals are to include guidance on procedures to be followed in the event of a fault or failure of the inert gas system.

## 7.8 Installation and tests

7.8.1 The inert gas system, including alarms and safety devices, is to be installed on board and tested under working conditions to the satisfaction of the Surveyors.

## 7.9 Nitrogen generator systems

7.9.1 The following requirements are specific only to the gas generator system and apply where inert gas is produced by separating air into its component gases by passing compressed air through a bundle of hollow fibres, semi-permeable membranes or adsorber materials.

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7.9.2 Where nitrogen generator systems are provided in place of boiler flue gas or oil fired inert gas generators referred to in 7.1, the following requirements of Chapter 15 of the FSS Code remain applicable for the piping arrangements, alarms and instrumentation downstream of the gas generator: 2.3.1.3.1, 2.3.1.3.2, 2.3.1.5, 2.3.2, 2.4.2, 2.4.3.1.6, 2.4.3.1.8, 2.4.3.1.9, 2.4.3.3, 2.4.3.4, 2.4.4, as well as SOLAS Reg.II-2/4.5.3.4.2, 4.5.6.3 and 11.6.3.4.

7.9.3 A nitrogen generator consisting of a feed air treatment system and any number of membrane or adsorber modules in parallel is to be capable of delivering nitrogen to the cargo tanks at a rate of at least 125 per cent of the maximum discharge capacity of the ship expressed as a volume to time rate.

7.9.4 The air compressor and the nitrogen generator may be installed in the engine room or in a separate compartment, which may be treated as an 'other machinery space' with respect to fire protection.

7.9.5 Where a separate compartment is provided, it is to be positioned outside the cargo area and is to be fitted with an independent mechanical extraction ventilation system providing at least 6 air changes per hour. The compartment is to have no direct access to accommodation spaces, service spaces and control stations, and is to be provided with oxygen level detection equipment with a low oxygen level alarm.

7.9.6 The nitrogen generator is to be capable of delivering high purity nitrogen with oxygen content not exceeding 5 per cent by volume. The system is to be fitted with automatic means to discharge gas to the atmosphere during start-up and abnormal operation when predetermined limits are reached, see 7.9.16(a) to (e).

7.9.7 The system is to be provided with two air compressors. The total required capacity of the system is preferably to be divided equally between the two compressors, and in no case is one compressor to have a capacity less than 1/3 of the total capacity required. A system with one air compressor only may be accepted provided that sufficient spares for the air compressor and its prime mover are carried on board to enable their failure to be rectified by the ship's crew.

7.9.8 A feed air treatment system is to be fitted to remove free water, particles and traces of oil from the compressed air, and to maintain the specification temperature.

7.9.9 Where a nitrogen receiver/buffer tank is required to be fitted it may be installed in a dedicated compartment or in the separate compartment containing the air compressor and the generator or may be located in the cargo area. Where the nitrogen receiver/buffer tank is installed in an enclosed space, the access is to be arranged from the open deck only and the access door is to open outwards. Permanent ventilation and alarm arrangements are to be fitted as required by 7.9.5.

7.9.10 The oxygen-enriched air from the nitrogen generator and the nitrogen-product enriched gas from the protective devices of the nitrogen receiver are to be arranged to discharge to a safe location on the open deck.

7.9.11 In order to permit maintenance, means of isolation are to be fitted between the generator and the receiver.

7.9.12 At least two non-return devices are to be fitted in the inert gas supply main, one of which is to be of the double block and bleed arrangement. The second non-return device is to be equipped with positive means of closure.

7.9.13 Instrumentation is to be provided for continuously indicating the temperature and pressure of air:

- (a) at the discharge of the compressor,
- (b) at the inlet to the nitrogen generator.

7.9.14 Instrumentation is to be fitted for continuously indicating and permanently recording the oxygen content of the inert gas downstream of the nitrogen generator when inert gas is being supplied.

7.9.15 The instrumentation referred to in 7.9.14 is to be placed in the cargo control room where provided. Where no cargo control room is provided, the instrumentation is to be placed in a position easily accessible to the officer in charge of cargo operations.

7.9.16 Audible and visual alarms are to be provided to indicate:

- (a) low feed-air pressure from compressor as referred to in 7.9.13(a),
- (b) high air temperature as referred to in 7.9.13(a),
- (c) high condensate level at automatic drain of water separator as referred to in 7.9.8,
- (d) failure of electrical heater, if fitted,
- (e) oxygen content in excess of that required in 7.9.6,
- (f) failure of power supply to the instrumentation as referred to in 7.9.14.

7.9.17 Automatic shut-down of the system is to be arranged upon alarm conditions as required by 7.9.16(a) to (e).

7.9.18 The alarms required by 7.9.16(a) to (f) are to be fitted in the machinery space and cargo control room, where provided, but in each case in such a position that they are immediately received by responsible members of the crew.

## 7.10 Nitrogen/inert gas systems fitted for purposes other than inerting required by SOLAS Reg. II-2/4.5.5.1.1

7.10.1 This section applies to systems fitted on oil tankers of less than 20000 DWT.

7.10.2 The requirements of 7.9 apply except paragraphs 7.9.1, 7.9.2, 7.9.3 and 7.9.7.

7.10.3 Where the connections to the cargo tanks, to the hold spaces or to cargo piping are not permanent, the non-return devices required by 7.9.12 may be substituted by two non-return valves.

### ■ Cross-reference

For vapour detection, see also Ch 13,2 of the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquid Chemicals in Bulk*.

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# Water Jet Systems

# Part 5, Chapter 16

Sections 1 & 2

## Section

- 1 **Scope**
- 2 **General requirements**
- 3 **Design requirements**
- 4 **Piping systems**
- 5 **Control and monitoring**
- 6 **Electrical systems**
- 7 **Inspection, testing and fitting of water jets**
- 8 **Installation, maintenance and replacement**

## ■ Section 1 Scope

### 1.1 General

1.1.1 For the purposes of these Rules, a water jet propulsion unit is described as a machine which takes in water, by means of a suitable inlet and conduit and accelerates the mass of water using an impeller and nozzle to form a jet propulsion system. The water jet system comprises the unit and its associated actuation and control devices. The detail of the prime mover is excluded but not its effect on the water jet system.

1.1.2 This Chapter defines the requirements for the design and service life of marine water jet propulsion systems and is to be read in conjunction with the General Requirements for the Design and Construction of Machinery in Chapter 1.

1.1.3 The requirements for a fixed or steerable water jet propulsion system rated at 500 kW and above, which is integral with the ship's hull structure and forms a means of main propulsion, are detailed in this Chapter. This includes support arrangements, controls and the systems necessary to maintain operation and functionality of the water jet unit.

1.1.4 These requirements relate to water jets driven by axial or mixed flow pumps. Where units driven by radial flow pumps or inducers are proposed, details are to be submitted for consideration.

## ■ Section 2 General requirements

### 2.1 Water jet arrangement

2.1.1 In general, for a ship to be assigned an unrestricted service notation, a minimum of two water jet systems are to be provided where these form the sole means of propulsion.

For ships where a single water jet system is the sole means of propulsion or steering, a detailed engineering and safety justification is to be evaluated by LR, see 2.3.22. This evaluation process will include a risk assessment analysis using a recognised technique to verify that sufficient levels of redundancy and monitoring are incorporated in the water jet unit's essential support systems and operating equipment.

2.1.2 Water jet propulsion units are to be capable of continuous operation between their maximum and minimum output power rating at specified operating conditions, see Ch 1,3 and within the operational service profiles defined by 2.3.11 and 2.3.12.

2.1.3 It is the Shipbuilder's responsibility to ensure that all of the installed equipment is suitable for operation in the location and under the environmental conditions defined in Chapter 1. Where anticipated environmental conditions are outside these limits or where additional conditions are to be considered, such as vibration and impulsive accelerations, requirements and details of compliance are to be submitted to LR.

### 2.2 Plans to be submitted

2.2.1 Plans, in triplicate, and information as detailed below and in 2.3 and 2.4, are to be submitted for consideration.

2.2.2 General arrangement plans showing details of the following:

- (a) Shafting assembly indicating bearing positions.
- (b) Steering assembly.
- (c) Reversing assembly.
- (d) Shaft sealing arrangement assembly.
- (e) Longitudinal section of the complete water jet unit.

2.2.3 Detailed and dimensioned plans indicating scantlings, materials of construction and where applicable surface finish of the following:

- (a) Arrangement of the system, including the intended method of attachment to the hull and building-in, tunnel geometry, shell openings, method of stiffening, reinforcement, etc.
- (b) All torque transmitting components, including the shafting system, impeller and stator if fitted.
- (c) Steering components, together with a description and line diagram of the control circuit. This is to include steerable exit water jet nozzles where fitted.
- (d) Components of the retractable buckets where these are used for providing astern thrust.
- (e) The bearing or bearings absorbing the thrust and supporting the impeller, together with the method of lubrication.
- (f) Details of any shafting support or guide vanes used in the water jet system.

2.2.4 Schematic plans of the lubrication and hydraulics required for steering/reversing systems, together with pipe material, relief valves and the working pressures required.



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## 2.3 Calculations and information

2.3.1 Strength calculations based on fatigue considerations incorporating the maximum continuous torque rating and the most 'onerous' operating condition, see 2.3.12, including any short-term high power operation, and including the effects of mean and fluctuating loads, transitory loadings, residual stress allowances, and stress raisers, for the following components:

- (a) Impeller, stator and any bolting arrangements supporting propulsion or steering loads.
- (b) Shaft supports and coupling arrangements.
- (c) Inlet guide vanes, if fitted.
- (d) Steering components, including the lugs of steerable nozzles where fitted.
- (e) Retractable buckets and associated mechanisms which are used to provide astern thrust. A calculation of the hydrodynamic transient loads is to be made for each design and is to include the full ahead to full astern condition. The calculation procedure used is to be supported, where possible, with full scale or model test data, or satisfactory service experience, to validate the design method.

2.3.2 Calculations supporting the connection method of the impeller to the shaft, including details of the fit, push-up, securing, bolting arrangements, etc. In addition, where lengths of shafts are joined using couplings of the shrunk element type, full particulars of the method of achieving the grip force.

2.3.3 Calculations relating to the design of the shaftline as evidence of compliance with Chapter 6.

2.3.4 Torsional vibration calculations of the complete dynamic system in accordance with the relevant requirements included in Chapter 8.

2.3.5 Shaft lateral vibration calculations where required by Chapter 8.

2.3.6 Calculations of the tunnel strength and supporting structure.

2.3.7 A calculation to determine the stresses within the impeller blade.

2.3.8 A calculation of the blade natural frequency for the impeller blades.

2.3.9 A calculation of the relative blade passing frequency between the rotor and stator blades.

2.3.10 The value of the fluctuating stresses during one revolution of the impeller and from transient loadings.

2.3.11 Details of the power/speed range of operation, indicating the maximum continuous torque rating, together with the associated thrusts; this information may be presented in the form of a characteristic curve for the water jet.

2.3.12 The water jet thrust for the assessment of the strength condition being considered is to be as follows:

- (a) For ships which are intended to operate predominantly in a free-running condition and at steady service conditions, the water jet thrust is to correspond to the absorption of the maximum continuous shaft power and corresponding revolutions per minute, giving the maximum torque for which the shaft system is approved.
- (b) For ships which are designed for several operating conditions, the maximum thrust associated with these conditions and the absorption of the corresponding power, in addition to the maximum continuous powering condition, are to be used in the calculation.
- (c) The justification for the thrust selected is to be submitted for consideration in the approval process and this is to include the ship type and the ship speed at the conditions considered.

2.3.13 A justification that the water jet system will meet the self-priming criteria, see 3.1.6.

2.3.14 Specifications of materials and NDE procedures for components essential for propulsion and steering operation and, in the case of the impeller and stator, the yield strength and the fatigue characteristics of the material intended for their manufacture.

2.3.15 A detailed weld specification where an impeller has welded blades.

2.3.16 Full details of the means of corrosion protection in the case of carbon or carbon manganese steel shafts. Alternatively, where it is proposed to use composite shafts, details of the connections at flanges, materials, resin, lay-up procedures, quality control procedures and documentary evidence of fatigue endurance strength is to be provided.

2.3.17 Dry impeller mass and polar moment of inertia.

2.3.18 The prime mover type and designation.

2.3.19 Details of the control engineering aspects of the system design in accordance with Pt 6, Ch 1.

2.3.20 The tolerance specification, agreed between the manufacturer and the Shipbuilder or Owner, to which the components of the unit are to be manufactured is to be defined, together with a justification.

2.3.21 Details of the water jet's loading reactions together with the positions of application within the hull and is to include the maximum applied thrust, tunnel pressures, moments and forces imposed on the ship.

2.3.22 The water jet unit's rated flow and head.

2.3.23 Where an engineering and safety justification report is required, the following supporting information is to be submitted:

- A Failure Mode and Effects Analysis report (FMEA), see 2.4.
- Design standards and assumptions.
- Limiting operating parameters.
- A statement and evidence in respect of the anticipated reliability of any non-duplicated components.

2.3.24 Recommended installation, inspection, maintenance and component replacement procedures. This is to include any in-water engineering procedures where recommended by the water jet manufacturer.

2.3.25 All transient loads which the steering unit is likely to experience from manoeuvring, accelerating, decelerating and the sea conditions.

## 2.4 Failure Mode and Effects Analysis (FMEA)

2.4.1 An FMEA is to be carried out where a single water jet system is the ship's sole means of propulsion, see 2.2.3. The FMEA is to identify components where a single failure could cause the loss of all propulsion and/or steering capability, and the proposed arrangements for preventing and mitigating the effects of such a failure.

2.4.2 The FMEA is to be carried out using the format presented in Table 22.2.1 in Chapter 22 or an equivalent format that addresses the same reliability issues. Analyses in accordance with IEC 60812 *Analysis for System Reliability – Procedure for Failure Mode and Effects Analysis*, or the IMO Code of Safety for High Speed Craft, 2000, Annex 4 – *Procedures for Failure Mode and Effects Analysis*, would be acceptable.

2.4.3 The FMEA is to be organised in terms of equipment and function. The effects of item failures at a stated level and at higher levels are to be analysed to determine these effects on the system as a whole. Actions for mitigation of the effects of failure are to be determined, see 2.4.1.

2.4.4 The FMEA is to:

- (a) identify the equipment or sub-system and mode of operation;
- (b) identify potential failure modes and their causes;
- (c) evaluate the effects on the system of each failure mode;
- (d) identify measures for reducing the risks associated with each failure mode;
- (e) identify measures for preventing failure; and
- (f) identify trials and testing necessary to prove conclusions.

2.4.5 At sub-system level it is acceptable, for the purpose of these Rules, to consider failure of equipment items and their functions. It is not required that the failure of components within that equipment item be analysed, see Ch 22,2.1.5.

2.4.6 Where a FMEA is used for consideration of systems that depend on software-based functions for control or co-ordination, the analysis is to investigate failure of the functions rather than a specific analysis of the software code itself.

## Section 3 Design requirements

### 3.1 General

3.1.1 The arrangement of water jet units is to be such that the ship can be satisfactorily manoeuvred to a declared performance capability. The operating conditions covered are to include the following:

- (a) Maximum continuous shaft power/speed to the impeller in the ahead condition at the declared steering angles and conditions.
- (b) Manoeuvring speeds of the impeller shaft and/or reversing mechanism in the ahead and astern direction at the declared steering angles and sea conditions.
- (c) The stopping manoeuvre described in Ch 1,5.2.2(b).
- (d) Astern running conditions for the ship.

3.1.2 The mean loadings are those loadings induced by the water jet absorbing the mean torque supplied by the prime mover.

3.1.3 Fluctuating loads are defined as those loads which occur during one revolution of the impeller due to cyclic variations. For example, the spatial flow variations and torsional vibration at nominally steady state operating conditions.

3.1.4 Transient loads are defined as those loadings resulting from acceleration and deceleration of the ship, manoeuvring, seaway conditions and other similar forms of loading. This also includes any significant back-pressure effects developed from the operation of the reversing bucket, if fitted.

3.1.5 To ensure self-priming of the water jet unit, the shaft centreline of the unit is to be lower than the light draught static waterline of the ship. In cases where this is either impracticable or undesirable, the distance of the impeller shaft centreline above the ship's light draught waterline is to be less than or equal to 10 per cent of the pump inlet diameter.

3.1.6 Provision is to be made to allow for the in-service visual inspection of the complete blade surfaces of both the impeller and stator blades using either a direct visual or borescope inspection technique.

### 3.2 Shaftline

3.2.1 The diameter of the shaftline components are to comply with Chapter 6. For calculation purposes the shaft carrying the impeller is to be taken as equivalent to a screw-shaft.

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3.2.2 Where it is proposed to use carbon or carbon manganese steel shafts which may be in contact with sea-water, these are to be protected.

3.2.3 The diameter of unprotected screwshafts of corrosion-resistant material is not to be less than that given in Vol 7, Pt 11, Ch 2,4.4.7 of the *Rules and Regulations for the Classification of Special Service Craft*.

3.2.4 The use of composite shafts is permitted, see 2.3.16.

3.2.5 Where lengths of shafts are joined using couplings of the shrunk element type, a factor of safety, based upon the mean plus the vibratory and transient torques, against slippage of 2,0 is to be achieved for couplings which are located inboard and 2,5 for couplings which are located outboard.

3.2.6 Where shaftline components are bolted together, a factor of safety of 1,5 is to be achieved for the design of the bolted connection when considered in the context of the mean, fluctuating and transitory loadings.

3.2.7 If a keyed fitting of the impeller to the shaft is contemplated, then the requirements of Ch 6,3.10 are to be satisfied.

3.2.8 Where it is proposed to fit a keyless impeller, the fitting is to comply with the requirements of Ch 7,3.2, as applicable, excluding the requirements for Ice Class. Use of the words 'propeller' and 'screwshaft' are to be taken as meaning 'impeller' and 'impellershaft' respectively.

### 3.3 Shaft support system and guide vanes

3.3.1 In cases where the shaft requires support from the tunnel walls ahead of the impeller or, alternatively, where guide vanes are required to assist the flow around a bend in the ducting system, the supports or guide vanes are to be suitably aligned to the flow and have suitably rounded leading and trailing edges or be of an aerofoil section.

3.3.2 In general, the fillet radius should be greater than or equal to the maximum thickness of the vane or support at that location. Smaller radii may be considered for which the results of an approved measurement programme or calculation procedure are to be submitted. In all cases, a factor of safety of at least 1,5 is to be demonstrated for the maximum designed operating conditions.

3.3.3 A facility for the inspection of the supports or guide vanes is to be provided which will allow either direct visual or borescope inspection of these components and their transition to other members.

### 3.4 Impeller

3.4.1 A calculation to determine the stresses within the impeller blades is to be carried out, which takes into account the mean blade loading, fluctuating loadings, transient loads and centrifugal force. The computations may be accomplished by either classical methods or numerical analysis. Designs of water jet systems which have been based on a combination of computational fluid dynamics and finite element methods will be considered. However, it will be necessary to demonstrate to the satisfaction of LR that the formulation of the methods used has been correlated with previous full scale measurement or other calculation experience.

3.4.2 For the purposes of the calculation required by this sub-Section, the fluctuating stresses during one revolution of the impeller is to be taken as 20 per cent of the maximum mean stress, and the stresses from transient loadings are to be taken as 15 per cent of the hydrodynamic mean stress, unless otherwise specified by the designer.

3.4.3 The fatigue assessment of the impeller blades is to be based on the stress in the root sections, excluding the influence of the blade root fillets. This assessment is to include the following components:

- the maximum stresses derived from the mean loading, including both the hydrodynamic and centrifugal components;
- the amplitude of the fluctuating stresses during one revolution of the impeller;
- the stresses derived from transient loading and an allowance for any residual stresses in the material.

It is permissible to combine the variable components of stress in a linear fatigue damage accumulation assessment procedure. A factor of safety of at least 1,5 against fatigue failure is to be demonstrated for the maximum continuous rating condition or any other more onerous condition, see 3.1.1.

3.4.4 In general, the fillet radius is to be greater than the maximum thickness of the impeller blade at that location. Composite radiused fillets or elliptical fillets which provide an improved stress concentration factor are preferred.

3.4.5 Where an impeller has bolted-on blades, consideration is to be given to the distribution of stress in the palms of the blade and in the boss and bolting arrangements.

3.4.6 Where an impeller has welded blades the welds are to be of the full penetration type or of equivalent strength. Where laser welding is to be used, details are to be submitted for consideration.

3.4.7 The blades are to be provided with hydrodynamically faired leading and trailing edges which may be either of simple radius or of a more complex aerofoil edge form. The tip clearance, whilst being kept to a minimum for hydrodynamic purposes, is to be sufficient to allow for any transient vibrational behaviour, axial shaft movement or differential thermal expansion.

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3.4.8 A calculation of the blade natural frequency for the impeller blades is to be undertaken. The fundamental natural frequency in water of the blade is to be shown to lie outside any expected excitation frequencies within a speed range of the water jet unit and up to 10 per cent above the maximum impeller speed.

### 3.5 Stator

3.5.1 The stator blades, where fitted, are to be designed to be capable of withstanding the combined hydrodynamic mean, fluctuating, transient and mechanical loads, including any loads transmitted via shaft bearings, developed by the unit and reacted through the blades when the impeller is absorbing full power. Consideration is to be given to situations when the vessel is either free running or in a condition specified by 3.1.1 or undergoing stopping, accelerating or decelerating manoeuvres. A factor of safety against mechanical failure by yielding of the blades of 1,5 is to be demonstrated.

3.5.2 In general, the fillet radius is to be greater than the maximum thickness of the blade at that location. Composite radiused fillets or elliptical fillets which provide improved stress concentration factors are preferred.

3.5.3 If the stator ring comprises a segmented assembly, then consideration is also to be given to the distribution of stress in the various adjacent members of the overall assembly.

3.5.4 A calculation of the relative blade passing frequency between the rotor and stator blades is to demonstrate that this does not coincide with the natural frequency of the stator blades over the speed range of the water jet unit and up to 10 per cent above maximum impeller speed.

3.5.5 The stator blades are to be provided with hydrodynamically faired leading edges which may have either a simple radius or a more complex aerofoil edge form.

