RULES AND REGULATIONS FOR THE CLASSIFICATION OF SHIPS

MAIN AND AUXILIARY MACHINERY

JULY 2007

PART 5

Lloyd's Register

Chapter Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Section

■ *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, economizers, desuper-heaters, steam heated steam generators and steam receivers. All other boilers having working pressures exceeding 3,4 bar (3,5 kgf/cm^2), and having heating surfaces greater than 4,65 m^2.
- 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 utilizing 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 require-ments 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.

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 Materials (Part 2). 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 installation should not be a recognized hazard to personnel. This includes the prohibition of asbestos except in the following applications:

(a) Vanes used in rotary vane compressors and rotary vane pumps.
(b) Watertight joints and linings used for the circulation of fluids when at high temperature (in excess of 350ºC) or pressure (in excess of 7 x 10^6 Pa) there is a risk of fire, corrosion or toxicity.
(c) Supple and flexible thermal insulation assemblies used for temperatures above 1000ºC.

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 manufacturer and agreed by the Owner/Operator.

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 for Ships for Liquefied Gases*.

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.

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 bar = 0,1 N/mm^2 = 1,02 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 engine 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.

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		+32, *see* Note 1

NOTES
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: *Electrical installations in ships – Part 101: Definitions and general requirements.*

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.

.

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

NOTES
1. Athwartships and fore-and-aft inclinations may occur simultaneously.
2. Where the length of the ship exceeds 100 m, the fore-and-aft static angle of inclination may be taken as:

$$\frac{500}{L} \text{ degrees}$$

where L = length of ship, in metres.
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°.

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.

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.

4.4.2 Machinery spaces shall be sufficiently 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 operation of the machinery.

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 stopping times, ship headings and distances recorded on trials, together with the results of trials to determine the ability of ships having multiple propellers to navigate and manoeuvre with one or more propellers inoperative, are to be available on board for the use of the master or designated personnel.

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 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 organization 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 authorized 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
(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:
(a) identify the design practices of the manufacturer's organization including departmental instructions to ensure the orderly and controlled preparation of design and subsequent verification;
(b) make provision for the identification, documentation and appropriate approval of all design change and modifications;
(c) prescribe methods for resolving incomplete, ambiguous or conflicting requirements; and
(d) 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:
(a) The type, class, grade, or other precise identification;
(b) 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:
(a) 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.
(b) 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:

(a) perform inspection during manufacture on all characteristics that cannot be inspected at a later stage;
(b) inspect test and identify products in accordance with specified requirements;
(c) establish product conformance to specified requirements by use of process monitoring and control methods where appropriate;
(d) hold products until the required inspections and tests are completed and verified; and
(e) clearly identify non-conforming products to prevent unauthorized 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:

(a) all activities defined in the specification, quality plan or other documented procedure have been completed;
(b) all inspections and tests that should have been conducted at earlier stages have been completed and that the data is acceptable; and
(c) 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.

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 (Part 2).
(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.
(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 authorized 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.

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 authorized senior member of the quality control department or by an authorized 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 authorized 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 authorized 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.

Section

■ *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.

■ *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. *See* also 1.1.4:
  - 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* 11.5.
- The specification for a mass produced engine including manufacturing processes and quality control procedures, *see* 11.1.4 and 11.2.3.
- Schematic layouts showing details and arrangements of oil mist detection/monitoring and alarm systems.

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 10.
- 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 Where engines incorporate electronic control systems, a failure mode and effects analysis (FMEA) is to be submitted to demonstrate that failure of an electronic control system will not result in the loss of essential services for the operation of the engine and that operation of the engine will not be lost or degraded beyond an acceptable performance criteria of the engine. This is concerned with the functioning of the control system and not failure of the software itself.

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

1.1.6 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.

1.1.7 Plans and details for dead ship condition starting arrangements are to be submitted for appraisal, *see* 8.1.

■ *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^2
(b) Carbon and carbon-manganese steel forgings (normalized and tempered) – 400 to 600 N/mm^2
(c) Carbon and carbon-manganese steel forgings (quenched and tempered) – not exceeding 700 N/mm^2
(d) Alloy steel castings – not exceeding 700 N/mm^2
(e) Alloy steel forgings – not exceeding 1000 N/mm^2
(f) Spheroidal or nodular graphite iron castings – 370 to 800 N/mm^2.