3.5.6 Where the stator blading assembly forms part of the nozzle, the requirements of 3.7 are to be considered in association with those for the stator assembly.

### 3.6 Tunnel and securing arrangements

3.6.1 The tunnel is to be adequately supported, framed and fully integrated into the hull structure. The critical locations and integrity of the supports and framing are to be as specified in the FMEA and agreed by the Shipbuilder and LR.

3.6.2 The tunnel and supporting structure scantlings are to be not less than the Rule requirements for the surrounding structure. The strength of the hull structure in way of tunnel(s) is to be maintained. The structure is to be adequately reinforced and compensated as necessary. All openings are to be suitably reinforced and have radiused corners.

3.6.3 Consideration is to be given to providing the inlet to the tunnel with a suitable guard to prevent the ingress of large objects into the rotodynamic machinery. The dimensions of this guard, if fitted, are to strike a balance between undue efficiency loss due to flow restriction and viscous losses, the size of object allowed to pass and the susceptibility to clog with weed and other flow-restricting matter.

3.6.4 The inlet profile of the tunnel is to be designed so as to provide a smooth uptake of the water over the range of vessel operating trims and avoid significant separation and/or cavitation of the flow which may then pass downstream into the rotating machinery.

3.6.5 Design consideration is to take account of pressures which could develop as a result of a duct blockage as well as in relation to the axial location of rotating parts.

3.6.6 The strength of the tunnel and supporting structure are to be examined by direct calculation procedures.

### 3.7 Nozzle/steering arrangements

3.7.1 In general, the steering systems and components are to comply with the requirements of Chapter 19.

3.7.2 For vessels with more than one steerable water jet, the requirement for auxiliary steering arrangements in Ch 19,2 is to be achieved by equipping each of the steerable water jets with its own dedicated and independent steering gear control system and power actuating system. Consideration will be given to alternative arrangements providing equivalence can be demonstrated.

3.7.3 The main steering arrangements are to be operated by power and capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,4 rev/min, with the ship running ahead at maximum ahead service speed.

3.7.4 The auxiliary steering arrangements are to be:

- (a) Capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,083 rev/min, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.
- (b) For all ships, operated by power where necessary to meet the requirements of (a) and in any ship having power more than 2,500 kW propulsion power per thruster unit.

3.7.5 Nozzles can be either of a fixed or steerable form. The design of the nozzle is to take into account fully the change in pressure distribution along its inner surface together with the other mechanical loads (e.g. stator assembly loads) and transient loads caused by the flow-directing attachments which may be reacted through the body of the nozzle. In this analysis the changes to the pressure distribution caused by transient manoeuvres are to be considered.

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3.7.6 In addition to the requirements of Chapter 19, the steering mechanism and bucket are to be capable of maintaining the manoeuvrability of the ship in terms of turning circle, zig-zag and stopping requirements within the limits defined by IMO Resolution MSC.137(76), *Standards for Ship Manoeuvrability*.

3.7.7 Consideration is to be given to all transient loads which the steering unit is likely to experience from manoeuvring, accelerating, decelerating and the sea conditions.

3.7.8 The nozzle/bucket is to be given mechanical protection by the Shipbuilder from other impact damage such as collision.

## 3.8 Bolts

3.8.1 Detailed consideration and analysis is to be given to essential bolting arrangements in critical locations as specified in the FMEA and where indicated by the manufacturer or Shipbuilder and agreed by LR. These are to include; bolts used in the securing of blades or guide vanes, assembly of the unit in the ship and any conduit components.

## Section 4 Piping systems

### 4.1 General

4.1.1 The piping systems for a water jet unit are to comply with the general requirements of Chapter 12.

4.1.2 Lubricating and hydraulic oil systems and standby arrangements are to comply with the requirements of Chapter 14; in addition, steering hydraulic systems are to comply with the applicable requirements of Chapter 19.

## Section 5 Control and monitoring

### 5.1 General

5.1.1 In addition to this Section, the control engineering systems are to comply with Pt 6, Ch 1.

5.1.2 For water jets used as the only means of propulsion and steering, a standby or alternative power source for the actuating device that controls the angular position and/or the reversing angle is to be provided. Automatic start of the standby pump supplying hydraulic power for steering and reversing is to be provided.

5.1.3 Means are to be provided at each control station to stop each water jet.

## 5.2 Monitoring and alarms

5.2.1 In addition to the requirements of Chapter 19, alarms and monitoring requirements are indicated in 5.2.2 to 5.2.4 and Table 16.5.1.

**Table 16.5.1 Alarms**

Item	Alarm	Note
Hydraulic system pressure	Low	—
Hydraulic oil supply tank level	Low	—
Hydraulic oil temperature	High	Where an oil cooler is fitted
Lubricating oil temperature	High	—
Lubricating oil pressure	Low	In forced lubrication systems
Lubricating oil tank level	Low	Where a tank is provided
Ratio of jet rpm/vessel speed	High	Only if installed power per jet >4 MW
Control system failure	Fault	Includes follow-up failure of steering or reversing system
Control system power supply	Failure	—

5.2.2 An indication of the angular position of the nozzle is to be provided at each station from which it is possible to control the direction of thrust from the units.

5.2.3 An indication of both the required and actual reversing bucket position is to be provided at each station from which it is possible to control the reversal of thrust.

5.2.4 All alarms associated with water jet unit faults are to be indicated individually at the control stations and in accordance with the alarm system specified by Pt 6, Ch 1.

## Section 6 Electrical systems

### 6.1 Installation and distribution arrangements

6.1.1 The electrical installation is to comply with the relevant sections of Pt 6, Ch 2.

6.1.2 Water jet auxiliaries and controls are to be served by individual circuits. Services that are duplicated are to be separated throughout their length as widely as practicable and without the use of common feeders, transformers, converters, protective devices or control circuits.

# Water Jet Systems

## Part 5, Chapter 16

Sections 7 &amp; 8

### ■ Section 7 Inspection, testing and fitting of water jets

#### 7.1 General

7.1.1 The finished impeller is to be statically balanced on completion of the manufacturing process and meet the requirements of ISO 1940 or an alternative standard acceptable to LR. In the case where the blade tip speed is greater than 60 m/s, dynamic balancing is required unless otherwise agreed by the manufacturer and LR.

7.1.2 The following tests, markings and inspections are to be carried out in the presence of the Surveyor:

- (a) The balancing of the impeller or the blades.
- (b) Non-destructive examination of the impeller blades and the principal component parts of the propulsion system; see Ch 4,8 for austenitic stainless steels and Ch 8,3 for aluminium alloys of the Rules for Materials.
- (c) The quality of the fit of the impeller boss on the shaft taper.
- (d) The fitting of the impeller to the shaft and its subsequent functional testing.
- (e) The finished surfaces of the impeller boss, conical bores, fillets, cones and blade surfaces are to be shown to conform to the tolerances specified on the impeller drawing.

7.1.3 Bolts and nuts in critical locations, as specified in the FMEA and where indicated by the manufacturer or Shipbuilder and agreed by LR, are to be equipped with adequate securing arrangements to the satisfaction of the LR Surveyor.

#### 7.2 Shop tests and installation of water jet systems

7.2.1 The completed water jet unit is to undergo a tightness test in which an internal hydrostatic pressure of 1,5 bar above the maximum working pressure of the unit is to be applied.

7.2.2 In cases where the impeller is fitted to the shaft using an interference fit, the bedding of the impeller with the shaft is to be demonstrated in the shop to the satisfaction of the LR Surveyor. Sufficient time is to be allowed for the temperature of the components to equalise before bedding. A contact marking between the bore of the impeller boss and the shaft surface of better than 80 per cent is to be demonstrated when the contact marking ink is spread thinly on the surface of the shaft. Alternative means for demonstrating the bedding of the impeller will be considered.

7.2.3 Means are to be provided to indicate the relative axial position of the impeller boss on the shaft. Permanent reference marks are to be made on the impeller boss, shaft and any nut to indicate angular and axial positioning of the impeller. Care is to be taken in marking the inboard end of the shaft taper to minimise stress-raising effects.

7.2.4 A copy of the fitting curve relative to temperature and means for determining any subsequent movement are to be placed on board.

7.2.5 The impeller running clearances are to be checked following the installation of the unit in the ship.

7.2.6 The thrust bearing clearances in the water jet system are to be verified against the required design values. This is to be done following the installation of the unit in the ship.

7.2.7 The piping systems are to be adequately flushed in accordance with the manufacturer's recommendations and the final levels of contamination recorded. Similarly, pressure testing of the piping systems is to comply with Chapter 12.

#### 7.3 Sea trial requirement

7.3.1 The following requirements are to be complied with:

- Ch 1,5.2 for sea trials.
- Ch 19,7.2 for steering trials.

In addition, the general design capability specified in 3.1.1 is to be demonstrated to the Surveyor's satisfaction.

7.3.2 The control systems relating to the correct functioning of the water jet are to be the subject of harbour and then sea trials. Demonstration of the requirements of Pt 6, Ch 1 is required and the design combinations of control functions are to be undertaken during the trials programme.

7.3.3 On sea trials and under free running conditions the relationship between ship speed and impeller rotational speed is to be verified against the water jet's design basis.

7.3.4 Any trials and testing identified from the FMEA report, see 2.4.4, are to be carried out.

### ■ Section 8 Installation, maintenance and replacement

#### 8.1 General

8.1.1 All water jet system propulsion units are to be provided with a copy of the manufacturer's installation and maintenance manual that is pertinent to the actual equipment. See 2.3.24.



8.1.2 The manual required by 8.1.1 is to be placed on board and is to contain the following information:

- (a) Description of the water jet propulsion system with details of function and design operating limits. This is also to include details of support systems such as lubrication, cooling and condition monitoring arrangements.
  - (b) Identification of all components together with details of any that have a defined maximum operating life.
  - (c) Instructions for installation of the system on board ship with details of any required specialised equipment.
  - (d) Instructions for commissioning at initial installation and following maintenance.
  - (e) Maintenance and service instructions to include inspection/renewal of bearings and sealing arrangements. This is also to include component fitting procedures, clearance measurements and lubricating oil treatment where applicable.
  - (f) Actions required in the event of fault/failure conditions being detected.
  - (g) Precautions to be taken by personnel working during installation and maintenance.
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# Requirements for Fusion Welding of Pressure Vessels and Piping

## Part 5, Chapter 17

Sections 1 & 2

### Section

- 1 **General**
- 2 **Manufacture and workmanship of fusion welded pressure vessels**
- 3 **Repairs to welds on fusion welded pressure vessels**
- 4 **Post-weld heat treatment of pressure vessels**
- 5 **Welded pressure pipes**
- 6 **Non-Destructive Examination**

### ■ Section 1 General

#### 1.1 Scope

1.1.1 The requirements of this Chapter apply to the welding of pressure vessels and process equipment, heating and steam raising boilers and pressure pipes. The allocation of Class is determined from the design criteria referenced in Chapters 10, 11 and 12.

1.1.2 Fusion welded pressure vessels will be accepted only if manufactured by firms equipped and competent to undertake the quality of welding required for the Class of vessel proposed. For Class 1, 2/1 and 2/2 pressure vessels, the manufacturer's works are to be approved in accordance with the requirements specified in *Materials and Qualification Procedures for Ships*, Book A Procedure MQPS 0-4.

1.1.3 For pressure vessels which only have circumferential seams, see Ch 10, 1.5.4 and Ch 11, 1.5.5.

#### 1.2 General requirements for welding plant and welding quality

1.2.1 In the first instance, and before work is commenced, the Surveyors are to be satisfied that the required quality of welding is attainable with the proposed welding plant, equipment and procedures in accordance with the guidelines specified in *Materials and Qualification Procedures for Ships Book A, Procedure 0-4*.

1.2.2 All welding is to be in accordance with the requirements specified in Chapter 13 of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

#### 1.3 Manufacture and workmanship of fusion welded pressure vessels

1.3.1 Pressure vessels are to be constructed and examined in accordance with the requirements specified in Chapter 13 of the Rules for Materials, unless more stringent requirements are specified.

### ■ Section 2 Manufacture and workmanship of fusion welded pressure vessels

#### 2.1 General requirements

2.1.1 Prior to commencing construction, the design of the vessel is to be approved where required by Ch 10, 1.6 and Ch 11, 1.6.

2.1.2 Pressure vessels will be accepted only if manufactured by firms that have been assessed and approved in accordance with MQPS 0-4.

#### 2.2 Materials of construction

2.2.1 Where the construction requires post weld heat treatment, consideration should be given to certifying the material after subjecting the test pieces to a simulated heat treatment.

#### 2.3 Tolerances for cylindrical shells

2.3.1 Measurements are to be made to the surface of the parent plate and not to a weld, fitting or other raised part.

2.3.2 In assessing the out-of-roundness of pressure vessels, the difference between the maximum and minimum internal diameters measured at one cross-section is not to exceed the amount given in Table 17.2.1.

**Table 17.2.1 Tolerances for cylindrical shells**

Nominal internal diameter of vessel in mm	Difference between maximum and minimum diameters	Maximum departure from designed form
$\leq 300$ $> 300 \leq 460$ $> 460 \leq 600$ $> 600 \leq 900$ $> 900 \leq 1220$ $> 1220 \leq 1520$ $> 1520 \leq 1900$	1,0 per cent of internal diameter	1,2 mm 1,6 mm 2,4 mm 3,2 mm 4,0 mm 4,8 mm 5,6 mm
$> 1900 \leq 2300$ $> 2300 \leq 2670$ $> 2670 \leq 3950$	19 mm	6,4 mm 7,2 mm 8,0 mm
$> 3950 \leq 4650$ $> 4650$	19 mm 0,4 per cent of internal diameter	0,2 per cent of internal diameter

Requirements for Fusion Welding of Pressure Vessels and Piping

Part 5, Chapter 17

Sections 2 to 5

2.3.3 The profile measured on the inside or outside of the shell, by means of a gauge of the designed form of the shell, and having a chord length equal to one-quarter of the internal diameter of the vessel, is not to depart from the designed form by more than the amount given in Table 17.2.1. This amount corresponds to x in Fig. 17.2.1.

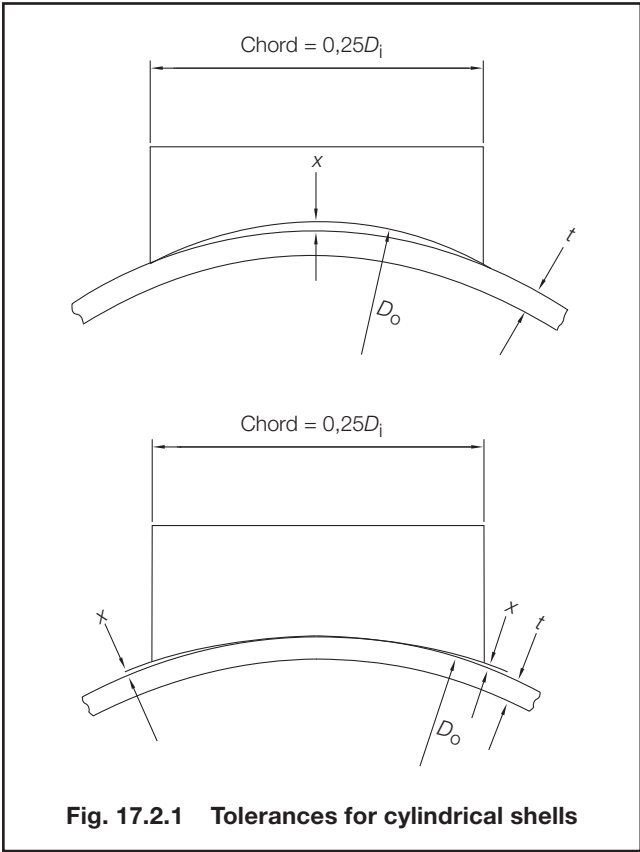


Fig. 17.2.1 Tolerances for cylindrical shells

2.3.4 Shell sections are to be measured for out-of-roundness, either when laid flat on their sides or when set up on end. When the shell sections are checked while lying on their sides, each measurement for diameter is to be repeated after turning the shell through 90° about its longitudinal axis. The two measurements for each diameter are to be averaged, and the amount of out-of-roundness calculated from the average values so determined.

2.3.5 Where there is any local departure from circularity due to the presence of flats or peaks at welded seams, the departure from designed form shall not exceed that of Table 17.2.1.

2.3.6 The external circumference of the completed shell is not to depart from the calculated circumference (based upon nominal inside diameter and the actual plate thickness) by more than the amounts given in Table 17.2.2.

Table 17.2.2 Circumferential tolerances

Outside diameter (nominal inside diameter plus twice actual plate thickness), in mm	Circumferential tolerance
300 to 600 inclusive	±5 mm
Greater than 600	±0,25 per cent

Section 3  
Repairs to welds on fusion welded pressure vessels

3.1 General

3.1.1 Repairs to welds on fusion welded pressure vessels are to be in accordance with the requirements of Chapter 13 of the Rules for Materials.

Section 4  
Post-weld heat treatment of pressure vessels

4.1 General

4.1.1 Post-weld heat treatment of fusion welded pressure vessels are to be in accordance with the requirements of Chapter 13 of the Rules for Materials.

Section 5  
Welded pressure pipes

5.1 General

5.1.1 Fabrication of pipework is to be carried out in accordance with the requirements of Ch 13,5 of the Rules for Materials.

5.2 Welding workmanship

5.2.1 Preheating is to be effected by a method which ensures uniformity of temperature at the joint. The method of heating and the means adopted for temperature control are to be to the satisfaction of the Surveyors.

5.2.2 All welding is to be performed in accordance with the approved welding procedures in this Section by welders who are qualified for the materials, joint types and welding processes employed.

# Requirements for Fusion Welding of Pressure Vessels and Piping

## Part 5, Chapter 17

Sections 5 & 6

5.2.3 Welding without filler metal is generally not permitted for welding of duplex stainless steel materials.

5.2.4 All welds in high pressure and high temperature pipelines are to have a smooth surface finish and even contour; if necessary, they are to be made smooth by grinding.

5.2.5 Check tests of the quality of the welding are to be carried out periodically at the discretion of the Surveyors.

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## ■ Section 6 Non-Destructive Examination

### 6.1 General

6.1.1 Non-Destructive Examination (NDE) of pressure vessels and piping is to be performed in accordance with the requirements of Ch 13,4 and 5 of the Rules for Materials.

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# Integrated Propulsion Systems

# Part 5, Chapter 18

Sections 1 & 2

## Section

- 1 **General requirements**
- 2 **Machinery arrangements**
- 3 **Control arrangements**

## ■ Section 1 General requirements

### 1.1 General

1.1.1 This Chapter applies to both cargo ships and passenger ships and is in addition to other relevant Chapters of the Rules.

1.1.2 The Rules contained in this Chapter cover machinery arrangements and control systems necessary for operating essential machinery from a (centralised) control station on the bridge under normal sea-going and manoeuvring conditions, but do not signify that the machinery space may be operated unattended.

1.1.3 In general, ships complying with the requirements of this Chapter will be eligible for the machinery class notation IP, see Pt 1, Ch 2.2.4.

1.1.4 The details of control systems will vary with the type of machinery being controlled, and special consideration will be given to each case.

### 1.2 Plans

1.2.1 **Control systems.** Where control systems are applied to essential machinery or equipment the following plans are to be submitted in triplicate:

- Details of operating medium, i.e. pneumatic, hydraulic or electric including standby sources of power.
- Description of operation with explanatory diagrams.
- Line diagrams of control circuits.
- List of monitored points.
- List of control points.
- List of alarm points.
- Test schedule including test facilities provided.

1.2.2 Plans for the control systems of the following machinery are to be submitted:

- Main propelling machinery, including all auxiliaries essential for propulsion.
- Controllable pitch propellers.
- Electric generating plant.
- Evaporating and distilling systems for use with main steam machinery.
- Steam raising plant for essential services.

1.2.3 **Alarm systems.** Details of the overall alarm system linking the machinery space control station with the bridge control station are to be submitted.

1.2.4 **Control stations.** Details of bridge and machinery space control stations are to be submitted, e.g. control panels and consoles.

1.2.5 **Machinery configurations.** Plans showing the general arrangement of the machinery space, together with the layout and configuration of the main propulsion and essential machinery, are to be submitted.

## ■ Section 2 Machinery arrangements

### 2.1 Main propulsion machinery

2.1.1 The main propulsion machinery may be oil engines, turbines or electric motors but the configuration of the propulsion system and its relationship with other essential equipment is to comply with the remaining requirements of this Section.

2.1.2 The main propulsion machinery is to drive one of the generators required by 2.2.2. This generator is to be capable of supplying the essential electrical load under all normal sea-going and manoeuvring conditions.

2.1.3 Standby machinery is to be provided capable of being readily connected to the main propulsion system so as to provide emergency propulsion. This standby machinery is to be capable of connection so as to provide an alternative drive to the generator required in 2.1.2. It need not provide power to both systems simultaneously, see also 2.2.2.

### 2.2 Supply of electric power and essential services

2.2.1 Continuity of electrical power supply and essential services are to be ensured under all normal sea-going and manoeuvring conditions without manual intervention in the machinery space. Methods by which this may be achieved include automatic start-up of generating sets and essential pumps or manual start-up of these services from the bridge.

2.2.2 Generating sets and converting sets are to be sufficient to ensure the operation of services essential for the propulsion and safety of the ship even when one generating set or converting set is out of service.

### 2.3 Controllable pitch propellers

2.3.1 For propulsion systems with controllable pitch propellers a standby or alternative power source for the actuating medium for controlling the pitch of the propeller blades is to be provided.



# Integrated Propulsion Systems

# Part 5, Chapter 18

Section 3

## Section 3 Control arrangements

### 3.1 Bridge control

3.1.1 Means are to be provided to ensure satisfactory control of propulsion from the bridge in both the ahead and astern directions when operating on either the main or standby engine(s).

3.1.2 Instrumentation to indicate the following is to be fitted on the bridge and at any other station from which the propulsion machinery may be controlled:

- (a) Propeller speed.
- (b) Direction of rotation of the propeller for a fixed pitch propeller.
- (c) Pitch position for a controllable pitch propeller.
- (d) Direction and magnitude of thrust.
- (e) Clutch position, where applicable.