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 Materials.

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

Table 2.2.1 Test requirements for oil engine components

Component	Material tests	Non-destructive tests: Magnetic particle or Liquid penetrant	Non-destructive tests: 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	–

NOTES
1. For closed-die forged crankshafts the ultrasonic examination may be confined to the initial production and to subsequent occasional checks.
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.
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.
4. Bore dimensions refer to engine cylinder bores.
5. All required material tests are to be witnessed by the Surveyor unless alternative arrangements have been specifically agreed by LR.
6. For mass produced engines, *see* Section 11.

■ *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.
- Digitized 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.

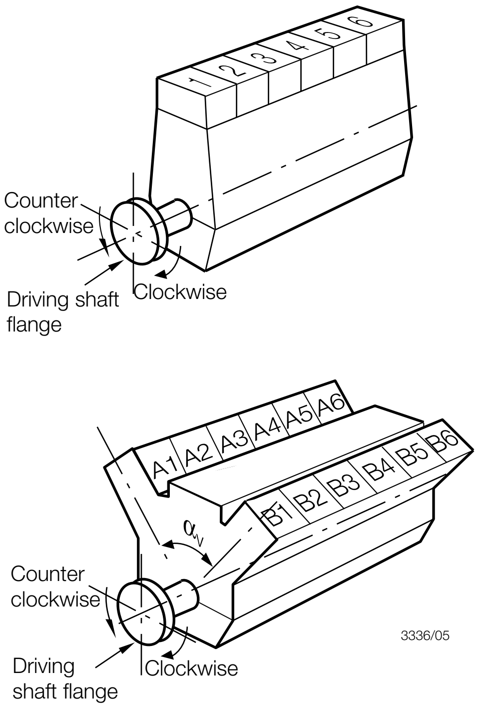


Fig. 2.3.1 Designation of cylinders

- Centre of gravity of connecting rod from large end centre, in mm.
- Radius of gyration of connecting rod, in mm.
- 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^2.
- Specified minimum yield strength, in N/mm^2.
- 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)

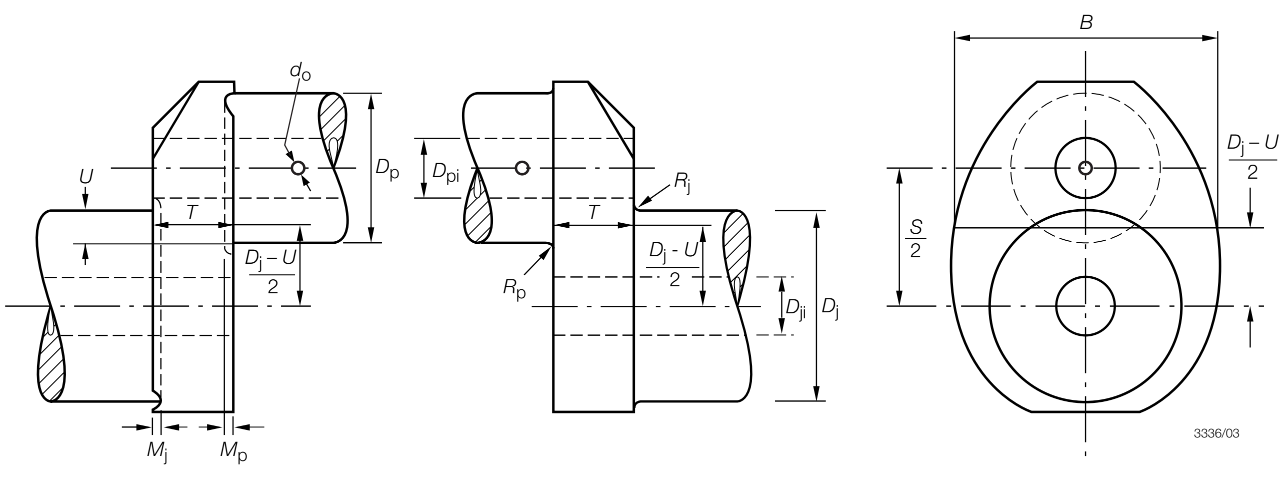
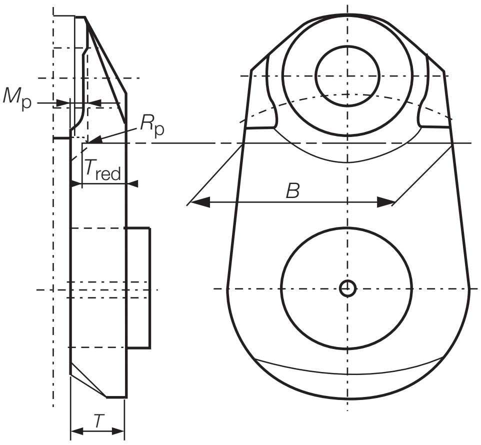