3.1.3 An alarm is to operate in the event of a failure of the power supply to the bridge control system.

3.1.4 Emergency Stop Functions, independent of the bridge control system, are to be provided on the bridge to enable the watchkeeping officer to stop the main propulsion machinery in an emergency.

### 3.2 Alarm system

3.2.1 An alarm system is to be provided to indicate faults in essential machinery and control systems in accordance with this Chapter.

3.2.2 Machinery faults are to be indicated at the control stations on the bridge and in the machinery space.

3.2.3 In the event of a machinery fault occurring, the alarm system is to be such that the watchkeeping officer on the bridge is made aware of the following:

- (a) A machinery fault has occurred.
- (b) The machinery fault is being attended to, and
- (c) The machinery fault has been rectified. (Alternative means of communication between the bridge control station and the machinery control station may be used for this function.)

3.2.4 The alarm system should be designed with self-monitoring properties. As far as practicable, any fault in the alarm system should cause it to fail to the alarm condition.

3.2.5 The alarm system should be capable of being tested during normal machinery operation.

3.2.6 Failure of the power supply to the alarm system is to be indicated as a separate fault alarm.

3.2.7 Alarm indication is to be both audible and visual. If arrangements are made to silence audible alarms they are not to extinguish visual alarms.

3.2.8 The acceptance of an alarm on the bridge is not to silence the audible alarm in the machinery space.

3.2.9 Machinery alarms should be distinguishable from other audible alarms, e.g. fire, carbon dioxide.

3.2.10 Acknowledgement of visual alarms is to be clearly shown.

3.2.11 If the audible alarm has been silenced and a second fault occurs before the first has been rectified, the audible alarm is again to operate. To assist in the detection of transient faults which are subsequently self-correcting, fleeting alarms should lock-in until accepted.

### 3.3 Communication

3.3.1 Two means of communication are to be provided between the bridge and the control station in the machinery space. One of these means may be the bridge control system; the other is to be independent of the main electrical power supply.

3.3.2 The bridge, machinery space control station and any other control position from which the propulsion machinery can be controlled are to be fitted with means to indicate which station is in command.

3.3.3 Change-over between control stations is to be possible under all normal sea-going and manoeuvring conditions without affecting the speed or direction of propulsion. This changeover may be effected only with the acceptance of the station taking control.

### 3.4 Engine starting safeguards

3.4.1 Where it is possible to start a main propulsion or auxiliary oil engine from the bridge, an indication that sufficient starting air pressure is available is to be provided on the bridge.

3.4.2 The number of automatic consecutive attempts which fail to produce a start is to be limited to safeguard sufficient starting air pressure, or, in the case of electric starting, a sufficient charge level in the batteries.

3.4.3 An alarm is to be provided for low starting air pressure, set at a limit which will still permit engine starting operations.

3.4.4 Where propulsion or auxiliary engines are started from the bridge, interlocks are to be provided to prevent starting of the engine under conditions which could hazard the machinery. These are to include 'turning gear engaged', 'low lubricating oil pressure' and 'shaft brake engaged'.

### 3.5 Operational safeguards

3.5.1 Means are to be provided to prevent the machinery and shafting being subjected to excessive torque or other detrimental mechanical and thermal overloads.

# Integrated Propulsion Systems

# Part 5, Chapter 18

Section 3

3.5.2 Prolonged running in a restricted speed range is to be prevented automatically or, alternatively, an indication of restricted speed ranges is to be provided at each control station.

3.5.3 For ships propelled by steam turbines the risk of thermal distortion of the turbines is to be prevented by automatic steam spinning when the shaft is stopped in the manoeuvring mode. An audible and visual alarm is to operate on the bridge and in the machinery space when the shaft has been stopped for two minutes.

3.5.4 In the case of lubricating oil systems for main propulsion and standby engine(s), the engine(s) is to be stopped automatically on failure of the lubricating oil supply. The circuit and sensor employed for this automatic shutdown are to be additional to the alarm circuit and sensor required by Ch 14.8. Where means are provided to over-ride the automatic shutdown required by this paragraph, the arrangements are to be such as to preclude inadvertent operation. Visual indication of operation of the over-ride is to be fitted.

3.5.5 In the case of oil engines, oil mist monitoring is to be provided for crankcase protection where arrangements are fitted to over-ride the automatic stop for failure of the lubricating oil supply.

3.5.6 Boilers with automatic controls which under normal operating conditions do not require any manual intervention by the operators are to be provided with safety arrangements which automatically shut-off the oil fuel to all the burners in the event of either low water level or combustion air failure. Oil fuel is to be shut-off automatically to any burner in the event of flame failure.

3.5.7 Arrangements are to be provided to automatically stop propulsion gas turbines for the following fault conditions:

- (a) Overspeed, see Ch 4,4.
- (b) High exhaust temperature, see Ch 4,3.
- (c) Flame failure, or
- (d) Excessive vibration.

3.5.8 Where standby pumps are arranged to start automatically in the event of low discharge pressure from the working pump an alarm is to be given to indicate when the standby pump has started.

## 3.6 Automatic control of essential services

3.6.1 All control systems for essential services are to be stable throughout the operating range of the main propulsion machinery.

3.6.2 The temperature of the following is to be automatically controlled within normal operating limits:

### Oil engines:

- (a) Lubricating oil to the main engine and/or auxiliary engines.
- (b) Oil fuel – temperature or viscosity.
- (c) Piston coolant, where applicable.
- (d) Cylinder coolant main and auxiliary engines, where applicable.
- (e) Fuel valve coolant, where applicable.

### Steam plant:

- (a) Lubricating oil to main engine and/or auxiliary engines.
- (b) Oil fuel to burners – temperature or viscosity.
- (c) Superheated steam.
- (d) External de-superheated steam.

### Gas turbines:

- (a) Lubricating oil to main engine and auxiliary engines.
- (b) Oil fuel – temperature or viscosity.
- (c) Exhaust gas.

3.6.3 The pressure of the following is to be automatically controlled within normal operating limits:

### Steam plant:

- (a) Superheated steam.
- (b) Oil fuel.
- (c) External de-superheated steam system(s).
- (d) Gland steam.
- (e) Reduced steam ranges.

3.6.4 The level of the following is to be automatically controlled within normal operating limits:

### Steam plant:

- (a) Boiler drum level.
- (b) De-aerator level.
- (c) Condenser level.

3.6.5 Boilers essential for the propulsion of the vessel are to be provided with an automatic combustion control system.

## 3.7 Local control

3.7.1 The arrangements are to be such that essential machinery can be operated with the system of bridge control or any automatic controls out of action. Alternatively, the control systems should have sufficient redundancy so that failure of the control equipment in use does not render essential machinery inoperative.



# Steering Gear

# Part 5, Chapter 19

Section 1

## Section

- 1 **General**
- 2 **Performance**
- 3 **Construction and design**
- 4 **Steering control systems**
- 5 **Electric power circuits, electric control circuits, monitoring and alarms**
- 6 **Emergency power**
- 7 **Testing and trials**
- 8 **Additional requirements**
- 9 **'Guidelines' for the acceptance of non-duplicated rudder actuators for tankers, chemical tankers and gas carriers of 10 000 tons gross and upwards but of less than 100 000 tons deadweight**

## ■ Section 1 General

### 1.1 Application

1.1.1 The requirements of this Chapter apply to the design and construction of steering gear.

1.1.2 Whilst the requirements satisfy the relevant regulations of the *International Convention for the Safety of Life at Sea 1974* as amended, and the IMO Protocol of 1978, attention should be given to any relevant statutory requirements of the National Authority of the country in which the ship is to be registered.

1.1.3 Consideration will be given to other cases, or to arrangements which are equivalent to those required by the Rules.

### 1.2 Definitions

1.2.1 **Steering gear control system** means the equipment by which orders are transmitted from the navigating bridge to the steering gear power units. Steering gear control systems comprise transmitters, receivers, hydraulic control pumps and their associated motors, motor controllers, piping and cables.

1.2.2 **Main steering gear** means the machinery, rudder actuator(s), the steering gear power units, if any, and ancillary equipment and the means of applying torque to the rudder stock (e.g., tiller or quadrant) necessary for effecting movement of the rudder for the purpose of steering the ship under normal service conditions.

1.2.3 **Steering gear power unit** means:

- (a) in the case of electric steering gear, an electric motor and its associated electrical equipment;
- (b) in the case of electrohydraulic steering gear, an electric motor and its associated electrical equipment and connected pump;
- (c) in the case of other hydraulic steering gear, a driving engine and connected pump.

1.2.4 **Auxiliary steering gear** means the equipment other than any part of the main steering gear necessary to steer the ship in the event of failure of the main steering gear but not including the tiller, quadrant or components serving the same purpose.

1.2.5 **Power actuating system** means the hydraulic equipment provided for supplying power to turn the rudder stock, comprising a steering gear power unit or units, together with the associated pipes and fittings, and a rudder actuator. The power actuating systems may share common mechanical components, i.e., tiller quadrant and rudder stock, or components serving the same purpose.

1.2.6 **Maximum ahead service speed** means the maximum service speed which the ship is designed to maintain, at the summer load waterline at maximum propeller RPM and corresponding engine MCR.

1.2.7 **Rudder actuator** means the components which converts directly hydraulic pressure into mechanical action to move the rudder.

1.2.8 **Maximum working pressure** means the maximum expected pressure in the system when the steering gear is operated to comply with 2.1.2(b).

1.2.9 **Steering arrangements** means the complete system of components for providing ship directional control.

1.2.10 **Directional control system** means the equipment used to effect changes in ship direction e.g., the rudder, podded propulsion unit, azimuth thrusters or water jet nozzle. Note that for podded propulsion systems, azimuth thrusters, water jet systems, or other similar systems for effecting changes in ship direction, it is to be assumed that the units must provide thrust in addition to rotation and hence the directional control system must include the propulsion system.

### 1.3 General

1.3.1 The steering gear is to be secured to the seating by fitted bolts, and suitable chocking arrangements are to be provided. The seating is to be of substantial construction.

1.3.2 The steering gear compartment is to be:

- (a) readily accessible and, as far as practicable, separated from machinery spaces; and
- (b) Provided with suitable arrangements to ensure working access to steering gear machinery and controls. These arrangements are to include handrails and gratings or other non-slip surfaces to ensure suitable working conditions in the event of hydraulic fluid leakage.

# Steering Gear

# Part 5, Chapter 19

Section 1

## 1.4 Plans

1.4.1 Before starting construction, the steering gear machinery plans, specifications and calculations are to be submitted. The plans are to give:

- (a) Details of scantlings and materials of all load bearing and torque transmitting components and hydraulic pressure retaining parts together with proposed rated torque and all relief valve settings.
- (b) Schematic of the hydraulic system(s), together with pipe material, relief valves and working pressures.
- (c) Details of control and electrical aspects.

## 1.5 Materials

1.5.1 All components used in steering arrangements for ship directional control are to be of sound reliable construction to the Surveyor's satisfaction.

1.5.2 All components transmitting mechanical forces to the rudder stock are to be tested according to the requirements of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

1.5.3 Ram cylinders; pressure housings of rotary vane type actuators, hydraulic power piping, valves, flanges and fittings; and all steering gear components transmitting mechanical forces to the rudder stock (such as tillers, quadrants, or similar components) are to be of steel or other approved ductile material, duly tested in accordance with the requirements of the Rules for Materials. In general, such material is to have an elongation of not less than 12 per cent nor a tensile strength in excess of 650 N/mm<sup>2</sup>. Special consideration will be given to the acceptance of grey cast iron for valve bodies and redundant parts with low stress levels.

1.5.4 Where appropriate, consideration will be given to the acceptance of non-ferrous material.

## 1.6 Rudder, rudder stock, tiller and quadrant

1.6.1 For the requirements of rudder and rudder stock, see Pt 3, Ch 13,2.

1.6.2 For the requirements of tillers and quadrants including the tiller to stock connection, see Table 19.1.1.

1.6.3 In bow rudders having a vertical locking pin operated from the deck above, positive means are to be provided to ensure that the pin can be lowered only when the rudder is exactly central. In addition, an indicator is to be fitted at the deck to show when the rudder is exactly central.

1.6.4 The factor of safety against slippage,  $S$  (i.e., for torque transmission by friction) is generally based on

$$S = \frac{\text{the torque transmissible by friction}}{M}$$

where

$M$  is the maximum torque at the relief valve pressure which is generally equal to the design torque as specified by the steering gear manufacturer.

1.6.5 For conical sections,  $S$  is based on the following equation:

$$S = \frac{\mu A \sigma_r}{\sqrt{(W + A \sigma_r \theta)^2 + Q^2}}$$

where

$A$  = interfacial surface area, in mm<sup>2</sup>

$W$  = weight of rudder and stock, if applicable, when tending to separate the fit, in N

$Q$  = shear force =  $\frac{2M}{d_m}$  in N

where

$d_m$  in mm is the mean contact diameter of tiller/stock interface and  $M$  in Nmm is defined in 1.6.4

$\theta$  = cone taper half angle in radians (e.g., for cone taper 1:10,  $\theta = 0,05$ )

$\mu$  = coefficient of friction

$\sigma_r$  = radial interfacial pressure or grip stress, in N/mm<sup>2</sup>.

## Steering Gear

## Part 5, Chapter 19

## Section 1

Table 19.1.1 Connection of tiller to stock

Item	Requirements
(1) Dry fit – tiller to stock, see also 1.6.4 and 1.6.5	<p>(a) For keyed connection, factor of safety against slippage, <math>S = 1,0</math> The maximum stress in the fillet radius of the tiller keyway should not exceed the yield stress For conical sections, the cone taper should be <math>\leq 1:10</math></p> <p>(b) For keyless connection, factor of safety against slippage, <math>S = 2,0</math> The maximum equivalent von Mises stress should not exceed the yield stress For conical sections, the cone taper should be <math>\leq 1:15</math></p> <p>(c) Coefficient of friction (maximum) = 0,17</p> <p>(d) Grip stress not to be less than 20 N/mm<sup>2</sup></p>
(2) Hydraulic fit – tiller to stock, see also 1.6.4 and 1.6.5	<p>(a) For keyed connection, factor of safety against slippage, <math>S = 1,0</math> The maximum stress in the fillet radius of the tiller keyway should not exceed the yield stress For conical sections, the cone taper should be <math>\leq 1:10</math></p> <p>(b) For keyless connection, factor of safety against slippage, <math>S = 2,0</math> The maximum equivalent von Mises stress should not exceed the yield stress For conical sections, the cone taper should be <math>\leq 1:15</math></p> <p>(c) Coefficient of friction (maximum) = 0,14</p> <p>(d) Grip stress not to be less than 20 N/mm<sup>2</sup></p>
(3) Ring locking assemblies fit – tiller to stock, see also 1.6.3	<p>(a) Factor of safety against slippage, <math>S = 2,0</math> The maximum equivalent von Mises stress should not exceed the yield stress</p> <p>(b) Coefficient of friction = 0,12</p> <p>(c) Grip stress not to be less than 20 N/mm<sup>2</sup></p>
(4) Bolted tiller and quadrant (this arrangement could be accepted provided the proposed rudder stock diameter in way of tiller does not exceed 350 mm diameter), see symbols	<p>Shim to be fitted between two halves before machining to take rudder stock, then removed prior to fitting</p> <p>Minimum thickness of shim, For 4 connecting bolts: <math>t_s = 0,0014 \delta_t</math> mm For 6 connecting bolts: <math>t_s = 0,0012 \delta_t</math> mm</p> <p>Key(s) to be fitted</p> <p>Diameter of bolts, <math>\delta_{tb} = \frac{0,60 \delta_{su}}{\sqrt{n_{tb}}}</math> mm</p> <p>A predetermined setting-up load equivalent to a stress of approximately 0,7 of the yield strength of the bolt material should be applied to each bolt on assembly. A lower stress may be accepted provided that two keys, complying with item (5), are fitted.</p> <p>Distance from centre of stock to centre of bolts should generally be equal to <math>\delta_t \left( 1,0 + \frac{0,30}{\sqrt{n_{tb}}} \right)</math> mm</p> <p>Thickness of flange on each half of the bolted tiller <math>\geq \frac{0,66 \delta_t}{\sqrt{n_{tb}}}</math> mm</p>
(5) Key/keyway, see symbols	<p>Effective sectional area of key in shear <math>\geq 0,25 \delta_t^2</math> mm<sup>2</sup></p> <p>Key thickness <math>\geq 0,17 \delta_t</math> mm</p> <p>Keyway is to extend over full depth of tiller and is to have a rounded end. Keyway root fillets are to be provided with suitable radii to avoid high local stress</p>
(6) Section modulus – tiller arm (at any point within its length about vertical axis), see symbols	<p>To be not less than the greater of:</p> <p>(a) <math>Z_{TA} = \frac{0,15 \delta_t^3 (b_T - b_s)}{1000 b_T}</math> cm<sup>3</sup></p> <p>(b) <math>Z_{TA} = \frac{0,06 \delta_t^3 (b_T - 0,9 \delta_t)}{1000 b_T}</math> cm<sup>3</sup></p> <p>If more than one arm fitted, combined modulus is to be not less than the greater of (a) or (b)</p> <p>For solid tillers, the breadth to depth ratio is not to exceed 2</p>
(7) Boss, see symbols	<p>Depth of boss <math>\geq \delta_t</math></p> <p>Thickness of boss in way of tiller <math>\geq 0,4 \delta_t</math></p>
Symbols	
$b_s$ = distance between the section of the tiller arm under consideration and the centre of the rudder stock, in mm NOTE: $b_T$ and $b_s$ are to be measured with zero rudder angle  $b_T$ = distance from the point of application of the load on the tiller to the centre of the rudder stock, in mm  $n_{tb}$ = number of bolts in the connection flanges, but generally not to be taken greater than six	$t_s$ = thickness of shim for machining bolted tillers and quadrants, in mm  $Z_{TA}$ = section modulus of tiller arm, in cm <sup>3</sup> $\delta_t$ = Rule rudderstock diameter in way of tiller, see Pt 3, Ch 13 $\delta_{tb}$ = diameter of bolts securing bolted tillers and quadrants, in mm



# Steering Gear

# Part 5, Chapter 19

Sections 2 &amp; 3

## Section 2

### Performance

#### 2.1 General

2.1.1 Unless the main steering arrangements for ship directional control comprise two or more identical power units, in accordance with 2.1.4 or 8.1.1, every ship is to be provided with main steering arrangements and auxiliary steering arrangements in accordance with the requirements of the Rules. The main steering arrangements and the auxiliary steering arrangements are to be so arranged that the failure of one of them will not render the other one inoperative.

2.1.2 The main steering arrangements for ship directional control are to be:

- (a) Of adequate strength and capable of steering the ship at maximum ahead service speed which shall be demonstrated in accordance with 7.2;
- (b) Capable of putting the rudder over from 35° on one side to 35° on the other side with the ship at its deepest sea-going draught and running ahead at maximum ahead service speed and under the same conditions, from 35° on either side to 30° on the other side in not more than 28 seconds.
- (c) Operated by power where necessary to meet the requirements of (b) and in any case when the Rules excluding strengthening for navigation in ice, require a rudder stock over 120 mm diameter in way of the tiller; and
- (d) So designed that they will not be damaged at maximum astern speed; however, this design requirement need not be proved by trials at maximum astern speed and maximum rudder angle.

2.1.3 The auxiliary steering arrangements for ship directional control are to be:

- (a) Of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;
- (b) Capable of putting the rudder over from 15° on one side to 15° on the other side in not more than 60 seconds with the ship at its deepest sea-going draught and running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater; and
- (c) Operated by power where necessary to meet the requirements of (b) and in any case when the Rules, excluding strengthening for navigation in ice, require a rudder stock over 230 mm diameter in way of the tiller.

2.1.4 Where the main steering arrangements for ship directional control comprise two or more identical power units, auxiliary steering arrangements need not be fitted, provided that:

- (a) In a passenger ship, the main steering arrangements are capable of operating the ship's directional control system as required by 2.1.2(b) while any one of the power units is out of operation;
- (b) In a cargo ship, the main steering arrangements are capable of operating the ship's directional control system as required by 2.1.2(b) while operating with all power units;
- (c) The main steering arrangements are arranged so that after a single failure in its piping system or in one of the power units the defect can be isolated so that steering capability can be maintained or speedily regained.

2.1.5 Main and auxiliary steering gear power units are to be:

- (a) Arranged to re-start automatically when power is restored after power failure;
- (b) Capable of being brought into operation from a position on the navigating bridge. In the event of a power failure to any one of the steering gear power units, an audible and visual alarm is to be given on the navigating bridge;
- (c) Arranged so that transfer between units can be readily effected.

2.1.6 Where the steering gear is so arranged that more than one power or control system can be simultaneously operated, the risk of hydraulic locking caused by a single failure is to be considered.

2.1.7 A means of communication is to be provided between the navigating bridge and the steering gear compartment.

2.1.8 Steering gear, other than of the hydraulic type, will be accepted provided the standards are considered equivalent to the requirements of this Section.

2.1.9 Manually operated gears are only acceptable when the operation does not require an effort exceeding 16 kg under normal conditions.

#### 2.2 Rudder angle limiters

2.2.1 Power-operated steering gears are to be provided with positive arrangements, such as limit switches, for stopping the gear before the rudder stops are reached. These arrangements are to be synchronised with the gear itself and not with the steering gear control.

## Section 3

### Construction and design

#### 3.1 General

3.1.1 Rudder actuators other than those covered by 8.3 and the 'Guidelines' are to be designed in accordance with the relevant requirements of Chapter 11 for Class I pressure vessels (notwithstanding any exemptions for hydraulic cylinders).

3.1.2 Accumulators, if fitted, are to comply with the relevant requirements of Chapter 11.

3.1.3 The welding details and welding procedures are to be approved. All welded joints within the pressure boundary of a rudder actuator or connecting parts transmitting mechanical loads are to be of full penetration type or of equivalent strength.

3.1.4 The construction is to be such as to minimise local concentrations of stress.

# Steering Gear

# Part 5, Chapter 19

Section 3

3.1.5 The design pressure for calculations to determine the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1,25 times the maximum working pressure to be expected under the operational conditions specified in 2.1.2(b) taking into account any pressure which may exist in the low pressure side of the system. Fatigue criteria may be applied for the design of piping and components, taking into account pulsating pressures due to dynamic loads, see Section 9.

3.1.6 For the rudder actuator, the permissible primary general membrane stress is not to exceed the lower of the following values:

$$\frac{\sigma_B}{A} \text{ or } \frac{\sigma_y}{B}$$

where

$\sigma_B$  = specified minimum tensile strength of material at ambient temperature

$\sigma_y$  = specified minimum yield stress or 0,2 per cent proof stress of the material, at ambient temperature

A and B are given by the following Table:

	<i>Wrought steel</i>	<i>Cast steel</i>	<i>Nodular cast iron</i>
A	3,5	4	5
B	1,7	2	3

## 3.2 Components

3.2.1 Special consideration is to be given to the suitability of any essential component which is not duplicated. Any such essential component shall, where appropriate, utilise anti-friction bearings such as ball bearings, roller bearings or sleeve bearings which shall be permanently lubricated or provided with lubrication fittings.

3.2.2 All steering gear components transmitting mechanical forces to the rudder stock, which are not protected against overload by structural rudder stops or mechanical buffers, are to have a strength at least equivalent to that of the rudder stock in way of the tiller.

3.2.3 Actuator oil seals between non-moving parts, forming part of the external pressure boundary, are to be of the metal upon metal type or of an equivalent type.

3.2.4 Actuator oil seals between moving parts, forming part of the external pressure boundary, are to be duplicated, so that the failure of one seal does not render the actuator inoperative. Alternative arrangements providing equivalent protection against leakage may be accepted.

3.2.5 Piping, joints, valves, flanges and other fittings are to comply within the requirements of Chapter 12 for Class I piping systems components. The design pressure is to be in accordance with 3.1.5.

3.2.6 Hydraulic power operated steering gear are to be provided with the following:

- Arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system;

- A fixed storage tank having sufficient capacity to recharge at least one power actuating system including the reservoir, where the main steering gear is required to be power operated. The storage tank is to be permanently connected by piping in such a manner that the hydraulic systems can be readily recharged from a position within the steering gear compartment and provided with a contents gauge.

## 3.3 Valve and relief valve arrangements

3.3.1 For vessels with non-duplicated actuators, isolating valves are to be fitted at the connection of pipes to the actuator, and are to be directly fitted on the actuator.

3.3.2 Arrangements for bleeding air from the hydraulic system are to be provided, where necessary.

3.3.3 Relief valves are to be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. The settings of the relief valves is not to exceed the design pressure. The valves are to be of adequate size and so arranged as to avoid an undue rise in pressure above the design pressure.

3.3.4 Relief valves for protecting any part of the hydraulic system which can be isolated, as required by 3.3.3 are to comply with the following:

- The setting pressure is not to be less than 1,25 times the maximum working pressure.
- the minimum discharge capacity of the relief valve(s) is not to be less than 110 per cent of the total capacity of the pumps which can deliver through it (them). Under such conditions the rise in pressure is not to exceed 10 per cent of the setting pressure. In this regard, due consideration is to be given to extreme foreseen ambient conditions in respect of oil viscosity.

## 3.4 Flexible hoses

3.4.1 Hose assemblies approved by Lloyd's Register (hereinafter referred to as 'LR') may be installed between two points where flexibility is required but are not to be subjected to torsional deflection (twisting) under normal operating conditions. In general, the hose should be limited to the length necessary to provide for flexibility and for proper operation of machinery, see also Ch 12,7.

3.4.2 Hoses should be high pressure hydraulic hoses according to recognised Standards and suitable for the fluids, pressures, temperatures and ambient conditions in question.

3.4.3 Burst pressure of hoses is to be not less than four times the design pressure.

# Steering Gear

# Part 5, Chapter 19

Sections 4 & 5

## Section 4 Steering control systems

### 4.1 General

4.1.1 Steering gear control is to be provided:

- (a) For the main steering gear, both on the navigating bridge and in the steering gear compartment;
- (b) Where the main steering gear is arranged according to 2.1.4, by two independent control systems, both operable from the navigating bridge. This does not require duplication of the steering wheel or steering lever. Where the control system consists of a hydraulic telemotor, a second independent system need not be fitted, except in a tanker, chemical tanker or gas carrier of 10 000 gross tonnage and upwards;
- (c) For the auxiliary steering gear, in the steering gear compartment and, if power operated, it shall also be operable from the navigating bridge and is to be independent of the control system for the main steering gear.
- (d) Where the steering gear is so arranged that more than one control system can be simultaneously operated, the risk of hydraulic locking caused by single failure is to be considered.

4.1.2 Any main and auxiliary steering gear control system operable from the navigating bridge is to comply with the following:

- (a) Means are to be provided in the steering gear compartment for disconnecting any control system operable from the navigating bridge from the steering gear it serves;
- (b) The system is to be capable of being brought into operation from a position on the navigating bridge.

4.1.3 The angular position of the rudder shall:

- (a) If the main steering gear is power-operated, be indicated on the navigating bridge. The rudder angle indication is to be independent of the steering gear control system;
- (b) Be recognisable in the steering gear compartment.

4.1.4 Appropriate operating instructions with a block diagram showing the changeover procedures for steering gear control systems and steering gear actuating systems are to be permanently displayed in the wheelhouse and in the steering gear compartment.

4.1.5 Where the system failure alarms for hydraulic lock, see Table 19.5.1, are provided, appropriate instructions shall be placed on the navigating bridge to shut down the system at fault.

## Section 5 Electric power circuits, electric control circuits, monitoring and alarms

### 5.1 Electric power circuits

5.1.1 Short-circuit protection, an overload alarm and, in the case of polyphase circuits, an alarm to indicate single phasing is to be provided for each main and auxiliary motor circuit. Protective devices are to operate at not less than twice the full load current of the motor or circuit protected and are to allow excess current to pass during the normal accelerating period of the motors.

5.1.2 Where steering gear motor circuits are supplied by converters, consideration will be given to arrangements that provide an equivalent level of safety, reliability, availability and indication to those specified in 5.1.1 provided that technical justification is submitted.

5.1.3 The alarms required by 5.1.1 are to be provided on the bridge and in the main machinery space or control room from which the main machinery is normally controlled.

5.1.4 Indicators for running indication of each main and auxiliary motor are to be installed on the navigating bridge and at a suitable main machinery control position.

5.1.5 A low-level alarm is to be provided for each power actuating system hydraulic fluid reservoir to give the earliest practicable indication of hydraulic fluid leakage. Alarms are to be given on the navigation bridge and in the machinery space where they can be readily observed.

5.1.6 Two exclusive circuits are to be provided for each electric or electrohydraulic steering gear arrangement consisting of one or more electric motors.

5.1.7 Each of these circuits is to be fed from the main switchboard. One of these circuits may pass through the emergency switchboard.

5.1.8 One of these circuits may be connected to the motor of an associated auxiliary electric or electrohydraulic power unit.

5.1.9 Each of these circuits is to have adequate capacity to supply all the motors which can be connected to it and which can operate simultaneously.

5.1.10 These circuits are to be separated throughout their length as widely as is practicable.

5.1.11 In ships of less than 1600 gross tonnage, if an auxiliary steering gear is not electrically powered or is powered by an electric motor primarily intended for other services, the main steering gear may be fed by one circuit from the main switchboard. Consideration would be given to other protective arrangements than described in 5.1.1, for such a motor primarily intended for other services.

# Steering Gear

## Part 5, Chapter 19

Sections 5, 6 &amp; 7

### 5.2 Electric control circuits

5.2.1 Electric control systems are to be independent and separated as far as is practicable throughout their length.

5.2.2 Each main and auxiliary electric control system which is to be operated from the navigating bridge is to comply with the following:

- (a) It is to be served with electric power by a separate circuit supplied from the associated steering gear power circuit, from a point within the steering gear compartment, or directly from the same section of switchboard busbars, main or emergency, to which the associated steering gear power circuit is connected.
- (b) Each separate circuit is to be provided with short-circuit protection only.

### 5.3 Monitoring and alarms

5.3.1 Alarms and monitoring requirements are indicated in 5.3.2 and Table 19.5.1.

**Table 19.5.1 Alarm requirements**

Item	Alarm	Note
Rudder position	— Failure	Indication, see 4.1.3 See 5.3.3
Steering gear power units, power	Failure	—
Steering gear motors	Overload, Single phase	For alarm and running indication locations, see 5.1.3 and 5.1.4
Control system	Failure	See 5.3.3
Control system power	Failure	—
Steering gear hydraulic oil level	Low	Each reservoir to be monitored. For alarm locations, see 5.1.5
Auto pilot	Failure	Running indication
Hydraulic oil temperature	High	Where oil cooler is fitted
Hydraulic lock	Fault	Where more than one system (either power or control) can be operated simultaneously each system is to be monitored, see Note
Hydraulic oil filter differential pressure	High	When oil filters are fitted
<b>NOTE</b> This alarm is to identify the system at fault and to be activated when (for example): <ul style="list-style-type: none"> <li>• position of the variable displacement pump control system does not correspond with given order; or</li> <li>• incorrect position of 3-way full flow valve or similar in constant delivery pump system is detected.</li> </ul>		

5.3.2 The alarms described in Table 19.5.1 are to be indicated on the navigating bridge and the additional locations described and are to be in accordance with the alarm system specified by Pt 6, Ch 1,2,3.

5.3.3 Steering control systems are to be monitored and an audible and visual alarm is to be initiated on the navigation bridge in the event of:

- failure of the control system, including command and feedback circuits; or
- unacceptable deviation between the rudder order and actual rudder position and/or unacceptable delay in response to changes in the rudder order.

## Section 6 Emergency power

### 6.1 General

6.1.1 Where the rudder stock is required to be over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice, or for ships fitted with podded propulsion units or water jet systems where the power per propulsion unit exceeds 2,500 kW, an alternative power supply, sufficient at least to supply the steering arrangements which comply with the requirements of 2.1.3 and also its associated control system and the steering response indicator, shall be provided automatically, within 45 seconds, either from the emergency source of electrical power or from an independent source of power located in the steering gear compartment. This independent source of power shall be used only for this purpose.

6.1.2 In every ship of 10 000 gross tonnage and upwards, the alternative power supply shall have a capacity for at least 30 minutes of continuous operation and in any other ship for at least 10 minutes.

6.1.3 Where the alternative power source is a generator, or an engine driven pump, starting arrangements are to comply with the requirements relating to the starting arrangements of emergency generators.

## Section 7 Testing and trials

### 7.1 Testing

7.1.1 The requirements of the Rules relating to the testing of Class 1 pressure vessels, piping, and related fittings including hydraulic testing apply.

7.1.2 After installation on board the vessel the steering gear is to be subjected to the required hydrostatic and running tests.

# Steering Gear

# Part 5, Chapter 19

Sections 7 & 8

**7.1.3** Each type of power unit pump is to be subjected to a type test. The type test shall be for a duration of not less than 100 hours, the test arrangements are to be such that the pump may run in idling conditions, and at maximum delivery capacity at maximum working pressure. During the test, idling periods are to be alternated with periods at maximum delivery capacity at maximum working pressure. The passage from one condition to another should occur at least as quickly as on board. During the whole test no abnormal heating, excessive vibration or other irregularities are permitted. After the test, the pump is to be opened out and inspected. Type tests may be waived for a power unit which has been proven to be reliable in marine service.

## 7.2 Trials

**7.2.1** The steering gear is to be tried out on the trial trip in order to demonstrate to the Surveyor's satisfaction that the requirements of the Rules have been met. The trial is to include the operation of the following:

- (a) The steering gear, including demonstration of the performances required by 2.1.2(b) and 2.1.3(b):
  - For the main steering gear trial, the propeller pitch of controllable pitch propellers is to be at the maximum design pitch approved for the maximum continuous ahead RPM;
  - If the ship cannot be tested at the deepest draught then the loading condition can be accepted on the conditions that either the rudder is fully submerged (at zero speed waterline) and the vessel is in an acceptable trim condition, or the rudder load and torque at the trial loading condition have been reliably predicted and extrapolated to the full load condition, to the satisfaction of the Administration. In any case, for the main steering gear trial, the speed of the ship corresponding to the maximum continuous revolutions of main engine and maximum design pitch applies;
- (b) The steering gear power units, including transfer between steering gear power units;
- (c) The isolation of one power actuating system, checking the time for regaining steering capability;
- (d) The hydraulic fluid recharging system;
- (e) The emergency power supply required by 6.1.1;
- (f) The steering gear controls, including transfer of control and local control;
- (g) The means of communication between the steering gear compartment and the wheelhouse, also the engine room, if applicable;
- (h) The alarms and indicators;
- (j) Where the steering gear is designed to avoid hydraulic locking this feature shall be demonstrated.

Test items (d), (g), (h) and (j) may be effected at the dockside.

**7.2.2** The ability of the machinery to reverse the direction of thrust in sufficient time and bring the ship to rest within a reasonable distance from maximum ahead service speed is to be demonstrated and recorded.

**7.2.3** The stopping times, ship headings and distances recorded on trials, together with the results of trials to determine the ability of ships having multiple propulsion/steering arrangements to navigate and manoeuvre with one or more of these devices inoperative, shall be available on board for the use of the Master or designated personnel.

## Section 8 Additional requirements

### 8.1 For tankers, chemical tankers or gas carriers of 10 000 tons gross and upwards and every other ship of 70 000 tons gross and upwards

**8.1.1** The main steering gear is to comprise two or more identical power units complying with provisions of 2.1.4.

### 8.2 For tankers, chemical tankers or gas carriers of 10 000 tons gross and upwards

**8.2.1** Subject to 8.3 the following are to be complied with:

- (a) The main steering gear is to be so arranged that in the event of loss of steering capability due to a single failure in any part of one of the power actuating systems of the main steering gear, excluding the tiller, quadrant or components serving the same purpose, or seizure of the rudder actuators, steering capability is to be regained in not more than 45 seconds after the loss of one power actuating system.
- (b) The main steering gear is to comprise either:
  - (i) two independent and separate power actuating systems, each capable of meeting the requirements of 2.1.2(b); or
  - (ii) at least two identical power actuating systems which, acting simultaneously in normal operation, are capable of meeting the requirements of 2.1.2(b). Where necessary to comply with these requirements, inter-connection of hydraulic power actuating systems is to be provided. Loss of hydraulic fluid from one system is to be capable of being detected and the defective system automatically isolated so that the other actuating system or systems remain fully operational.
- (c) Steering gears other than of the hydraulic type are to achieve equivalent Standards.

### 8.3 For tankers, chemical tankers or gas carriers of 10 000 tons gross and upwards but of less than 100 000 tons deadweight

**8.3.1** Solutions other than those set out in 8.2.1 which need not apply the single failure criterion to the rudder actuator or actuators, may be permitted provided that an equivalent safety Standard is achieved and that:



- (a) Following loss of steering capability due to a single failure of any part of the piping system or in one of the power units, steering capability is regained within 45 seconds; and
- (b) Where the steering gear includes only a single rudder actuator special consideration is given to stress analysis for the design including fatigue analysis and fracture mechanics analysis, as appropriate, the material used, the installation of sealing arrangements and the testing and inspection and provision of effective maintenance. In consideration of the foregoing, regard will be given to the 'Guidelines' in Section 9.

8.3.2 Manufacturers of steering gear who intend their product to comply with the requirements of the 'Guidelines' are to submit full details when plans are forwarded for approval.

## Section 9 'Guidelines' for the acceptance of non-duplicated rudder actuators for tankers, chemical tankers and gas carriers of 10 000 tons gross and upwards but of less than 100 000 tons deadweight

### 9.1 Materials

9.1.1 Parts subject to internal hydraulic pressure or transmitting mechanical forces to the rudder-stock are to be made of duly tested ductile materials complying with recognised Standards. Materials for pressure retaining components are to be in accordance with recognised pressure vessel Standards. These materials are not to have an elongation less than 12 per cent nor a tensile strength in excess of 650 N/mm<sup>2</sup>.

### 9.2 Design

9.2.1 **Design pressure.** The design pressure should be assumed to be at least equal to the greater of the following:

- (a) 1,25 times the maximum working pressure to be expected under the operating conditions required in 2.1.2(b).
- (b) The relief valve(s) setting.

9.2.2 **Analysis.** In order to analyse the design the following are required:

- (a) The manufacturers of rudder actuators should submit detailed calculations showing the suitability of the design for the intended service.
- (b) A detailed stress analysis of pressure retaining parts of the actuator should be carried out to determine the stresses at the design pressure.

- (c) Where considered necessary because of the design complexity or manufacturing procedures, a fatigue analysis and fracture mechanics analysis may be required. In connection with these analyses, all foreseen dynamic loads should be taken into account. Experimental stress analysis may be required in addition to, or in lieu of, theoretical calculations depending upon the complexity of the design.

9.2.3 **Dynamic loads for fatigue and fracture mechanics analysis.** The assumption for dynamic loading for fatigue and fracture mechanics analysis where required by 3.1.5, 8.3 and 9.2.2 are to be submitted for appraisal. Both the case of high cycle and cumulative fatigue are to be considered.

9.2.4 **Allowable stresses.** For the purpose of determining the general scantlings of parts of rudder actuators subject to internal hydraulic pressure the allowable stresses should not exceed:

$$\begin{aligned}\sigma_m &\leq f \\ \sigma_1 &\leq 1,5f \\ \sigma_b &\leq 1,5f \\ \sigma_1 + \sigma_b &\leq 1,5f \\ \sigma_m + \sigma_b &\leq 1,5f\end{aligned}$$

where

$$f = \text{the lesser of } \frac{\sigma_B}{A} \text{ or } \frac{\sigma_y}{B}$$

$\sigma_b$  = equivalent primary bending stress

$\sigma_m$  = equivalent primary general membrane stress

$\sigma_y$  = specified minimum yield stress or 0,2 per cent proof stress of material at ambient temperature

$\sigma_B$  = specified minimum tensile strength of material at ambient temperature

$\sigma_1$  = equivalent primary local membrane stress

A and B are as follows:

	<i>Wrought steel</i>	<i>Cast steel</i>	<i>Nodular cast iron</i>
A	4	4,6	5,8
B	2	2,3	3,5

9.2.5 **Burst test.** Pressure retaining parts not requiring fatigue analysis and fracture mechanics analysis may be accepted on the basis of a certified burst test and the detailed stress analysis required by 9.2.2 need not be provided. The minimum bursting pressure should be calculated as follows:

$$P_b = P A \frac{\sigma_{Ba}}{\sigma_B}$$

where

A = as from table in 9.2.4

P = design pressure as defined in 9.2.1

$P_b$  = minimum bursting pressure

$\sigma_B$  = tensile strength as defined in 9.2.4

$\sigma_{Ba}$  = actual tensile strength.

### 9.3 Construction details

9.3.1 **General.** The construction should be such as to minimise local concentrations of stress.



# Steering Gear

# Part 5, Chapter 19

Section 9

## 9.3.2 Welds.

- (a) The welding details and welding procedures should be approved.
- (b) All welded joints within the pressure boundary of a rudder actuator or connection parts transmitting mechanical loads should be full penetration type or of equivalent strength.

9.3.3 **Oil seals.** Oil seals forming part of the external pressure boundary are to comply with 3.2.3 and 3.2.4.

9.3.4 **Isolating valves** are to be fitted at the connection of pipes to the actuator, and should be directly mounted on the actuator.

9.3.5 **Relief valves** for protecting the rudder actuator against over-pressure as required in 3.3.3 are to comply with the following:

- (a) The setting pressure is not to be less than 1,25 times the maximum working pressure expected under operating conditions required by 2.1.2(b).
- (b) The minimum discharge capacity of the relief valve(s) is to be not less than 110 per cent of the total capacity of all pumps which provided power for the actuator. Under such conditions the rise in pressure should not exceed 10 per cent of the setting pressure. In this regard due consideration should be given to extreme foreseen ambient conditions in respect of oil viscosity.

## 9.4 Non-destructive testing

9.4.1 The rudder actuator should be subjected to suitable and complete non-destructive testing to detect both surface flaws and volumetric flaws. The procedure and acceptance criteria for non-destructive testing should be in accordance with requirements of recognised Standards. If found necessary, fracture mechanics analysis may be used for determining maximum allowable flaw size.

## 9.5 Testing

9.5.1 Tests, including hydrostatic tests, of all pressure parts at 1,5 times the design pressure should be carried out subject to any limitations imposed by valves and other components. Where additional testing of systems or sub-systems following final assembly is required, the test pressure may be subject to any limitations imposed by valves and other components.

9.5.2 When installed on board the ship, the rudder actuator should be subjected to a hydrostatic test at the pressure defined in 9.5.1 and a running test.

## 9.6 Additional requirements for steering gear fitted to ships with Ice Class notations

9.6.1 See Pt 3, Ch 9.

# Azimuth Thrusters

## Part 5, Chapter 20

Sections 1, 2 & 3

### Section

- 1 **General requirements**
- 2 **Performance**
- 3 **Construction and design**
- 4 **Control engineering arrangements**
- 5 **Electrical equipment**
- 6 **Testing and trials**

### ■ Section 1 General requirements

#### 1.1 Application

1.1.1 This Chapter applies to azimuth or rotatable thruster units, for propulsion or D.P. duty which transmit a power greater than 220 kW used as the sole means of steering and are in addition to the relevant requirements of Chapter 19.

1.1.2 In general, for a vessel to be assigned an unrestricted service notation a minimum of two azimuth thruster units are to be provided where these form the sole means of propulsion. Where a single thruster installation is proposed, it will be subject to special consideration.

#### 1.2 Plans

1.2.1 The following additional plans are to be submitted for consideration together with particulars of materials and the maximum shaft power and revolutions per minute:

- Sectional assembly including nozzle ring structure, nozzle support struts, etc.
- Shafts, gears and couplings.
- Steering mechanisms with details of ratings.
- Bearing specifications.
- Schematic piping systems.