Fig. 2.3.2(a) Crank dimensions necessary for the calculation of stress concentration factors



Crankshaft without overlap

Fig 2.3.2(b)
Crank dimensions for crankshaft without overlap

U = pin overlap

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

α_B = bending stress concentration factor for crankpin
α_T = torsional stress concentration factor for crankpin
β_B = bending stress concentration factor for main journal
β_Q = direct shear stress concentration factor for main journal
β_T = torsional stress concentration factor for main journal
γ_B = bending stress concentration factor for radially drilled oil hole in the crankpin
γ_T = torsional stress concentration factor for radially drilled oil hole in the crankpin
σ_{ax} = alternating axial stress, in N/mm^2
σ_b = alternating bending stress, in N/mm^2
σ_{BON} = alternating bending stress in the outlet of the oil bore, in N/mm^2
σ_p, σ_j = maximum bending stress in pin and main journal taking into account stress raisers, in N/mm^2
σ_{BO} = maximum bending stress in the outlet of the oil bore, in N/mm^2
σ_Q = alternating direct stress, in N/mm^2
σ_U = specified minimum UTS of material, in N/mm^2
σ_y = specified minimum yield stress of material, in N/mm^2
τ_a = alternating torsional stress, in N/mm^2
τ_p, τ_j = maximum torsional stress in pin and main journals taking into account stress raisers, in N/mm^2
τ_{tob} = maximum torsional stress in outlet of crankpin oil bore taking into account stress raisers, in N/mm^2.

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

3.4.2 Crankpin stress concentration factors:

- Bending

α_B = 2,70 f(ut). f(t). f(b). f(r). f(dp). f(dj). f(rec)

where

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

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

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

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

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

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

f(rec) = $1 + (m_p + m_j)\,(1,8 + 3,2u)$
valid only between $u = -0,5$ and 0,5.

- Torsion

α_T = 0,8 f(ru). f(b). f(t)

where

f(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

β_B = $2{,}71 f_B(ut).\ f_B(t).\ f_B(b).\ f_B(r).\ f_B(dj).\ f_B(dp).\ f(rec)$

where

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

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

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

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

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

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

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

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

- Direct shear

β_Q = $3{,}01 f_Q(u).\ f_Q(t).\ f_Q(b).\ f_Q(r).\ f_Q(dp).\ f(rec)$

where

$f_Q(u) = 1{,}08 + 0{,}88u - 1{,}52u^2$

$$f_Q(t) = \frac{t}{0{,}0637 + 0{,}937t}$$

$f_Q(b) = b - 0{,}5$

$f_Q(r) = 0{,}533 r_{JB}^{(-0{,}204)}$

$f_Q(dp) = 1 - 1{,}19d_p + 1{,}74(d_p)^2$

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

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

- Torsion

where

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

$f(ru) = r_{jT}^{-(0{,}22 + 0{,}1u)}$

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

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

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

- Bending

$\gamma_B = 3 - 5{,}88 \bullet d_o + 34{,}6 \bullet d_o^2$

- Torsion

$\gamma_T = 4 - 6 \bullet d_o + 30 \bullet d_o$

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:

$T_{red} = T - (M_p - R_p)$ 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, σ_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:

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

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

k_e = 0,8 for crosshead engines
= 1,0 for trunk piston engines.