### ■ Section 2 Performance

#### 2.1 General

2.1.1 The arrangement of thrusters is to be such that the ship can be satisfactorily manoeuvred.

2.1.2 For vessels with multiple azimuthing thrusters, the requirement for auxiliary steering arrangements in Ch 19,2 is to be achieved by equipping each of the azimuthing thrusters with its own dedicated and independent steering gear control system and power actuating system. Consideration will be given to alternative arrangements providing equivalence can be demonstrated.

2.1.3 In addition to the requirements of Chapter 19, the azimuthing mechanism is to be capable of a rotational speed of not less than 1,5 rev/min.

2.1.4 The main steering arrangements are to be capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,4 rev/min, with the ship running ahead at maximum ahead service speed.

2.1.5 The auxiliary steering arrangements are to be:

- (a) Capable of changing the direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 0,083 rev/min, with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.
- (b) For all ships, operated by power where necessary to meet the requirements of (a) and in any ship having power more than 2,500 kW propulsion power per thruster unit.

### ■ Section 3 Construction and design

#### 3.1 Materials

3.1.1 Specification for materials of gears, shafts, couplings and propeller, giving chemical composition, heat treatment and mechanical properties are to be submitted for approval.

3.1.2 Specification for materials for the stock, struts, etc., are to be submitted for approval.

3.1.3 Where an ice class notation is included in the class of a ship, additional requirements are applicable as detailed in Part 8 and Pt 3, Ch 9.

#### 3.2 Design

3.2.1 The requirements detailed in Chapters 1, 5, 6, 7, 8, 9, 14 and 19 are to be complied with where applicable.

# Azimuth Thrusters

## Part 5, Chapter 20

Sections 3 & 4

3.2.2 For steerable thrusters with a nozzle, the equivalent rudder stock diameter in way of tiller, used in Table 19.1.1 in Chapter 19, is to be determined as follows:

$$\delta_t = 26,03 \sqrt[3]{(V + 3)^2 A_N x_P} \text{ mm}$$

where

$V$  = maximum service speed, in knots, which the ship is designed to maintain under thruster operation

$A_N$  = projected nozzle area, in  $m^2$ , and is equal to the length of the nozzle multiplied by the mean external vertical height of the nozzle

and

$x_P$  = horizontal distance from the centreline of the steering tube to the centre of pressure, in metres. The position of the centre of pressure is determined for both ahead and astern cases from Pt 3, Ch 13, 2.3.1.

The corresponding maximum turning moment,  $M_T$ , is to be determined as follows:

$M_T$  = turning moment for conical couplings and is to be taken as the greatest of  $M_F$ ,  $M_A$  or  $M_W$

$M_F$  =  $P_L x_P \times 10^6$  N mm (kgf mm) in the ahead condition

$M_A$  =  $P_L x_P \times 10^6$  N mm (kgf mm) in the astern condition

$M_W$  = the torque generated by the steering gear at the maximum working pressure supplied by the manufacturer, in N mm (kgf mm).  $M_W$  is not to exceed the greater of  $3,0M_F$  or  $3,0M_A$

$P_L$  = lateral force on rudder acting at centre of pressure, as defined in Pt 3, Ch 13, 2.2.1 (where  $A_R$  equals  $2A_N$ ), in kN (tonne-f).

3.2.3 The nozzle structure is to be in accordance with Pt 3, Ch 13, 3.

3.2.4 In addition to the requirements of Table 13.3.1, in Pt 3, Ch 13, the scantlings of the nozzle stock or steering tube are to be such that the section modulus against transverse bending at any section xx is not less than:

$$Z = 1,73 \sqrt{\left((V + 3)^4 A_N^2 x_P^2 + \frac{a^2}{4} T_M^2 10^4\right)} \text{ cm}^3$$

where

$a$  = dimension, in metres, as shown in Fig. 20.3.1

$T_M$  = maximum thrust of the thruster unit in tonnes.

3.2.5 The scantlings of nozzle connections or struts will be specially considered. In the case of certain high powered ships, direct calculation may be required.

3.2.6 For steerable thrusters without a nozzle the scantlings in way of the tiller will be specially considered.

### 3.3 Steering gear elements

3.3.1 These gears are to be considered for the following conditions:

- a design maximum dynamic duty steering torque;
- a static duty ( $\leq 10^3$  load cycles) steering torque, and the static duty steering torque should be not less than  $M_T$ .

Values for the above should be submitted together with the plans.

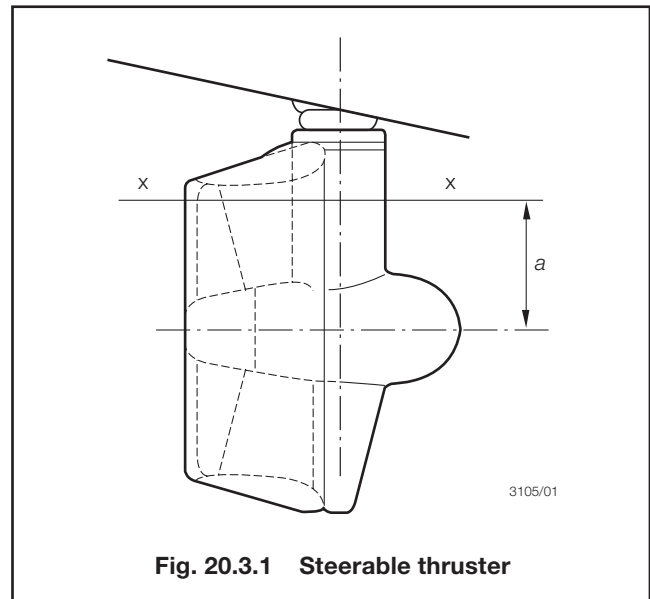


Fig. 20.3.1 Steerable thruster

### 3.4 Components

3.4.1 The hydraulic power operating systems for each azimuth thruster are to be provided with the following:

- arrangements to maintain the cleanliness of the hydraulic fluid, taking into consideration the type and design of the hydraulic system;
- a fixed storage tank having sufficient capacity to recharge at least one azimuth power actuating system including the reservoir. The piping from the storage tank is to be permanent and arranged in such a manner as to allow recharging from within the thruster space.

## Section 4 Control engineering arrangements

### 4.1 General

4.1.1 Except where indicated in this Section the control engineering systems are to be in accordance with Pt 6, Ch 1.

4.1.2 Steering control is to be provided for the azimuth thrusters from the navigating bridge, the main machinery control station and locally.

4.1.3 An indication of the angular position of the thruster(s) and the magnitude of the thrust are to be provided at each station from which it is possible to control the direction of thrust.

4.1.4 Means are to be provided at the remote control station(s) to stop each thrust unit.

### 4.2 Monitoring and alarms

4.2.1 Alarms and monitoring requirements are indicated in 4.2.2 and Table 20.4.1.

# Azimuth Thrusters

## Part 5, Chapter 20

Sections 4, 5 &amp; 6

**Table 20.4.1 Alarms for control systems**

Item	Alarm	Note
Thruster azimuth	–	Indicator, see 4.1.3
Steering motor	Power failure, single phase	Also running indication on bridge and at machinery control station
Propulsion motor	Overload, power failure	Also running indication on bridge and at machinery control station
Control system power	Failure	
Hydraulic oil supply tank level	Low	
Hydraulic oil system pressure	Low	
Hydraulic oil system temperature	High	Where oil cooler is fitted
Hydraulic oil filters differential pressure	High	Where oil filters are fitted
Lubricating oil supply	Low	If separate forced lubrication

4.2.2 The alarms described in Table 20.4.1 are to be indicated individually on the navigating bridge and in accordance with the alarm system specified by Pt 6, Ch 1,2,3.

### Section 5 Electrical equipment

#### 5.1 General

5.1.1 The electrical installation is to be designed, constructed and installed in accordance with the requirements of 5.2 to 5.4.

5.1.2 Where the thruster units are electrically driven the relevant requirements, including surveys, of Pt 6, Ch 2 are to be complied with.

#### 5.2 Generating arrangements

5.2.1 Where a central power generation system is employed, the requirements of Pt 6, Ch 2,16.3.5 are to be complied with.

5.2.2 The generating and distribution system is to be so arranged that after any single failure, steering capability can be maintained or regained within a period not exceeding 45 seconds, and the effectiveness of the steering after such a fault will not be reduced by more than 50 per cent. This may be achieved by the parallel operation of two or more generating sets, or alternatively when the electrical requirements may be met by one generating set in operation, on loss of power, the automatic starting and connection to the switchboard of a standby set, provided that this set can restart and run a thruster with its auxiliaries.

5.2.3 The failure of one thruster unit or its control system is not to render any other thruster inoperative.

#### 5.3 Distribution arrangements

5.3.1 Thruster auxiliaries and controls are to be served by individual circuits. Services that are duplicated are to be separated throughout their length as widely as is practicable and without the use of common feeders, transformers, converters, protective devices or control circuits.

#### 5.4 Auxiliary supplies

5.4.1 Where the auxiliary services and thruster units are supplied from a common source, the following requirements are to be complied with:

- the voltage regulation and current sharing requirements defined in Pt 6, Ch 2,9.4.2 and 9.4.7 are to be maintained over the full range of power factors that may occur in service,
- auxiliary equipment and services are to operate with any waveform distortion introduced by converters without deleterious effect. (This may be achieved by the provision of suitably filtered/converted supplies).

### Section 6 Testing and trials

#### 6.1 General

6.1.1 The requirements detailed in Chapters 1, 5 and 19 are to be complied with and, in addition, the performance specified in 2.1.2 is to be demonstrated to the Surveyor's satisfaction.

6.1.2 The actual values of steering torque should be verified during sea trials to confirm that the design maximum dynamic duty torque has not been exceeded.



# Requirements for Condition Monitoring Systems and Machinery Condition-Based Maintenance Systems

## Part 5, Chapter 21

Section 1

### Section

#### 1 Requirements for Condition Monitoring Systems and Machinery Condition-Based Maintenance Systems

### Section 1 Requirements for Condition Monitoring Systems and Machinery Condition-Based Maintenance Systems

#### 1.1 Scope

1.1.1 The requirements of this Chapter are applicable to condition monitoring systems and machinery condition-based maintenance systems which:

- (a) provide control, alarm or safety functions for essential machinery and equipment (see Pt 6, Ch 1,2.1.1) in accordance with manufacturers recommendations; or
- (b) provide machinery condition related information as part of a machinery planned maintenance scheme for use as an alternative to machinery and equipment surveys required by the Regulations (see Pt 1, Ch 3) in accordance with LR's ShipRight procedures.

1.1.2 Condition monitoring systems which deviate from the requirements of this Section but provide an equivalent level of performance may be submitted to LR for consideration.

1.1.3 The requirements of this Section are to be applied to condition monitoring systems where the assignment of the **MCM** descriptive note is requested.

1.1.4 The requirements of this Section are to be applied to machinery condition-based maintenance systems where the assignment of the **MCBM** Descriptive Note is requested in addition to the **MCM** Descriptive Note.

#### 1.2 Plans and particulars

1.2.1 The information and plans required to be submitted are as specified in the relevant Chapters of Parts 5 and 6 applicable to the particular machinery and where specified in this Chapter.

1.2.2 In addition to information required by 1.2.1, the documents listed in the *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring* are to be submitted to LR for consideration.

1.2.3 In addition to information required by 1.2.1, the documents listed in the *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring* are to be submitted to LR for consideration where the **MCBM** Descriptive Note is requested.

1.2.4 Equipment type approval reports providing evidence of compliance with 1.3.1 and 1.3.2 are to be submitted.

1.2.5 Additional information and plans providing evidence of compliance with the requirements of 1.3.3, 1.4.1 and 1.5.4 are to be submitted.

#### 1.3 General requirements for condition monitoring systems

1.3.1 Condition monitoring equipment is to be capable of providing the service for which it is intended and is to satisfy the relevant requirements for condition monitoring equipment in LR's Type Approval System, *Product Assessment and Test Specification (TACM)*.

1.3.2 Condition monitoring equipment is to be suitable for the environment in which it is intended to operate and is to satisfy the relevant requirements for environmental testing in LR's Type Approval System, *Test specification No.1*.

1.3.3 The installation of condition monitoring equipment in spaces and locations in which flammable mixtures are liable to collect, e.g., areas containing flammable gas or vapour and/or combustible dust, is to be minimised as far as is practicable and is to satisfy the relevant requirements for the use of electrical equipment in flammable atmospheres in Pt 6, Ch 2,14.

1.3.4 Where permanently installed condition monitoring systems are used, the cables are to comply with the relevant Sections of Pt 6, Ch 2,11 and the piping systems are to comply with relevant Sections of Chapters 12 and 13.

1.3.5 Where the system is based on programmable electronic systems, the requirements of Pt 6, Ch 1,3.6.3 are to be complied with.

1.3.6 Portable condition monitoring equipment is to be maintained and calibrated in accordance with a recognised National or International Standard to ensure the accuracy of the readings obtained. The standard is to include the issue of calibration certificates by a recognised test house in accordance with a recognised National or International Standard for instrument calibration. Copies of calibration certificates are to be retained on board and referenced on all condition monitoring reports submitted as part of the onboard condition monitoring program. Portable equipment used in hazardous areas is to be of a safe type suitable for use in the appropriate hazardous zone.

1.3.7 Measuring points are to be clearly identified in the submission and proposals to ensure repeatability of measurements are to be included.

1.3.8 The condition monitoring equipment is, as far as is practicable, to be located and installed such that it is accessible for maintenance and survey.



# Requirements for Condition Monitoring Systems and Machinery Condition-Based Maintenance Systems

## Part 5, Chapter 21

Section 1

1.3.9 The condition monitoring equipment is to be installed in accordance with the manufacturer's instructions, see the *Product Assessment and Test Specification (PACM)*, or by an approved technical organisation as defined in the LR *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*, and to the satisfaction of the LR Surveyor.

### 1.4 Requirements for systems providing control, alarm and safety functions

1.4.1 In addition to the requirements of 1.3, condition monitoring equipment which provides control, alarm or safety functions for essential machinery and equipment is also to satisfy the relevant requirements for control, alarm and safety systems in Pt 6, Ch 1 and the installation of electrical equipment in Pt 6, Ch 2.

### 1.5 Requirements for systems providing machinery condition related information as part of machinery condition-based maintenance systems

1.5.1 In addition to the requirements of 1.3, condition monitoring equipment which provides machinery condition related information as part of a machinery planned maintenance scheme for use as an alternative to machinery and equipment surveys required by the Regulations is also to satisfy the relevant requirements of LR's *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*.

1.5.2 Where condition monitoring data is used as part of a machinery condition-based maintenance system, persons interpreting data and making diagnostic decisions are to be suitably competent, in accordance with ISO 18436 or an equivalent recognised National Standard. Evidence of competence, including training certificates of those providing analysis and data interpretation, are to be submitted and held on board. These certificates are to be made available to LR on request for audit and survey purposes.

1.5.3 The condition monitoring equipment is, as far as is practicable, to be located and installed such that it is accessible for maintenance and survey.

1.5.4 The condition monitoring equipment is to be installed in accordance with the manufacturer's instructions, see the *Product Assessment and Test Specification (TACM)* or by an approved technical organisation as defined in the LR *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*, and to the satisfaction of the LR Surveyor.

### 1.6 Requirements for machinery condition-based maintenance systems

1.6.1 Any vessel applying to operate a machinery condition-based maintenance system with the **MCBM** Descriptive Note is also to have an approved planned maintenance system in place with the **MPMS** Descriptive Note assigned.

1.6.2 Where a **MCBM** Descriptive Notation is requested and a vessel operates both an approved continuous machinery (CSM) survey cycle and has an approved machinery condition monitoring system in place which meets the requirements of the **MCM** Descriptive Notation, the **MCBM** Descriptive Notation is to be taken to mean that the vessel complies with the requirements of the **MCM** notation; however, the **MCM** Descriptive Notation will not be assigned.

1.6.3 Proposals for machinery condition-based maintenance systems are to be submitted for approval and are to meet the requirements of LR's *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*, and be to the satisfaction of the LR Surveyor. This plan is to include proposals for returning the vessel to a conventional maintenance and survey regime, and withdrawal of the **MCBM** Descriptive Notation, if the Owner decides for any reason to withdraw from condition-based maintenance or if the vessel should change ownership and the new Owners do not wish to retain the **MCBM** Descriptive Note.

1.6.4 Machinery condition-based maintenance systems are to be developed in accordance with the methodology given in ISO 17359 or an equivalent recognised National Standard.

1.6.5 Proposals are to identify those items of machinery and equipment which are to be maintained according to their condition and those which are to be maintained in accordance with manufacturer's time-based and running hours-based service and maintenance requirements. To assess which items are to be maintained according to their condition, a criticality assessment is to be carried out.

1.6.6 The criticality assessment is to include a FMEA/FMECA assessment and is to take account of:

- machinery and equipment redundancy;
- failure rate and mean time to repair;
- local effects of failure on the safe operation of the machinery and equipment; and
- wider effects of failure on the ship's essential services and the safe operation of the ship, including environmental impact.

The criticality assessment is included in the submission for approval in accordance with LR's *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*, as stated in 1.6.3, and is to be to the satisfaction of the LR Surveyor.

1.6.7 Boilers and pressure vessels are not eligible for condition-based monitoring.

# Requirements for Condition Monitoring Systems and Machinery Condition-Based Maintenance Systems

## Part 5, Chapter 21

Section 1

1.6.8 For all machinery and equipment which is proposed for maintenance based on condition monitoring data, in addition to the criticality assessment in 1.6.5, evidence is to be submitted which demonstrates that the condition of the machinery and equipment can be measured accurately and that the measured parameters are clearly defined in the condition monitoring plan.

1.6.9 Machinery condition monitoring is to meet the requirements of 1.3 and 1.5; in addition, the machinery condition-based maintenance plan is to include guidance on parameter limit values, trend analysis and fault diagnosis. This requirement for guidance information does not remove the requirement for those persons with responsibility for analysing condition monitoring data to be suitably trained and competent, in accordance with 1.5.2.

1.6.10 As part of the criticality assessment, it is to be demonstrated that any machinery included in the list of items for condition-based maintenance shall have measurable performance parameters which will give adequate warning of machinery deterioration that may result in failure, to allow maintenance to be scheduled in advance of such failure.

1.6.11 The condition-based maintenance plan is to maintain records of all data included in the plan approval document. The plan shall include proposals for:

- essential data describing the machine;
- essential data describing operating conditions;
- the measurement position;
- the measured quantity units and processing; and
- date and time information.

These records are to be available on request to any LR Surveyor or representative.

1.6.12 Proposals to ensure repeatability of results are to be submitted for approval.

1.6.13 Those items of machinery and equipment which are subject to a mandatory five-year survey are still required to be surveyed by a LR Surveyor at intervals not exceeding five years. A list of these items is to be found in LR's *ShipRight Procedures for Machinery Planned Maintenance and Condition Monitoring*.

1.6.14 For items which are not suitable for condition-based maintenance, see 1.6.7, the required maintenance will, as a minimum, comply with the equipment manufacturer's maintenance requirements.

1.6.15 The **MCBM** records, including diagnostic analysis and condition assessment reports, for items of machinery and equipment being maintained on the basis of condition monitoring data, are to be surveyed over a five-year continuous survey cycle, with 20 per cent of the records being subject to survey each year such that all records are surveyed over a five-year period.



## Section

- 1 **General requirements**
- 2 **Failure Mode and Effects Analysis (FMEA)**
- 3 **Machinery arrangements**
- 4 **Control arrangements**
- 5 **Separate machinery spaces ★ (star) Enhancement**
- 6 **Testing and trials**

## ■ Section 1 General requirements

### 1.1 General

1.1.1 This Chapter states the requirements for ships having machinery redundancy, and are in addition to the relevant requirements in other relevant Sections of these Rules.

1.1.2 The requirements, which are optional, cover machinery arrangements and control systems necessary for ships which have propulsion and steering systems configured such that, in the event of a single failure of a system or item of active equipment, see 1.1.3, the ship will retain the ability to use available installed prime mover capacity and installed propulsion systems that are unaffected by the failure. The ship is also to retain steering capability at a service speed of not less than seven knots. The requirements also cover machinery arrangements where the propulsion and steering systems are installed in separate compartments such that, in the event of a loss of one compartment, the ship will retain availability of propulsion power and manoeuvring capability.

1.1.3 For the purpose of this Chapter, items of active equipment are those which have a defined function for operation of a propulsion or steering system, such as but not limited to:

- Prime movers, i.e. diesel engines, electric motors, steam turbines and gas turbines;
- Generators and their excitation equipment;
- Transformers and converters;
- Gearing and shafting systems;
- Propulsion devices, i.e. propellers, water jets and thrusters;
- Pumps;
- Valves (where power actuated);
- Fuel treatment plant;
- Coolers/heaters;
- Filters;

Piping and electrical cables connecting items of active equipment are not considered to be active.

1.1.4 Requirements additional to these Rules may be imposed by the Flag State with whom the ship is registered and/or by the Administration within whose territorial jurisdiction the ship is intended to operate.

1.1.5 Sections 2, 3 and 4 state the applicable requirements for arrangements necessary to maintain availability of propulsion and manoeuvring capability, in the event of a single failure in equipment. Ships complying with the applicable requirements of Sections 2 to 4 will be eligible for the machinery class notation **PMR** or **PMRL** (Propulsion Machinery Redundancy), **SMR** or **SMRL** (Steering Machinery Redundancy) or **PSMR** or **PSMRL** (Propulsion and Steering Machinery Redundancy), which will be recorded in the *Register Book*.

#### NOTE

The additional **L** character to **PMR**, **SMR** and **PSMR** notations indicates a limited capability.

1.1.6 Section 5 states the additional requirements necessary to maintain availability of propulsion and manoeuvring capability where machinery is installed in separate compartments and the loss of any one compartment due to fire or flooding has been addressed. Ships complying with the applicable requirements of Sections 2 to 5 of this Chapter will be eligible for the machinery class notation **PMR★** or **PMRL★** (Propulsion Machinery Redundancy in separate machinery spaces), **SMR★** or **SMRL★** (Steering Machinery Redundancy in separate machinery spaces) or **PSMR★** or **PSMRL★** (Propulsion and Steering Machinery Redundancy in separate machinery spaces) which will be recorded in the *Register Book*.

1.1.7 For assignment of **PSMR** or **PSMR★** machinery class notations, the ship is to retain the ability to use not less than 50 per cent of the installed prime mover capacity and not less than 50 per cent of the installed propulsion systems and retain steering capability at a service speed of not less than seven knots in the event of a single failure of a system or item of equipment.

1.1.8 Where the ship does not comply with 1.1.7 but can retain a service speed of not less than seven knots using available installed prime mover capacity and propulsion systems (which may be less than 50 per cent) following a failure of a system or item of equipment, machinery class notations **PSMRL** or **PSMRL★** may be assigned. The available installed prime mover capacity and installed propulsion systems are to be identified and included in 1.2.7.

### 1.2 Plans and information

1.2.1 In addition to the plans and information required by Parts 5 and 6, the information detailed in 1.2.2 to 1.2.6 is also to be submitted.

1.2.2 **Machinery spaces.** Plans showing the general arrangement of the machinery spaces, together with a description of the propulsion system, main and emergency electrical power supply systems and steering arrangements are to be submitted. The plans are to indicate segregation and access arrangements for machinery spaces and associated control rooms/stations.

**1.2.3 Failure Mode and Effects Analysis (FMEA).** For the propulsion systems, electrical power supplies, essential services, control systems and steering arrangements, a FMEA report is to be submitted and is to address the requirements identified in Sections 2 and 5.

**1.2.4 Manoeuvring capability.** An assessment of the ship's ahead and astern manoeuvring capability, under the following operating conditions, is to be submitted:

- (a) Where only 50 per cent or less of the installed prime mover capacity and 50 per cent or less of the installed propulsion systems are available.
- (b) Where the steering capability requirements described in 3.2.1 are available.

IMO Resolution MSC 137(76) – *Standards for Ship Manoeuvrability*, provides guidance, on standard manoeuvres required in an assessment of the manoeuvrability of ships.

**1.2.5 Testing and trials procedures.** A schedule of testing and trials to demonstrate that the ship is capable of being operated with machinery functioning as described in 4.2 is to be submitted. In addition, any testing programme that may be necessary to prove the conclusions of the FMEA is to be submitted.

**1.2.6 Operating Manuals.** Operating Manuals are to be submitted for information and provided on board. The manuals are to include the following information:

- (a) Particulars of machinery and control systems.
- (b) General description of systems for propulsion and steering.
- (c) Operating instructions for all machinery and control systems used for propulsion and steering.
- (d) Procedures for dealing with the situations identified in the FMEA report.

**1.2.7 Installed prime mover capacity and installed propulsion systems.** A schedule of the propulsion systems and their operating capacity and capability under normal and foreseeable failure conditions is to be submitted.

## Section 2 Failure Mode and Effects Analysis (FMEA)

### 2.1 General

**2.1.1** An FMEA is to be carried out in accordance with 2.1.2 to 2.1.7 for the propulsion systems, electrical power supply systems and steering systems to demonstrate that a single failure in active equipment or loss of an associated sub-system, see 1.1.3, will not cause loss of all propulsion and/or steering capability as required by a class notation. Typical sub-systems include associated control and monitoring arrangements, data communications, power supplies (electrical, hydraulic or pneumatic), fuel, lubricating, cooling, etc.

**2.1.2** The FMEA is to be carried out using the format presented in Table 22.2.1 or an equivalent format that addresses the same safety issues. Analyses in accordance with IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)* or IMO MSC Resolution 36(63) Annex 4 – *Procedures for Failure Mode and Effects Analysis*, would be acceptable.

**2.1.3** The FMEA is to be organised in terms of equipment and function. The effects of item failures at a stated level and at higher levels are to be analysed to determine the effects on the system as a whole. Actions for mitigation are to be determined.

**2.1.4** The FMEA is to:

- (a) identify the equipment or sub-system, mode of operation and the equipment;
- (b) identify potential failure modes and their causes;
- (c) evaluate the effects on the system of each failure mode;
- (d) identify measures for reducing the risks associated with each failure mode; and
- (e) identify trials and testing necessary to prove conclusions.

**Table 22.2.1 Failure Mode and Effects Analysis**

Project: Failure Mode and Effects Analysis											
System:				Element:							Sheet No:
Item No.	Component Description	Function	Mode of Operation	Failure Mode	Failure Cause	Failure Detection	Effect of Failure		Severity	Corrective Action	Remarks
							On Item	On System			
NOTE The 'severity category' is to be in accordance with the following: (a) Catastrophic; (b) Hazardous; (c) Major; or (d) Minor.											

2.1.5 At sub-system level it is acceptable, for the purpose of these Rules, to consider failure of equipment items and their functions, e.g. failure of a pump to produce flow or pressure head. It is not required that the failure of components within that pump be analysed. In addition, their failure need only be dealt with as a cause of failure of the pump.

2.1.6 Where FMEA is used for consideration of systems that depend on software-based functions for control or co-ordination, the analysis is to investigate failure of the functions rather than a specific analysis of the software code itself.

2.1.7 The FMEA is to establish that in the event of a single failure:

- (a) for **PSMR** and **PSMR★** notations, that the ship will retain not less than 50 per cent of the installed prime mover capacity and not less than 50 per cent of the installed propulsion systems and retain steering capability;
- (b) for **PMR** and **PMR★** notations, that the ship will retain not less than 50 per cent of the installed prime mover capacity and not less than 50 per cent of the installed propulsion systems;
- (c) for **SMR** and **SMR★** notations, that the steering capability remains available;
- (d) for **PSMRL★** notation, that the ship will retain the ability to use available installed prime mover capacity and installed propulsion systems that are not directly affected by the failure and retain steering capability at a service speed of not less than seven knots; and
- (e) for **PMRL★** notation, that the ship will retain the ability to use available installed prime mover capacity and installed propulsion systems that are not directly affected by the failure.

## ■ Section 3 Machinery arrangements

### 3.1 Main propulsion machinery

3.1.1 For **PSMR**, **PSMR★**, **PMR** and **PMR★** notations, independent main propulsion systems are to be provided so that the ship will retain not less than 50 per cent of the prime mover capacity and not less than 50 per cent of the installed propulsion systems in the event of a single failure of a system or active item of equipment, see 1.1.3. In the event of a single failure in equipment, the remaining system(s) is to be capable of maintaining a service speed of not less than seven knots and, for **PSMR** and **PSMR★** notations, give adequate manoeuvring capability, see 1.2.4.

3.1.2 For **PMRL**, **PSMRL**, **PMRL★** and **PSMRL★** notations, independent main propulsion systems are to be provided so that there remains the ability to use the remaining available installed prime mover capacity and installed propulsion systems following a single failure of a system or item of equipment. In the event of a single failure in equipment, the remaining system(s) is to be capable of maintaining a manoeuvring speed and, for **PSMRL** and **PSMRL★** notations, give adequate manoeuvring capability, see 1.2.4.

### 3.2 Steering machinery

3.2.1 For **PSMR**, **PSMR★**, **SMR** and **SMR★** notations, independent steering systems for manoeuvring the ship are to be installed, such that steering capability will continue to be available in the event of any of the following:

- (a) Single failure in the steering gear equipment.
- (b) Loss of power supply or control system to any steering system.

### 3.3 Electrical power supply

3.3.1 The main busbars of the switchboard supplying the propulsion machinery and essential services are to be capable of being isolated by a multi-pole linked circuit breaker, disconnecter, or switch-disconnector into at least two independent sections.

3.3.2 In the event of the loss of one section or failure of the power supply from one generator, there is to be continuity of sufficient electrical power to supply essential services such that the available installed prime mover capacity and installed propulsion systems will continue to have the ability of functioning at their operational capability where **PSMRL**, **PSMRL★**, **PMRL** and **PMRL★** notations are required. See 3.2.1 for steering machinery requirements.

3.3.3 In the event of the loss of one section or failure of the power supply from one generator, there is to be continuity of sufficient electrical power to supply essential services such that the ship will retain not less than 50 per cent of the prime mover capacity and not less than 50 per cent of the installed propulsion systems where **PSMR**, **PSMR★**, **PMR** and **PMR★** notations are required. See 3.2.1 for steering machinery requirements.

3.3.4 For ships capable of operating with one service generator connected to the switchboard, arrangements are to be such that a standby generator will automatically start and connect to the switchboard on loss of the service generator. Sequential starting of essential services is to be provided.

3.3.5 For ships operating with two or more generator sets in service connected to the switchboard, arrangements are to be such that, in the event of loss of one generator, the remaining set(s) is to be adequate for the continuity of essential services supplied from that switchboard. This may be achieved by preferential tripping of non-essential services. Alternatively, arrangements can be such that a standby generator will start automatically and connect to the switchboard on loss of one of the generator sets in service.

### 3.4 Essential services for machinery

3.4.1 Services essential for the operation of the propulsion machinery, steering and the supply of electrical power are to be arranged so to that the ship will retain not less than 50 per cent of the prime mover capacity and 50 per cent of the installed propulsion systems and retain steering capability in the event of a single failure in any of the services, where required by the respective class notations.



## 3.5 Oil fuel storage and transfer systems

3.5.1 The arrangements for the storage of oil fuel bunkers are to ensure that there is an adequate supply of existing oil fuel on board to allow sufficient time for a shore-based quality analysis of new bunkers, in accordance with ISO 8217 *Petroleum Products – Fuels (Class F) Specification of Marine Fuels* prior to use.

3.5.2 Provision is to be made to enable samples of oil fuel to be taken at the bunkering manifolds.

## Section 4 Control arrangements

### 4.1 General

4.1.1 This Section states the requirements for the installation of control, alarm and safety systems but does not signify that machinery spaces may be operated unattended. For unattended machinery space operation, compliance with Pt 6, Ch 1,4 is also required.

4.1.2 The control, alarm and safety systems required in 4.2 are to comply with Pt 6, Ch 1,2.

### 4.2 Bridge control

4.2.1 The controls, alarms, instrumentation and safeguards required in 4.2.2 to 4.2.6 are to be provided on the bridge.

4.2.2 For **PSMR**, **PSMR★**, **PMR** and **PMR★** notations, means are to be provided to ensure satisfactory control of propulsion in both the ahead and astern directions when all main propulsion systems are functioning and when one propulsion system is not available.

4.2.3 For **PSMR**, **PSMR★**, **SMR** and **SMR★** notations, means are to be provided to ensure satisfactory control of steering when all steering systems are functioning and when any one steering system is not available.

4.2.4 Where required by 5.4.3, isolation of essential services is to be carried out either automatically or manually from the bridge. Indication of the status of isolation arrangements is to be provided.

4.2.5 Instrumentation to indicate the operational status of running and standby machinery is to be provided for the propulsion systems, the supply of electrical power, steering systems and other essential services.

4.2.6 Alarms are to be provided in the event of:

- A fire in any machinery compartment.
- A high bilge level in any machinery compartment. Irrespective of the assignment of the **UMS** notation, the bilge level detection system and arrangements for automatically pumping bilges, if applicable, are to comply with Pt 6, Ch 1,4.6.

## Section 5 Separate machinery spaces ★ (star) Enhancement

### 5.1 General

5.1.1 This Section states the additional requirements where propulsion and steering machinery are installed in separate compartments such that, in the event of the loss of one compartment, the ship will retain availability of propulsion power and manoeuvring capability.

5.1.2 The machinery arrangements, control arrangements and FMEA required by Sections 2 to 4, together with testing and trials requirements in Section 6, are to be complied with in addition to 5.2 to 5.7.

### 5.2 Machinery arrangements

5.2.1 The main propulsion machinery is to be arranged in not less than two compartments such that, in the event of the loss of one compartment, propulsion power and/or manoeuvring capability will continue to be available, where required by the respective class notations.

5.2.2 The steering systems are to be arranged in not less than two separate compartments, such that steering capability will continue to be available in the event of the loss of one compartment, where required by the respective class notations.

### 5.3 Electrical power supply

5.3.1 The generating sets and converting sets required by Pt 6, Ch 2,2 are to be arranged so that they are located in at least two separate machinery compartments.

5.3.2 The independent sections of the switchboard required by 3.3.1 are to be arranged in not less than two separate compartments.

5.3.3 In the event of the loss of one compartment, there is to be continuity of sufficient electrical power to supply essential services, such that propulsion power and steering capability will continue to be available.

### 5.4 Essential services for machinery

5.4.1 Services essential for the operation of the propulsion machinery, steering and the supply of electrical power are to be arranged, so that propulsion power and steering capability are maintained in the event of the loss of one machinery compartment.

5.4.2 The design of systems which may have a common source, such as those used for supplying oil fuel, lubricating oil, fresh and sea-water cooling, ventilation of compartments and engine starting energy, is to ensure continuous availability of supply in the event of the loss of any one compartment. Where applicable, continuous availability of heating services, oil fuel and water treatments is also to be provided. See 3.5 and 5.6 for oil fuel storage and transfer systems.

5.4.3 Where essential services are arranged so that they may supply machinery in another compartment, means of isolation from that compartment is to be provided.

5.4.4 Where pumps for essential services are arranged to supply more than one compartment, standby pumps for the same supplies are to be provided in a different compartment. The standby pumps are to be arranged to start automatically if the discharge pressure from the working pumps falls below a predetermined value.

## **5.5 Bilge drainage arrangements**

5.5.1 The independent power pumps for bilge drainage are to be located in two separate watertight compartments. Each pump is to be capable of draining any compartment. Means of isolation from other compartments is to be provided.

5.5.2 In addition to the independent power pumps installed to comply with 5.5.1, an emergency bilge drainage arrangement is to be provided in each main propulsion machinery space.

5.5.3 Each separate machinery compartment is to be provided with at least one independent power pump direct bilge suction.

## **5.6 Oil fuel storage**

5.6.1 The oil fuel service tanks required by Ch 14.4.18 are to be located in separate compartments.

5.6.2 Provision is to be made to ensure that oil fuel preparation and transfer arrangements to the oil fuel service tanks are continuously available in the event of the loss of any one compartment, *see also* 5.4.2.

## **5.7 FMEA**

5.7.1 The FMEA required by 2.1.1 for the propulsion systems, electrical power supplies, essential services, control systems and steering arrangements is also to address the following:

- (a) Fire in a machinery space or control room.
- (b) Flooding of any watertight compartment which could affect propulsion or steering capability.
- (c) Separation of machinery spaces.

## **Section 6 Testing and trials**

### **6.1 Sea trials**

6.1.1 In addition to the requirements for sea trials in Ch 1.5.2, trials are to be carried out to demonstrate that when the ship is operating 50 per cent of the prime mover capacity and 50 per cent of the installed propulsion systems, a speed of not less than 7 knots can be maintained with adequate steering capability, where required by the respective class notations.

6.1.2 Trials are to be carried out to demonstrate the ship's steering capability in accordance with the assessment required by 1.2.4 with one steering system out of action.

6.1.3 Where the FMEA report has identified the need to prove the conclusions, testing and trials are to be carried out as necessary to investigate the following:

- (a) The effect of a specific component failure.
- (b) The effectiveness of automatic/manual isolation systems.
- (c) The behaviour of any interlocks that may inhibit operation of essential systems.

6.1.4 During sea trials, the operational envelope(s) is to be determined under the conditions detailed in 3.1.1 and/or 3.2.1, as required for the class notation.



# Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships

## Part 5, Chapter 23

Section 1

### Section

1	<b>General</b>
2	<b>Safe return to port</b>
3	<b>Qualitative failure analysis for propulsion and steering</b>
4	<b>Orderly evacuation and abandonment after a casualty</b>
5	<b>Verification, testing and trials</b>

## ■ Section 1 General

### 1.1 Scope and application

1.1.1 The requirements of this Chapter are additional for passenger ships and are related to machinery and equipment providing services necessary to support safe return to port under the ship's own propulsion in the event of flooding or after a fire and to support orderly evacuation and abandonment in the event of a fire.

1.1.2 The requirements of this Chapter are restricted to machinery and equipment specifically addressed by relevant engineering systems Rules.

1.1.3 The performance of machinery and equipment for services referred to in the relevant SOLAS Regulations that are not specifically addressed by relevant engineering systems Rules are not considered (e.g., basic services to safe areas, radiocommunications, navigation systems, etc.). However, these services are to be considered in terms of:

- (a) the supply of electrical power in accordance with SOLAS 1974, as amended; and
- (b) protection provided to machinery and equipment described in 1.1.2 (e.g., fire suppression measures in spaces containing propulsion machinery).

1.1.4 For passenger ships having a length of 120 m or more, or having three or more main vertical zones, the requirements of Sections 1 to 5 apply. For other passenger ships, the requirements of Sections 2 and 4 are not applicable and the requirements of Section 3 may be restricted to the qualitative failure analysis described in 3.2.2.

1.1.5 These requirements do not address operational decisions on the actual use of machinery and equipment in the event of flooding or fire (e.g., the use of propulsion and steering in a flooding damage condition).

### 1.2 Definitions

1.2.1 For the purposes of this Chapter, 'the relevant SOLAS Regulations' refers to SOLAS 1974, as amended:

- (a) Chapter II-1/B-1, Regulation 8-1, *System capabilities after a flooding casualty on passenger ships*;
  - (b) Chapter II-2/G, Regulation 21, *Casualty threshold, safe return to port and safe areas*; and
  - (c) Chapter II-2/G, Regulation 22, *Design criteria for systems to remain operational after a fire casualty*.
- (a) and (b) apply for Sections 2 and 3, (c) applies for Section 4.

1.2.2 For the purposes of this Chapter, 'relevant engineering systems Rules' refers to this Part (i.e., Part 5), Pt 6, Ch 1 and Pt 6, Ch 2.

1.2.3 The 'casualty threshold' in the context of a fire includes:

- (a) loss of space of origin up to the nearest 'A' class boundaries, which may be a part of the space of origin, if the space of origin is protected by a fixed fire extinguishing system; or
- (b) loss of the space of origin and adjacent spaces up to the nearest 'A' class boundaries, which are not part of the space of origin.

1.2.4 Ship lengths and main vertical zones considered are to be as defined by Pt 3, Ch 1.6.1.8 and SOLAS 1974, as amended Chapter II-2/A, Regulation 3.32, respectively.

1.2.5 'Safe areas' are those that will be available, during a ship's return to port under its own propulsion after a casualty that does not exceed the casualty threshold stipulated, to provide the basic services to ensure that the health of passengers and crew is maintained.

1.2.6 For the purposes of this Chapter, 'reversionary control stations' are those control stations provided for use during safe return to port and orderly evacuation and abandonment to satisfy the requirements of Sections 2 and 4 in the event of the normal control station being subject to fire damage or flooding.

1.2.7 A 'failure' is the termination of the ability of an item to perform a required function. For the purposes of Section 3:

- (a) failures result from a fault in a component or system such that it cannot perform an intended or required function, including faults resulting from fire or flooding damage;
- (b) 'common cause failures' are those failures which will cause more than one item to fail simultaneously, or within a sufficiently short period of time as to have the effect of simultaneous failures; and
- (c) 'consequential failures' are secondary failures caused by the effects of a primary failure, i.e., where the occurrence of a failure leads directly to further failures.

# Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships

## Part 5, Chapter 23

Section 1

### 1.3 General requirements and risk management

1.3.1 For passenger ships having a length of 120 m or more, or having 3 or more main vertical zones, it is the responsibility of the Shipbuilder to ensure that the arrangement of the ship's machinery and equipment as described in 1.1.2 are sufficient for the intended operating modes and to support the provision of the services that the National Administration has determined to be necessary for:

- (a) the ship's safe return to port under its own propulsion, see Section 2:
  - (i) after a casualty that does not exceed the casualty threshold; or
  - (ii) when the ship is subject to flooding of any single watertight compartment; and/or
- (b) supporting the orderly evacuation and abandonment of the ship if the casualty threshold is exceeded, see Section 4.

This necessitates activities, which will normally be risk based, to determine the machinery and equipment needed to remain operational for a period of time to satisfy the requirements of the relevant SOLAS Regulations to the satisfaction of the National Administration. These activities are to be carried out prior to the submission of plans in accordance with this Chapter.

1.3.2 The activities referred to in 1.3.1 may be conducted at the same time, or in conjunction with, activities to determine the criteria that the National Administration specify as necessary to achieve overall compliance with the relevant SOLAS Regulations. The ship's intended operational routes and/or service restrictions may be considered when establishing criteria.

1.3.3 It is the responsibility of the Shipbuilder to ensure that watertight and fire divisions, fire-fighting systems and bulkhead decks shown on the plans are those approved by the National Administration.

1.3.4 Where alternatives to the requirements of this Chapter are proposed, details demonstrating that the machinery and engineering systems comply with the relevant SOLAS Regulations are to be submitted for consideration.

### 1.4 Plans and information

1.4.1 In addition to the plans and information otherwise required by relevant engineering systems Rules, the plans and information detailed in 1.4.2 to 1.4.12 are to be submitted.

1.4.2 The analysis report described in 3.1.5(a) that includes the following information:

- (a) identification of any applicable standards used for analysis of the design;
- (b) description of the analysis team and their roles for information only;
- (c) identification of the objectives of the analysis, including any National Administration acceptance criteria;
- (d) identification of assumptions made in the analysis;
- (e) description of intended system function under normal conditions and in the event of fire or flooding;

- (f) identification of the equipment, system or sub-system and mode of operation, including the design plans and information considered;
- (g) identification of casualty scenarios, probable failure modes and acceptable deviations from the intended or required function;
- (h) evaluation of the local effects and the effects on the overall installation of each failure mode as applicable;
- (j) identification of the worst case scenario in the event of a fire casualty or flooding, as described in 2.1.1, and an assessment of the ship's ahead and astern manoeuvring capability under these conditions (IMO Resolution MSC.137(76), *Standards for Ship Manoeuvrability*, provides standards to assess the manoeuvrability of ships); and
- (k) trials, testing and other activities necessary to verify compliance with Section 3. The final report described in 3.1.5(b) is to be submitted once the proposed design is finalised.

1.4.3 Description of intended system function under normal conditions and in the event of fire or flooding for the services referred to in Sections 2 and 4.