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

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

where

M_{BON} is taken as the ½ range value $M_{BON} = \pm \tfrac{1}{2}\,(M_{BOmax} - M_{BOmin})$

and

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

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

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

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

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

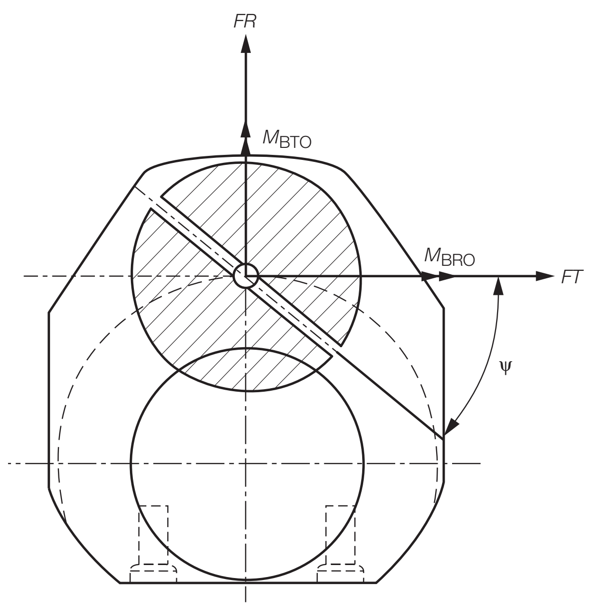


Fig. 2.3.3 Crankpin section through the oil bore

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:

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

where

A_{web} = BT mm^2.

3.5.8 The nominal alternating torsional stress, τ_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:

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

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

τ_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, σ_b, the axial vibratory stress, σ_{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:

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

  where

  α_B = bending stress concentration, *see* 3.4.2
- Maximum alternating torsional stress:

  $\tau_p = \alpha_T \tau_a$ N/mm^2

  where

  α_T = torsional stress concentration, *see* 3.4.2

  τ_a = nominal alternating torsional stress in crankpin N/mm^2.

3.6.2 Outlet of crankpin oil bore.

- Maximum alternating bending stress:

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

  where

  γ_B = bending stress concentration factor, *see* 3.4.4
- Maximum alternating torsional stress:

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

  where

  γ_T = torsional stress concentration factor, *see* 3.4.4

  τ_a = nominal alternating torsional stress in crankpin N/mm^2.

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

- Maximum alternating bending stress:

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

  where

  β_B = bending stress concentration, *see* 3.4.3

  β_Q = direct stress concentration, *see* 3.4.3
- Maximum alternating torsional stress:

  $\tau_j = \beta_T \tau_a$ N/mm^2

  where

  β_T = torsional stress concentration, *see* 3.4.3

  τ_a = nominal alternating torsional stress in main journal N/mm^2.

3.7 Equivalent alternating stress

3.7.1 Equivalent alternating stress of the crankpin, σ_{ep}, or crank journal σ_{ej}, is defined as:

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

where

σ = σ_p or σ_j N/mm^2

τ = τ_p or τ_j N/mm^2.

3.7.2 Equivalent alternating stress for the outlet of the crankpin oil bore σ_{eob}, is defined as:

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

3.8 Fatigue strength

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

$$\sigma_{fp} = K_1 K_2 (0{,}42\sigma_u + 39{,}3)\left(0{,}264 + 1{,}073 D_p^{-0,2} + \frac{785 - \sigma_u}{4900} + \frac{196}{\sigma_u}\sqrt{\frac{1}{R_p}}\right)$$

To calculate the fatigue strength in the oil bore area, replace R_p with ½d_o and σ_{fp} with σ_{fob}.

$$\sigma_{fj} = K_1 K_2 (0{,}42\sigma_u + 39{,}3)\left(0{,}264 + 1{,}073 D_j^{-0,2} + \frac{785 - \sigma_u}{4900} + \frac{196}{\sigma_u}\sqrt{\frac{1}{R_j}}\right)$$

where

σ_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 zone 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:

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

where

σ_f = σ_{fp} or σ_{fj} or σ_{fob}

σ_e = σ_{ep} or σ_{ej} or σ_{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 δ_{min} and δ_{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:

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

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

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

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

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^2

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
μ = 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
σ_{yj} = minimum yield strength of material for journal pin
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, δ_{max}, is not to be greater than:

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

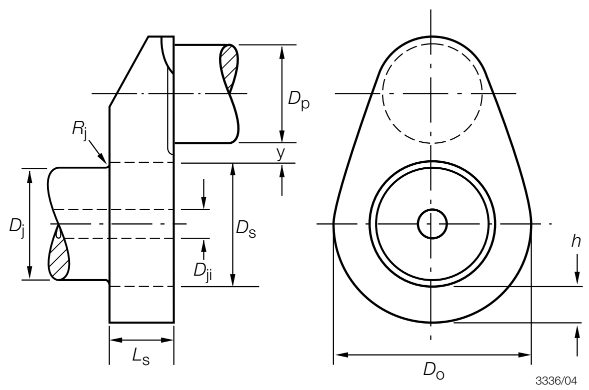


Fig. 2.3.4 Crank throw of semi-built crankshaft

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

■ *Section 4* Construction and welded structures

4.1 Crankcases

4.1.1 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.

4.2 Welded joints

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

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

4.2.3 Girder 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.

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

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

4.2.6 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.

4.2.7 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.

4.3 Materials and construction

4.3.1 Plates, sections, forgings and castings are to be of welding quality in accordance with the requirements of the Rules for Materials (Part 2), 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.

4.3.2 Plates and weld preparations are to be accurately machined or flame-cut to shape. Flame-cut surfaces are to be cleaned by machining or grinding: if the flame-cut surfaces are smooth, wire brushing may be accepted.

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

4.3.4 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.

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

4.4 Post-weld heat treatment

4.4.1 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.

4.4.2 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.

4.5 Inspection

4.5.1 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.

4.5.2 On completion of welding and stress relief heat treatment, all welds are to be examined.

4.5.3 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 5* Safety arrangements on engines

5.1 Cylinder relief valves

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

5.2 Main engine governors

5.2.1 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.

5.2.2 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.

5.3 Auxiliary engine governors

5.3.1 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 full load is suddenly taken off or, when after having run on no-load for at least 15 minutes, load is suddenly applied as follows:

(a) For engines with BMEP less than 8 bar, full load, or

(b) 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.

5.3.2 Emergency engines are to comply with 5.3.1 except that the initial load required by 5.3.1(b) is to be not less than the total connected emergency statutory load.

5.3.3 For alternating current installations, the permanent speed variation of the machines intended for parallel operation are to be equal within a tolerance of ±0,5 per cent. Momentary speed variations with load changes in accordance with 5.3.1 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.

5.4 Overspeed protective devices

5.4.1 Each main engine developing 220kW (300 shp) or over which can be declutched or which drives a controllable (reversible) pitch propeller, 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.

5.4.2 The overspeed protective device, including its driving mechanism, is to be independent of the governor required by 5.2 or 5.3 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.

■ *Section 6* Crankcase safety fitting

NOTE
For the purpose of this Section, starting air compressors are to be treated as auxiliary engines.

6.1 Relief valves

6.1.1 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.

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

6.1.3 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 a standard acceptable to LR. 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.

6.1.4 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.

6.1.5 A copy of the installation and maintenance manual required by 6.1.4 is to be provided on board the ship.

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

6.1.7 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.

6.2 Number of relief valves

6.2.1 In engines having cylinders not exceeding 200 mm bore or having a crankcase gross volume not exceeding 0,6 m^3, relief valves may be omitted.

6.2.2 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 crank throws an additional valve is to be fitted near the centre of the engine.

6.2.3 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 crank throw with a minimum of two valves. For engines having 3, 5, 7, 9, etc., crank throws, the number of relief valves is not to be less than 2, 3, 4, 5, etc., respectively.

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

6.2.5 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^3.

6.3 Size of relief valves

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

6.3.2 The free area of each relief valve is to be not less than 45 cm^2.

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

6.3.4 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.

6.4 Vent pipes

6.4.1 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 minimize 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.

6.4.2 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.

6.4.3 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.