1.4.4 Details of analyses conducted to assess the availability of services referred to in Sections 2 and 4 in the event of fire or flooding.

1.4.5 Details of National Administration criteria (see also 1.3.1), including:

- (a) service speed, manoeuvring capability and time period of operation and ship range for ship return to port under its own propulsion;
- (b) systems determined to be vital to damage control efforts;
- (c) identification of required internal communications arrangements; and
- (d) identification of navigation light circuits to be capable of operation during return to port.

1.4.6 General arrangement plans of the ship showing the location of machinery and equipment, piping systems, cables and controls stations to be employed for:

- (a) each of the services described in 2.1.2, 2.1.3, and 4.1.2; and
- (b) the provision of electrical power described in 2.1.4 and 4.1.3.

The plans are to identify:

- (c) watertight compartments and the bulkhead deck; and
- (d) for passenger ships having a length of 120 m or more or having three or more main vertical zones:
  - (i) safe areas in the context of a casualty; and
  - (ii) casualty threshold 'A' class structural fire protection boundaries.

The plans are to indicate segregation and fire/flooding protection measures and access arrangements for machinery spaces and associated control stations. These plans are also to be made available to the Surveyor on board.

1.4.7 A functional description of the system configurations and intended systems operation in the event of a fire or flooding casualty for the services referred to in Sections 2 to 4. This is to include reversionary control stations and required internal communications. A copy is to be provided on board.

# Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships

## Part 5, Chapter 23

Sections 1 &amp; 2

### 1.4.8 Identification and details:

- (a) equipment designed to operate in flooded spaces or under fire conditions; and/or
- (b) other flooding or fire protection measures.

1.4.9 A schedule of normal and emergency operating loads on the electrical system for the different expected operating conditions and services described in Sections 2 and 4.

1.4.10 Details identifying the auxiliary systems required for the operation and control of machinery and equipment to provide the services described in Sections 2 and 4.

1.4.11 Details of time period of operation and ship range and service speed corresponding to fuel storage capacity available in the event of fire or flooding scenarios.

1.4.12 A schedule of activities, including testing and trials, to verify that the ship is capable of providing the services described in Sections 2 and 4.

## Section 2 Safe return to port

### 2.1 General

2.1.1 Consistent with the requirements of the relevant SOLAS Regulations, this Section provides design criteria for machinery and equipment described in 1.1.2 to remain operational for the ship's safe return to port under its own propulsion, in the event of:

- (a) a fire casualty that does not exceed the casualty threshold; or
- (b) flooding of any single watertight compartment.

2.1.2 When fire damage from a casualty does not exceed the casualty threshold or when the ship is subject to flooding of any single watertight compartment, machinery and equipment essential for the following services are to remain operational in the remaining part of the ship not affected by fire or flooding:

- (a) **propulsion systems and their necessary auxiliaries and control systems.** Propulsion machinery and auxiliary machinery essential for the propulsion of the ship at a service speed and range/distance acceptable to the National Administration for return to port under its own propulsion, see Section 3;
- (b) **steering systems and steering-control systems.** Steering systems and steering-control systems sufficient to provide manoeuvring capability acceptable to the National Administration for return to port under its own propulsion, see Section 3;
- (c) **systems for transfer and service of oil fuel.** Systems for internal transfer and service of oil fuel capable of fuel supply to active propulsion and power generation equipment;
- (d) **bilge and ballast system.** The bilge pumping systems, and all associated equipment essential for its operation, in all spaces not directly affected by the casualty, see also Chapter 13 and Pt 6, Ch 1,2.7;

- (e) **flooding detection systems.** See also Ch 13,14;
- (f) **internal communications.** The means of communication required by:
  - (i) Ch 1,4.7, Pt 6, Ch 1,2.2.2 and/or 2.6.4 between the bridge and machinery main and subsidiary control stations and engineer's accommodation; and
  - (ii) Ch 19,2.1.7 between the navigating bridge and the steering gear compartment; necessary for operation of machinery and equipment, or otherwise identified by the National Administration to be required, during a ship's return to port under its own propulsion; and
- (g) **navigation lights.** Electric circuit protection, controls and failure alarms for lights specified by the National Administration to be capable of operation, see also Pt 6, Ch 2,15.6.

2.1.3 In addition to the requirements of Pt 6, Ch 2,1.16 and 1.17, when fire damage from a casualty does not exceed the casualty threshold or when the ship is subject to flooding of any single watertight compartment, machinery and equipment essential for the following services are to remain operational in the remaining part of the ship not affected by fire or flooding:

- (a) for **internal communication:**
  - (i) general emergency alarm system. This is in addition to the requirements of Pt 6, Ch 2,18.2;
  - (ii) public address system. This is in addition to the requirements of Pt 6, Ch 2,18.3; and
  - (iii) from the safety centre as required by Pt 6, Ch 2,17.10.3;
 where identified by the National Administration to be required to satisfy the relevant SOLAS Regulations for communication between the bridge, engineering spaces, safety centre, fire-fighting and damage control teams, and for passenger and crew notification and mustering;
- (b) for **fire main systems** where supplied by electrically driven fire pumps, the pumps (and electrical equipment essential for their operation) are to be located and arranged such that operating capability will be available in the event of any main vertical zones being directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2,17.4;
- (c) for **fixed fire-extinguishing systems:**
  - (i) for automatic sprinkler systems where supplied by electrically driven pumps, the pumps are to be located and arranged such that operating capability will be available in all spaces not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2,17.2;
  - (ii) for electrically driven refrigeration units for carbon dioxide fire-extinguishing systems, the units are to be located and arranged such that operating capability will be available in all spaces not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2,17.5; and
  - (iii) electrically operated fire-extinguishing media release alarms in spaces not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2,17.9.



# Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships

## Part 5, Chapter 23

Sections 2 & 3

- (d) the fire detection and alarm system in all spaces not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 1,2.8 and Pt 6, Ch 2,17.1;
- (e) power-operated watertight doors in spaces not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2,19.1;
- (f) lighting of safe areas and escape route or electrically powered low location lighting. This is in addition to the requirements of Pt 6, Ch 2, 3, 5.4, 5.7, 18.1 and 18.4; and
- (g) other systems required by relevant engineering systems Rules that the National Administration has determined to be vital to damage control efforts.

**2.1.4** When fire damage from a casualty does not exceed the casualty threshold or when the ship is subject to flooding of any single watertight compartment, electrical power, where required, is to be available and sustainable for the following services:

- (a) those required by 2.1.2;
- (b) navigational systems, including navigation lights, required by the National Administration to be capable of operation during return to port (see *also* Pt 7, Ch 9 for relevant classification notations);
- (c) internal communication required during a ship's return to port under its own propulsion. Where applicable, charging power for portable means of communication is to be included;
- (d) external communication (for communicating via the GMDSS or the VHF Marine and Air Band distress frequencies even if the main GMDSS equipment is lost);
- (e) fire pumps for the fire main system not directly affected by the casualty;
- (f) fixed fire-extinguishing systems (gaseous and water) designed to protect an entire space in all spaces not directly affected by the casualty;
- (g) fire detection and alarm system in all spaces not directly affected by the casualty;
- (h) power-operated watertight and semi-watertight doors;
- (j) systems and equipment intended to support the provision of services to safe areas;
- (k) other systems that the National Administration has determined to be vital to damage control efforts; and
- (l) other fixed electrically powered loads intended to be operated during return to port.

The electrical power available is to be at least sufficient to supply the machinery and equipment specified by the National Administration as necessary and any additional loads identified in (l) during a ship's return to port under its own propulsion with due regard to such services as may be operated simultaneously.

**2.1.5** Auxiliary and support systems (e.g., engine-room ventilation, lighting of spaces outside safe areas not affected by the casualty, etc.) required for the operation and control of machinery and equipment required to operate in accordance 2.1.2 and 2.1.3 and to provide electrical power in accordance with 2.1.4 are to remain operational.

**2.1.6** Oil fuel stores, machinery and equipment are to have sufficient capacity to permit the services required by 2.1.2 to 2.1.5 to be provided for a time period of operation, ship range/distance and service speed acceptable to the National Administration for the ship's return to port under its own propulsion.

**2.1.7** To satisfy 2.1.2 to 2.1.6, machinery and equipment is to be provided, constructed, segregated and arranged such that the services specified may be provided safely and effectively in the event of potential damage to machinery and equipment as a result of a fire that does not exceed the casualty threshold or flooding of any single watertight compartment, including control, safety, alarm and monitoring equipment and control stations.

**2.1.8** A description of the intended system function in the event of fire or flooding for the services referred to in this Section are to be submitted for consideration, see 1.4.2 and 1.4.3. A risk based analysis is to be conducted in accordance with standards acceptable to LR to assess the availability of services required by this Section (for propulsion and steering, see Section 3; for other services, see 1.4.4 and 3.3.4).

## ■ Section 3 Qualitative failure analysis for propulsion and steering

### 3.1 General

**3.1.1** A qualitative risk based failure analysis is to be conducted in accordance with this Section to assess compliance with the analysis objectives.

**3.1.2** The analysis is to assess the magnitude and consequences of various types of potential hazards in the design that might lead to failure to fulfil the analysis objective(s) stated in 3.2. The following are to be considered during the analysis:

- (a) analysis facilitation;
- (b) these Rules;
- (c) relevant statutory regulations and National Administration criteria;
- (d) the ship design;
- (e) the intended ship operation; and
- (f) the relevant machinery, equipment and systems.

**3.1.3** Those conducting the analysis and their roles are to be recorded in the analysis report.

**3.1.4** Requirements specified by the National Administration to satisfy the relevant SOLAS Regulations for the ship's propulsion and steering during return to port, see 2.1.2, are to be identified in the analysis report, see *also* 1.3.1.

# Safe Return to Port and Orderly Evacuation and Abandonment in Passenger Ships

## Part 5, Chapter 23

Sections 3 & 4

3.1.5 The analysis is to be documented, see 1.4.2, and two reports are to be submitted:

- (a) a preliminary analysis, after the initial arrangements of different compartments and propulsion and steering arrangements are known, to permit an assessment of compliance with this Section. This is to include an assessment of propulsion and steering capability in the event of a failure, fire or flooding in any compartment casualty; and then
- (b) a final report on the design, documenting compliance with this Section, that includes a detailed assessment of machinery and equipment required to provide propulsion and steering safely and effectively in accordance with the applicable requirements of 2.1.2.

3.1.6 Consideration will be given, on application, to review the extent that compliance with the requirements of this Section may be demonstrated by assignment of the following machinery class notations (described in Chapter 22):

- (a) **PMR★** or **PMRL★** (Propulsion Machinery Redundancy in separate machinery spaces);
- (b) **SMR★** or **SMRL★** (Steering Machinery Redundancy in separate machinery spaces); or
- (c) **PSMR★** or **PSMRL★** (Propulsion and Steering Machinery Redundancy in separate machinery spaces).

### 3.2 Analysis objectives

3.2.1 For passenger ships having a length of 120 m or more, or having 3 or more main vertical zones, the analysis is to:

- (a) assess, identify and record the effects of failure in propulsion and steering equipment and systems after a fire casualty or flooding as described in 2.1.1(a) and (b); and
- (b) verify compliance with 2.1.2(a) and (b).

3.2.2 For other passenger ships, the analysis is to assess, identify and record the effects of failure in propulsion and steering equipment in any space.

### 3.3 Analysis scope

3.3.1 The analysis is to consider the propulsion and steering machinery, equipment and other associated systems and equipment which might impair the availability of propulsion and steering.

3.3.2 To consider the effects of fire or flooding, the analysis is to address the installed locations of relevant equipment and systems.

3.3.3 The analysis is to include assessment of potential common cause failures and consequential failures when analysing system redundancy intended to maintain propulsion and/or steering in the event of a failure.

3.3.4 Where the analysis scope is extended to additionally consider other services and verify additional compliance with the requirements of Sections 2 and/or 4, details may be submitted, see 1.4.3 and 1.4.4.

## Section 4 Orderly evacuation and abandonment after a casualty

### 4.1 General

4.1.1 Consistent with the requirements of the relevant SOLAS Regulations, this Section provides design criteria for machinery and equipment described in 1.1.2 to remain operational, thereby supporting orderly evacuation and abandonment of the ship in the event of a fire that exceeds the casualty threshold.

4.1.2 In addition to the requirements of Pt 6, Ch 2, 1.14, when fire damage from a casualty exceeds the casualty threshold, machinery and equipment essential for the provision of the following emergency services are to remain operational in the remaining part of the ship not affected by fire:

- (a) for **fire main systems** where supplied by electrically driven fire pumps, the pumps (and electrical equipment essential for their operation) are to be located and arranged such that operating capability will be available in all main vertical zones not directly affected by the casualty. This is in addition to the requirements of Pt 6, Ch 2, 17.4;
- (b) for **internal communication**:
  - (i) general emergency alarm system. This is in addition to the requirements of Pt 6, Ch 2, 18.2;
  - (ii) public address system. This is in addition to the requirements of Pt 6, Ch 2, 18.3; and
  - (iii) from the safety centre as required by Pt 6, Ch 2, 17.10.3;

where identified by the National Administration to be required to satisfy SOLAS 1974 as amended, Chapter II-2/G, Regulation 22.3.1.2 for communication in support of fire-fighting and/or for passenger and crew notification and evacuation;

- (c) for **bilge systems**, the bilge pumping systems, and all associated equipment essential for its operation, in all spaces not directly affected by the casualty to permit the removal of fire-fighting water. This is in addition to the requirements of Chapter 13 and Pt 6, Ch 1, 2.7; and
- (d) lighting of escape routes, assembly stations and at embarkation stations of life-saving appliances and electrically powered low location lighting. This is in addition to the requirements of Pt 6, Ch 2, 3, 5.4, 5.7, 18.1 and 18.4.

4.1.3 When fire damage from a casualty exceeds the casualty threshold, electrical power, where required, is to be available and sustainable for the following services:

- (a) those required by 4.1.2;
- (b) other required means of internal communications systems not addressed by 4.1.2(b);
- (c) means of external communications provided to communicate via the GMDSS or the VHF Marine and Air Band distress frequencies even if the main GMDSS equipment is lost;
- (d) guidance systems for evacuation not addressed by 4.1.2(d);
- (e) life-saving appliances and arrangements;

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- (f) other systems that the National Administration has determined to be necessary to comply with SOLAS 1974 as amended, Chapter II-2/G, Regulation 22.3.1; and
- (g) other fixed electrically powered loads intended to be operated during evacuation and abandonment.

The electrical power available is to be at least sufficient to supply the machinery and equipment specified by the National Administration as necessary to support orderly evacuation and abandonment with due regard to such services as may be operated simultaneously.

**4.1.4** Machinery and equipment required to satisfy this sub-Section is to be capable of operation for at least 3 hours based on the assumption of no damage outside the unserviceable main vertical zone. System operation within the unserviceable main vertical zones is not required.

**4.1.5** A description of the intended system function in the event of fire for the services referred to in this Section is to be submitted for consideration, see 1.4.3. A risk based analysis is to be conducted in accordance with standards acceptable to LR to assess the availability of services required by this Section, see 1.4.4 and 3.3.4.

## ■ Section 5 Verification, testing and trials

### 5.1 General

**5.1.1** Activities, including testing and trials, are to be carried out to verify that the services described in Sections 2 and 4 may be provided in the event of fire or flooding to the satisfaction of LR, see 1.4.12.

**5.1.2** Testing and trials, as identified in the risk based analyses, are to be carried out to verify the findings and demonstrate that the intended system operation addresses the hazards identified.

### 5.2 Trials

**5.2.1** In addition to the requirements for sea trials in Ch 1,5.2, trials are to be carried out to demonstrate that an acceptable service speed and steering capability for return to port can be achieved in the event of fire or flooding, see 2.1.2(a) and (b). The operational envelope(s) under the failure conditions is(are) to be determined.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Sections 1, 2 &amp; 3

### Section

- 1 **General**
- 2 **Functional requirements**
- 3 **Information to be submitted**
- 4 **Materials**
- 5 **Hull construction**
- 6 **Mechanical equipment**
- 7 **Pumping and piping**
- 8 **Pressure vessels**
- 9 **Electrical and control equipment**

### ■ Section 1 General

#### 1.1 Scope

1.1.1 The requirements of this Chapter apply to machinery and equipment fitted to combustion machinery in order to reduce emissions produced by the combustion of fuel. Such machinery and equipment is hereinafter referred to as emissions abatement plant.

The requirements are intended to ensure that the emissions abatement plant is safe to operate and maintain and, additionally, where the combustion machinery provides power for essential services, that failure of the emissions abatement plant does not result in an unacceptable loss or degradation of those essential services.

The requirements are applicable to emissions abatement plant making use of both primary techniques, which reduce emissions by controlling the combustion process or removing pollutants prior to combustion, and to secondary emissions abatement techniques which reduce emissions from the exhaust gas after combustion.

It should be noted that these requirements do not provide for the reliability or redundancy necessary to ensure continued operation of the emissions abatement plant, and thereby compliance with relevant emissions requirements, following failure of any machinery, equipment or components associated with the emissions abatement plant.

### ■ Section 2 Functional requirements

#### 2.1 Functional requirements of emissions abatement plant

2.1.1 Emissions abatement plant is to be capable of operating at the maximum output power of the combustion machinery to which it is connected. Where the machinery installation is configured such that it is not intended to operate all the combustion machinery connected to the emissions abatement plant simultaneously in normal operating conditions, this will be subject to special consideration and supported by the submission required by 3.1.2. For engines, the maximum power is as stated on the Engine International Air Pollution Prevention Certificate (EIAPPC) or an equivalent certificated engine rating for vessels which are not subject to MARPOL Annex VI.

2.1.2 Operation and maintenance of the emissions abatement plant is not to present a hazard to the ship's occupants or to the environment.

2.1.3 Failure of the emissions abatement plant is not to present a hazard to the ship's occupants or any other hazard other than untreated emissions to the environment.

2.1.4 Where the emissions abatement plant is connected to combustion machinery providing power for essential services, failure of, or the inability to operate, the emissions abatement plant is not to prevent the combustion machinery from delivering sufficient power to those essential services so as to ensure the safe operation of the ship.

2.1.5 Any discharges to water from the emissions abatement plant are to be in accordance with the requirements of National and International Regulations, as applicable.

### ■ Section 3 Information to be submitted

#### 3.1 General

3.1.1 The information required by this Section, the information required by Pt 3, Ch 1,5 and Chapter IV of the *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquid Chemicals in Bulk*, as applicable (hereinafter referred to as the Rules for Ships for Liquid Chemicals).

3.1.2 A description of the emissions abatement plant and the abatement technique(s) used. This is to include details of the proposed combustion machinery operating configurations where using a common emissions abatement system for multiple exhaust gas inlet streams and any limitations on the operation of combustion machinery connected to the emissions abatement system.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Section 3

3.1.3 Where emissions abatement plant makes use of more than one abatement technique, e.g., separate means for reducing NO<sub>x</sub> and SO<sub>x</sub>, details demonstrating their compatibility with the combustion machinery and with each other.

3.1.4 Diagram showing the process flows.

3.1.5 Details of the maximum and minimum ambient and sea-water temperatures within which the emissions abatement plant is to operate, and maximum and minimum ambient air temperature and humidity where applicable.

3.1.6 Details of the hazards associated with operation and maintenance and reasonably foreseeable failure of the emissions abatement plant and the means by which they are mitigated.

3.1.7 Details of any fuel treatments, fuel additives or fuel emulsification used as a primary means of emissions abatement from combustion machinery, together with a manufacturer's letter confirming the suitability of combustion machinery to operate with such treatments and additives. Details are to include evidence that materials, fuel filtration and arrangements for the control of viscosity and temperature have been suitably modified, along with evidence of the suitability of fuel pumps and fuel valves for the treated fuel, with particular attention to viscosity, lubricity and stability, as applicable.

### 3.2 Materials

3.2.1 Details of the materials proposed for all types of construction.

### 3.3 Chemical substances

3.3.1 Details of the flammability, toxicity, corrosivity and reactivity of any chemicals used, together with details of any exothermic and hazardous reactions, particularly with regard to sea-water.

3.3.2 General arrangement of spaces where toxic or flammable liquids, gases, dusts or vapours are stored or may accumulate, indicating the hatches and other access openings.

3.3.3 Details of arrangements for loading, storage, transfer and disposal of chemicals, by-products or waste products.

3.3.4 General arrangement showing spaces maintained at an over-pressure to prevent the ingress of gases, dusts or vapours.

3.3.5 Details and arrangements of blowdown and bleed-off systems, where applicable, including quantities of chemicals, substances and effluents and the capacity and working pressure of tanks and receivers installed for the reception of such substances and effluents.

3.3.6 Arrangements for purging, gas freeing, inerting or otherwise rendering safe of the emissions abatement plant and storage facilities for chemicals, effluent and by-products associated with the plant.

3.3.7 The flow and return flow of chemicals, substances, effluent or by-products, including:

- (a) Substance supply and product discharge, with details of the arrangements showing the location of shut-off valves and of the control and indicating stations.
- (b) The process plant parameters and analysis of conditions under which emergency shut-down will be initiated.
- (c) Measures to eliminate risk of process fluid reverse flows which could present a risk to propulsion engines, auxiliary engines and essential services.
- (d) The proposed emergency procedures for controlled shut-down of the plant, i.e., depressurising, isolating and the arrangements for the continued operation of the essential services necessary to allow for such controlled shut-down under the emergency conditions identified in 3.3.7(b), as applicable.

3.3.8 Proposals for the decontamination of the emissions abatement plant compartments for installations using chemicals, substances and/or producing effluent or by-products or where there is a possibility of generating hazardous substances during the operation of plant. These proposals are to include both normal operating requirements for decontamination (such as for carrying out maintenance) and post-incident decontamination.

3.3.9 Arrangement for the detection of liquids, gas and vapours where such substances could present a fire, explosion or health hazard.

### 3.4 Mechanical equipment

3.4.1 Details of mechanical equipment associated with the emissions abatement plant to be installed.

3.4.2 Details of any safety and pressure-relief devices and their discharge arrangements.

3.4.3 Plans showing the materials of construction, working pressures and temperatures, maximum and minimum exhaust gas flows, fuel quality parameters, maximum and minimum flow rates of any water, fluids, chemicals or substances required by the process, maximum effluent or by-product discharge rate resulting from the process.