6.5 Alarms

6.5.1 Alarms giving warning of the overheating of engine running parts, indicators of excessive wear of thrusts and other parts, and crankcase oil mist detectors are recommended as means for reducing the explosion hazard. These devices should be arranged to give an indication of failure of the equipment or of the instrument being switched off when the engine is running.

6.6 Warning notice

6.6.1 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.

6.7 Crankcase access and lighting

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

6.7.2 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.

6.8 Fire-extinguishing system for scavenge manifolds

6.8.1 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.

6.9 Oil mist detection/monitoring

6.9.1 Where crankcase oil mist detection/monitoring arrangements are fitted, they are to be of a type approved by LR, tested in accordance with Section 14 and comply with 6.9.2 to 6.9.15.

6.9.2 The oil mist detection/monitoring 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) Schematic layout of engine oil mist detection/monitoring and alarm system showing locations of engine crankcase sample points and piping arrangements together with pipe dimensions to detector/monitor.
(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 monitoring equipment.

6.9.3 A copy of the oil mist detection/monitoring equipment maintenance and test manual required by 6.9.2 is to be provided on board ship.

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

6.9.5 In the case of multi engine installations, each engine is to be provided with oil mist detection/monitoring and a dedicated alarm.

6.9.6 Oil mist detection/monitoring 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.

6.9.7 Alarms and shutdowns for the oil mist detection/monitoring system are to be in accordance with Pt 6, Ch 1 as applicable.

6.9.8 The oil mist detection/monitoring 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.

6.9.9 The oil mist detection/monitoring 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.

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

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

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

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

6.9.14 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.

6.9.15 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 7* **Piping**

7.1 Oil fuel systems

7.1.1 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.

7.1.2 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.

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

7.1.4 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.

7.1.5 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 inaccesible by a fire on any of the engines.

7.2 High pressure oil systems

7.2.1 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.

7.3 Exhaust systems

7.3.1 Where the surface temperature of the exhaust pipes and silencer may exceed 220ºC, they are to be water cooled or efficiently lagged to minimize 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.

7.3.2 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.

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

7.3.4 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.

7.3.5 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.

7.4 Starting air pipe systems and safety fittings

7.4.1 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.

7.4.2 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.

7.4.3 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.

7.4.4 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.

7.4.5 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.

7.4.6 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.

7.4.7 Alternative safety arrangements may be submitted for consideration.

■ *Section 8*
Starting arrangements and air compressors

8.1 Dead ship condition starting arrangements

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

8.1.2 Dead ship condition for the purpose of 8.1.1 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.

8.1.3 Where the emergency source of power is an emergency generator which fully complies with the requirements of Pt 6, Ch 2 of the Rules, 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.

8.1.4 Where there is no emergency generator installed or an emergency generator does not comply with Pt 6, Ch 2 of the Rules, 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.

8.1.5 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 8.1.3 or 8.1.4 may be proposed for consideration. Details of the alternative arrangements are to be included in the plans and details required by 1.1.6 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.

8.2 Air compressors

8.2.1 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 8.3. 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 8.1 is to be ignored.

8.2.2 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.

8.2.3 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.

8.3 Air receiver capacity

8.3.1 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 six 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.

8.3.2 For multi-engine installations, the number of starts required for each engine will be specially considered.

8.4 Electric starting

8.4.1 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 8.3. In other respects batteries are to comply with the requirements of Pt 6, Ch 2,11.

8.4.2 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.

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

8.4.4 Engine starting batteries are to be used only for the purposes of starting the engines and for the engines' own monitoring 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 8.4.1 and 8.4.3.

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

8.4.6 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 8.4.1 or 8.4.2 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.

8.5 Starting of the emergency source of power

8.5.1 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.

8.5.2 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.

8.5.3 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 energized 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.

8.5.4 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.

8.5.5 When hand (manual) starting is not practicable, the provisions under 8.5.2 and 8.5.3 are to be complied with except that starting may be manually initiated.

8.5.6 Engine starting batteries are to be used only for the purposes of starting the engines and for the engines' own monitoring arrangements.

■ *Section 9*
Component tests and engine type testing

9.1 Hydraulic tests

9.1.1 In general, items are to be tested by hydraulic pressure as indicated in Table 2.9.1. Where design features are such that modifications to the test requirements shown in Table 2.9.1 are necessary, alternative proposals for hydraulic tests are to be submitted for special consideration.