3.4.4 Details of the arrangements for protecting the emissions abatement plant, its tanks and vessels against temperature, over-pressure and vacuum. Details are to include consideration of storage temperature requirements and, where applicable, tanks are to be maintained within the temperature limits of the chemicals and substances they contain so as to avoid risks of boiling, stress corrosion, freezing and other temperature-sensitive processes.



# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Sections 3, 4 &amp; 5

3.4.5 Details of the by-pass arrangements or, where considered unnecessary, evidence demonstrating that the emissions abatement plant is capable of continued operation with the expected gas flows. Evidence is to include conditions where the emissions abatement plant is in a shut-down condition, both as a result of emergency conditions and when shut down for normal operational reasons. This is to be supported by detailed proposals demonstrating material suitability and is to ensure that, where there is a risk of blockage, this can be monitored so as to ensure that remedial action can be taken before blockage presents a risk to both propulsion and auxiliary engine and emissions abatement plant operations.

### 3.5 Pressure vessels

3.5.1 Plans of any pressure vessels, including details of the support of the vessels. Diagrammatic plans for systems associated with emissions abatement process equipment as required by Chapter 10 and Chapter 11, as applicable.

3.5.2 Details of the safety and pressure-relief devices and their discharge arrangements.

3.5.3 Stress calculations taking into account the ship linear and angular accelerations, roll and pitch amplitudes, ship flexure and wind loads, appropriate to any condition which may normally arise at sea.

### 3.6 Pumping and piping

3.6.1 Plans of the emissions abatement plant piping systems, showing the materials of construction, scantlings, support and expansion arrangements, together with the calculations.

3.6.2 Diagrammatic plans for systems associated with emissions abatement process equipment, as required by Chapter 12, Chapter 13 and Chapter 14 and by the Rules for Ships for Liquid Chemicals, as applicable.

3.6.3 Plans showing the arrangement and dimensions of main exhaust pipes, with details of flanges, bolts and weld attachments and particulars of the materials of the pipes, flanges, bolts and welding consumables.

3.6.4 Details of the safety and pressure-relief devices and their discharge arrangements.

3.6.5 Details of air and sounding pipes to tanks containing chemicals, substances and effluent.

3.6.6 The arrangements for the storage on board the ship, and the disposal, of bilge and effluent from the emissions abatement plant spaces, giving particular consideration to the risk of flooding as a result of emissions abatement plant failure. Recognition is to be given to the requirements of the appropriate National Authority.

### 3.7 Electrical and control equipment

3.7.1 General arrangement plan of the process plant, showing the location of the major items of electrical equipment.

3.7.2 Line diagram of the installation(s), indicating the rating of the various items of rotating machinery, converters and transformers.

3.7.3 Arrangement plans and circuit diagrams of the switchboards.

3.7.4 General arrangement plan of the process plant, showing the location of electrical equipment in hazardous zones.

3.7.5 A schedule of safe-type electrical equipment located in hazardous zones, giving details of the type of equipment employed, the certifying authority and the certificate number.

3.7.6 Line diagrams of any control system(s) fitted.

3.7.7 General arrangement plan of the process plant, showing the locations of items of control equipment and the locations of hazardous zones.

3.7.8 Schedule of the parameters which are monitored and controlled, including alarms and shut-down devices.

## Section 4 Materials

### 4.1 General

4.1.1 The materials used in the construction of the emissions abatement plant and any associated chemical and effluent storage tanks are to be manufactured and tested in accordance with the requirements of the *Rules for the Manufacture, Testing and Certification of Materials* and/or the Rules for Ships for Liquid Chemicals.

## Section 5 Hull construction

### 5.1 General

5.1.1 The hull structure is to comply with the relevant requirements of Parts 3 and 4, except where stated otherwise in this Section.

5.1.2 All substance and effluent tank structures and their location relative to the ship's hull are to comply with Chapters 2 and 4 of the Rules for Ships for Liquid Chemicals.



# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Section 5

**5.1.3** Where necessary, the probable temperature variations during operations and the thermal stress considerations are to be stated. Where it is necessary either to heat or cool chemical storage tanks, the arrangements are to meet the requirements of Chapter 7 of the Rules for Ships for Liquid Chemicals.

**5.1.4** Where independent tanks are used for chemical substances, these are to be bunded to contain spillage. The bund is to comply with the following:

- (a) the bund is dimensioned so as to contain the maximum contents of the tank at the angles of inclination required for main and auxiliary machinery in Table 1.3.2 in Chapter 1; or
- (b) there is a drain arrangement meeting the requirements of 5.1.6; or
- (c) the tank is located in a dedicated compartment containing no equipment other than that required by the tank with permanent access and floor plates positioned above the liquid level if the tank were to discharge its full contents into the compartment. Any valves, equipment and emergency stop functions are to be operable from outside this compartment and are to meet the requirements of 5.2.

Tanks and spill containment arrangements are to be fitted with alarms and safeguards, in accordance with Table 9.1.9.

**5.1.5** Proposals are to be made for the dimensioning of containment arrangements, relative to the potential leakage which may require containment. Where it is not practicable to contain the potential leakage fully and where this leakage can pose a hazard to personnel, proposals are to be submitted, demonstrating that leakage will be transferred to a suitable retention tank, and the means of transfer shall be capable of operating in a dead ship condition and shall be fitted with a flow detection alarm, in accordance with Table 9.1.9.

**5.1.6** Tanks are to be arranged such that any residues and slops can be pumped out, drained or otherwise removed from the tank without exposing personnel to these residues and slops.

**5.1.7** Chemical tanks are not to be located in the same space as essential machinery and equipment.

**5.1.8** Arrangements for venting and gas-freeing chemical tanks required by emissions abatement plant are to meet the requirements of Chapter 8 of the Rules for Ships for Liquid Chemicals.

### 5.2 Location service and control spaces

**5.2.1** Where flammable or toxic chemicals, gases or vapours are present, as identified in 3.3.1 and 3.3.2, service and control stations essential to the operation of the plant are to meet the requirements of 9.1.4, and should, wherever possible, be located so that access thereto is from a defined safe space. If such a location is not possible, the station is to be specially ventilated.

Arrangements are to be made in spaces occupied by emissions abatement plant, in order that substances which are flammable, corrosive, toxic or likely to present a hazard due to reaction when mixed are kept separate unless

they are fully contained within a part of the emissions abatement system which has been designed for the safe mixing of such substances.

### 5.3 Integrity of water and gastightness between compartments

**5.3.1** Where integrity of water or gastightness is required between compartments containing the plant, it is to be maintained in way of pipe tunnels or duct keels where these traverse such compartments.

**5.3.2** Installations and the spaces in which they are installed are to be, in all cases, compliant with applicable National and International requirements for prevention, detection and extinction of fire.

### 5.4 Cofferdams

**5.4.1** Cofferdams are to be sited as required by the Rules for Ships for Liquid Chemicals, as applicable, segregating any spaces in which chemicals, substances or effluents are stored or retained in bulk.

### 5.5 Plant support structure

**5.5.1** Decks and other structures supporting the plant are, in general, to comply with the requirements of Part 3. Such structures can, however, be considered on the basis of an agreed uniformly distributed loading in association with local loads at plant support points, provided that adequate transverse strength of the ship is maintained.

**5.5.2** Where the nature and dispositions of heavy plant items are such that forces on the ship and support structure due to ship motions are significant (whether underway with or without working fluids, or moored with working fluids), calculations of the loading and the structural response are to be submitted.

### 5.6 Loading due to wave-induced motions

**5.6.1** In cases where the mass distribution of large columnar equipment items is such that the centre of action of the dynamic force differs significantly from the centre of gravity of the item, due account of this is to be taken in the calculation of the forces and moments at the support positions.

### 5.7 Integrity of weather deck

**5.7.1** The integrity of the weather deck is to be maintained. Where items of plant penetrate the weather deck and are intended to constitute the structural barrier to prevent the ingress of water to spaces below the freeboard deck, their structural strength is to be equivalent to the Rule requirements for this purpose. Otherwise, such items are to be enclosed in superstructures or deckhouses fully complying with the Rules.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Section 6

### ■ Section 6 Mechanical equipment

#### 6.1 General

6.1.1 Emissions abatement plant associated with oil engines, gas turbine and boilers is to comply with the requirements of Chapters 2, 4 and 10 respectively, as applicable.

6.1.2 The mounting arrangements for the equipment is to be capable of withstanding the forces and moments stated in 5.5 and 5.6.

6.1.3 The design is to take account of the risk of fire or explosion hazards which may arise from deposition of chemicals, unburnt fuel, particulates or any by-products of chemical reactions which may arise during normal operation.

6.1.4 The emissions abatement plant is to be capable of being started in a hot condition without risk of failure due to thermal shock.

6.1.5 Safety or pressure-relief devices are to discharge to a place which will not present a hazard to the ship's occupants or to any machinery.

6.1.6 Where bursting discs or rupture panels are used as safety and pressure-relief devices, these are to be dimensioned and designed in accordance with a recognised National or International Standard.

6.1.7 Where it can be expected that there will be deposition of materials, caking and waste, arrangements are to be provided for the safe cleaning of such systems.

6.1.8 Where there is a possibility of operating conditions in the system falling below the dew point temperature of any gases or vapours present in the system, suitable drains are to be provided to permit the discharge of any condensate formed.

#### 6.2 By-pass or equivalent arrangements

6.2.1 The emissions abatement plant is to be provided with a by-pass capable of transmitting the minimum and maximum exhaust gas flows from the combustion machinery to which it is connected. Where a by-pass is considered unnecessary, the emissions abatement plant is to be capable of safely transmitting the minimum and maximum exhaust gas flows with the emissions abatement plant out of operation, such that the combustion machinery to which it is connected can continue to operate.

6.2.2 Where a by-pass is fitted, there is to be a flow path for exhaust gas at all times.

6.2.3 A means of measuring differential pressure across the emissions abatement plant is to be provided.

#### 6.3 Shared emissions abatement plant

6.3.1 Where emissions abatement plant is connected to more than one engine or source of exhaust gas, valves or equivalent means of isolating the exhaust systems of individual engines from common manifolds are to be provided to prevent reverse flow of exhaust gas into the exhaust manifolds of engines which have been shut down.

6.3.2 Where isolating valves are fitted, a means to verify the effectiveness of the isolation is to be provided.

#### 6.4 Maintenance of back-pressure

6.4.1 The exhaust back-pressure, after installation of emissions abatement plant, is to remain within the allowable limits stated by engine and combustion machinery manufacturers under all expected operating conditions, unless it is intended to operate the system at a negative pressure by means of an induced draught fan.

6.4.2 Where an induced draught fan is fitted to maintain the required exhaust back-pressure, a fan failure is not to prevent the combustion machinery from operating.

6.4.3 Where the emissions abatement plant is fed from multiple exhaust gas inlet streams, the back-pressure is to be maintained within the allowable limits provided by engine machinery manufacturers for all engine or combustion machinery operating configurations.

#### 6.5 Protection of combustion machinery

6.5.1 Measures are to be implemented to ensure that water from the emissions abatement plant cannot flow back into engine turbo-charger(s) or other machinery.

6.5.2 Means are to be provided for protecting critical engine components from foreign object damage resulting from failure of, or damage to, the emissions abatement plant. Where such damage is considered unlikely, evidence is to be submitted accordingly.

6.5.3 Where chemicals or substances are injected into the exhaust gas stream before turbo-charger(s) or emissions abatement plant are fitted, this is not to present a risk of damage, chemical attack or performance degradation to the turbo-charger(s) or engine(s) or machinery with which they are associated.

6.5.4 Where fuel treatments, additives or emulsification are used as a primary means of abating exhaust emissions, machinery is to be compatible with such additives, treatments and emulsified fuel.

6.5.5 Where exhaust gas is re-circulated as a means of emission abatement, the re-circulated exhaust gas is not to cause fouling and corrosion of critical engine components and scavenge air temperature is to be maintained at a level which does not adversely affect engine performance.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Sections 6, 7 & 8

6.5.6 Where a wet scrubber is used to clean and cool re-circulated exhaust gas, the scrubber is to satisfy the requirements of 7.1.9.

### Section 7 Pumping and piping

#### 7.1 General

7.1.1 Pipe work and transfer systems which may carry chemical substances are to meet the requirements of Chapter 5 of the Rules for Ships for Liquid Chemicals. Lining steel pipe systems with corrosion-resistant materials is subject to special approval. The elasticity of the lining is not to be less than that of the supporting boundary material.

7.1.2 Pipe systems carrying sea-water or fresh water are to meet the requirements of Chapters 12, 13 and 14. Where there is a risk of fresh water or sea-water systems becoming contaminated with process chemicals, substances or effluent, pipe systems are to comply with 7.1.1.

7.1.3 Chemical transfer and control arrangements are to meet the requirements of Ch 5,5.6 of the Rules for Ships for Liquid Chemicals.

7.1.4 Bilge and effluent pumping and piping systems in the emissions abatement plant spaces are to be constructed of material suitable for any chemicals or substances used by the emissions abatement plant, effluent that is produced or any combination of substances on board which might result from accidental admixture.

7.1.5 Arrangements are to be provided for the control of the bilge and effluent pumping and piping system. They are to be installed in the emissions abatement plant spaces from within these spaces and also from a position outside the spaces.

7.1.6 Bilge and effluent pumping and piping systems for hazardous materials should, wherever possible, be installed in the space associated with the particular hazard.

7.1.7 Piping systems carrying chemical substances or effluents and by-products are to meet the requirements of Chapter 6 of the Rules for Ships for Liquid Chemicals. This requirement includes exhaust piping where such substances are injected into exhaust gas or where the exhaust gas passes through a liquid scrubber which uses chemical substances.

7.1.8 Where filters are used, they are to be capable of being safely removed for cleaning and replacement safely without interrupting emissions abatement plant or engine operations.

7.1.9 Where scrubbers are used, the following apply:

- (a) Closed loop wet scrubbers are to have natural gravity fall drainage from the wet sump of the scrubber to the process tank or circulating pump suction, with the drain line dimensioned to accommodate 125 per cent of the maximum pumping capacity of the installed water pump(s). No valves are to be fitted to the drain line from the scrubber sump to the process tank unless it can be demonstrated that suitable precautions are in place to prevent the possibility of the scrubber filling with water and reverse-flowing into the engine exhaust duct. Where a valve is fitted to this line, the system is to be protected as for the overboard discharge valve of an open loop system, in accordance with Table 9.1.9.
- (b) For open loop wet scrubbers, the overboard discharge valve and any other sea-water valves downstream of the scrubber are to be protected in accordance with Table 9.1.9. The sea suction valve(s) are also to have position indicators which are to give remote indication of valve position. The scrubber is to be mounted above the waterline under all operating conditions to prevent sea-water ingress into the scrubber from the natural flow.
- (c) For wet scrubbing systems (open loop and closed loop), an overflow line is to be fitted to prevent the risk of reverse flow of water to engines, boilers and other machinery. This overflow is to be dimensioned to accommodate 125 per cent of maximum capacity of installed water pumps and is to have no impairment to flow. This overflow line is to be directed to the process tank in closed loop or hybrid installations. On open loop installations, it is to be directed overboard. The overboard discharge is to have an effective means of preventing reverse flow of sea-water. Alternative arrangements to prevent the risk of reverse flow are subject to special consideration.
- (d) Overboard discharge connections from scrubbers are to be positioned below the lowest operating waterline and are to be internally protected from effluent-induced corrosion.

7.1.10 Where applicable, tanks are to be maintained within the temperature limits of the chemicals and substances they contain so as to avoid risks of boiling, stress corrosion, freezing and other temperature-sensitive processes.

### Section 8 Pressure vessels

#### 8.1 General

8.1.1 Pressure vessels are to be in accordance with the requirements of the relevant Sections of Chapter 10 or Chapter 11 as applicable, or with agreed Codes and specifications normally used for similar plants in land installations, suitably modified and/or adapted for the marine environment.

8.1.2 Mounting arrangements are to take account of forces and moments generated at the supports. Mounting arrangements are to take account of thermal expansion and contraction.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Sections 8 &amp; 9

8.1.3 Access is to be provided for inspection, and checking of mountings, fittings, controls and pressure-relief devices.

8.1.4 Arrangements are to allow the pressure settings of pressure-relief devices to be checked.

8.1.5 Where provision is made to isolate pressure-relief devices from pressure vessels for maintenance purposes, at least two such pressure-relief devices are to be fitted.

The isolating or blocking valves are to be arranged such that at least one pressure-relief device remains operational at all times.

### ■ Section 9 Electrical and control equipment

#### 9.1 General

9.1.1 Electrical system(s) associated with emissions abatement plant are to meet the requirements of Pt 6, Ch 2.

9.1.2 Control system(s) associated with the emissions abatement plant are to meet the requirements of Pt 6, Ch 1.

9.1.3 Electrical and control equipment associated with the emissions abatement plant is to be compatible with any chemicals used and meet the requirements of Chapter 10 of the Rules for Ships for Liquid Chemicals.

9.1.4 Where flammable or toxic chemicals, gases or vapours are present, as identified in 3.3.1 and 3.3.2, or where there is a possibility that flammable gases and vapours can be produced as a result of deviations from normal operation, the defining of hazardous zones is to be in accordance with Pt 6, Ch 2, 14.

As a minimum, for the detection of gas and vapours, a gas detection system is to be fitted which is to activate at a concentration corresponding to the substance safe occupational level. The locations of the detectors are to be determined relative to the layouts of the individual spaces and are to be indicated on the plan submission required by 3.3.9. Where it is not practicable to install a detection system where gas detection equipment is not appropriate, e.g., for substances not emitting gases or vapours, alternative proposals are to be submitted to ensure the safety of persons from exposure to such substances.

9.1.5 Process tanks which form part of the operating loop of any emissions abatement equipment are to have a high level alarm, in accordance with Table 9.1.9. Effluent tanks which are not part of the normal process loop and which are used for storage of effluent or substances prior to discharge from the vessel are to be protected, in accordance with Table 9.1.9.

Tank alarm and trip sensors are to be positioned at a point which will allow the system shut-down to operate before the tank overflows, based on the maximum design flow rates and shut-down response time. Where a low level is identified as presenting a risk to crew or machinery, tanks are to have a low level alarm and a low level trip. These are to be

positioned so as to operate before a low level results in a hazardous condition, based on system design flow rates and a system shut-down response time.

9.1.6 An emergency stop function is to be provided, which is to:

- Close quick-closing valves on chemical tank(s) (where applicable).
- Stop chemical feed pump(s) (where applicable).
- Where fitted, open exhaust gas cleaning by-pass valve.
- Stop scrubber water pumps and close scrubber water inlet valve (where applicable).

9.1.7 The emergency stop function is to be capable of being actuated from the machinery control room, the navigating bridge and from within compartments containing chemical tanks and exhaust gas cleaning plant.

9.1.8 Alarms and safeguards are to be provided for the critical system parameters in order to avoid danger to crew and machinery. As a minimum, the alarms and safeguards listed in Table 9.1.9 are to be fitted. Where these Rules require alarms and also trip protection to be fitted, the alarm and trip are to be independent of each other.

9.1.9 Where emissions abatement plant makes use of chemical substances, a means of monitoring abnormal flows of such chemicals is to be provided.

# Emissions Abatement Plant for Combustion Machinery

## Part 5, Chapter 24

Section 9

**Table 9.1.9 Machinery emissions to air abatement plant: alarms and safeguards**

Item	Alarm	Note
Exhaust gas outlet temperature	High	
Exhaust gas inlet temperature	High	
Exhaust gas inlet temperature	Low	Only for selective catalytic reduction
Differential pressure across abatement plant unit	High	
Abatement plant by-pass valve in exhaust duct	Valve movement	See Note 1
Machinery exhaust duct isolating valve	Valve movement	See Note 2
Wet emissions abatement unit overboard discharge valve	Closed	Emissions abatement plant is to be shut down automatically, see Note 6
Wet emissions abatement unit overflow line flow detection	Flow present	Emissions abatement plant is to be shut down automatically, see Note 6
Wet emissions abatement water pressure	Low	
Wet emissions abatement unit water temperature	High	
Chemical feed flow	High	
Wet emissions abatement unit water level	1st Stage high	
Wet emissions abatement unit water level	2nd Stage high	Emissions abatement plant is to be shut down automatically, see Note 6
Chemical feed flow	High	Chemical feed pump is to be shut down automatically
Chemical feed flow	1st Stage low	
Chemical feed flow	2nd Stage low	Chemical feed pump is to be shut down automatically
Process tank level	1st Stage high	See Note 3
Process tank level	2nd Stage high	Emissions abatement plant is to be shut down automatically, see Note 3
Chemical storage tank level	1st Stage high	
Chemical storage tank level	2nd Stage high	
Chemical storage tank level	Low	
Chemical storage tank temperature	High	See Note 4
Chemical storage tank temperature	Low	See Note 4
Chemical tank containment bund level	High	Tank outlet quick closing valve is to close automatically, see Note 5
Chemical tank containment drain line flow detection	Flow present	Tank outlet quick closing valve is to close automatically, see Note 5
Exhaust gas recirculating fan failure	Failure	
Recirculating exhaust gas temperature return to engine	High	
Induced draught fan failure	Failure	Where fitted

**NOTES**

1. Only where a by-pass valve is fitted, see 3.3.5. This valve shall open to the by-pass position as part of the unit shut-down logic.
2. Only where fitted, see 5.1.
3. The process tank is any tank forming part of a wet abatement system flow loop or effluent tanks which receive bleed-off from the main flow loop, or such tanks not forming part of the system flow loop but which are essential for operation of the system, including those on exhaust gas recirculating installations, see 7.1.9. Where low level can present a hazard, process tanks are also to have low level protection.
4. Where chemical substances are to be kept within a defined temperature range, alarms will be fitted, based on the allowable temperature range, see 5.1.2 and 7.1.10.
5. Chemical spillage detection alarm will depend on the means of spill containment fitted, see 5.1.2.
6. Wet emissions abatement unit shall include such systems fitted as part of the exhaust gas recirculating installations.

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