9.1.2 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 2.9.1. Recognition and acceptance of the works quality control processes can be by one of the following routes:

(a) Approval under the LR Quality Scheme for Machinery.
(b) Approval of an alternative quality scheme recognized by LR.
(c) Approval by LR through auditing of the manufacturer's quality system.

9.2 Alignment gauges

9.2.1 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 weardown 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.

Table 2.9.1 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 + 295 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

NOTES
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 alternative testing methods will be specially considered.

9.3 Engine type testing

9.3.1 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.

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

9.3.3 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.

9.3.4 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.

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

■ *Section 10* Turbo-chargers

10.1 Plans and particulars

10.1.1 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.

10.2 Type test

10.2.1 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 turbocharger is to be completely dismantled for examination of all parts.

10.2.2 Alternative arrangements will be specially considered.

10.3 Dynamic balancing

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

10.4 Overspeed test

10.4.1 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.

10.5 Mechanical running test

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

10.5.2 Upon application, with details of an historical audit covering previous testing of turbochargers manufactured under an approved quality assurance scheme, consideration will be given to confining the test outlined in 10.5.1 to a representative sample of turbochargers.

■ *Section 11* Mass produced engines

11.1 Definition

11.1.1 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.

11.1.2 Castings, forgings and other parts for use in mass produced engines are also to be produced by methods similar to those given in 11.1.1(a), (b) and (c), with appropriate inspection.

11.1.3 Pressure testing of components is to comply with 9.1.1.

11.1.4 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* 11.1.1(a).

11.2 Procedure for approval of mass produced engines

11.2.1 The procedure outlined in 11.2.2 to 11.2.5 applies to the inspection and certification of mass produced oil engines having a bore not exceeding 300 mm.

11.2.2 For the approval of a mass produced engine type, the manufacturer is to submit, in addition to the plans and particulars required by 1.1 and information required by 3.2, a list of subcontractors for main parts.

11.2.3 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.

11.2.4 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 11.5.

11.2.5 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, in the manufacturing or control processes, in the selection of materials or in the list of subcontractors for main parts.

11.3 Continuous review of production

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

11.3.2 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.

11.4 Compliance and inspection certificate

11.4.1 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 11.2.4, 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.

11.5 Type test conditions

11.5.1 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.

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

11.5.3 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 over-speed device.
(j) Testing of lubricating oil system failure alarm device.
(k) Testing of the engine with turbocharger out of action when applicable.
(l) Testing of minimum speed for main propulsion engines and the idling speed for auxiliary engines.

11.5.4 The type tests in 11.5.3 at the required outputs are to be combined together in working cycles for the whole duration within the limits indicated. *See also* 11.5.10 and 11.5.11.

11.5.5 The overload testing required by 11.5.3 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.

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

11.5.7 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.

11.5.8 In addition to the particulars stated in 11.5.7 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.

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

11.5.10 For engines that are required to be approved for different purposes (multi-purpose engines), and that have different performances 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).

11.5.11 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.

■ *Section 12* Mass produced turbo-chargers

12.1 Application

12.1.1 The following procedure applies to the inspection of exhaust driven turbo chargers which are manufactured on the basis of mass production methods similar to 11.1 as applicable and for which the maker has requested the approval.

12.2 Procedure for approval of mass produced turbo-chargers

12.2.1 The procedure outlined in 12.2.2 to 12.2.5 applies to the inspection and certification of mass produced turbo-chargers when a simplified method of inspection has been requested by the manufacturers.

12.2.2 For the approval of a mass produced turbo-charger, the manufacturer is to submit, in addition to the plans and particulars required by 10.1.1, a list of main current suppliers and subcontractors for rotating parts and an operation and maintenance manual.

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

12.2.4 A Type test, *see* 10.2, 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.

12.2.5 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.

12.3 Continuous inspection of individual units

12.3.1 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 12.3.3 to 12.3.7 as deemed necessary, and to have free access to all control records and subcontractor's certificates.

12.3.2 Each individual unit is to be tested in accordance with 12.3.4 to 12.3.7 by the maker who is to issue a final certificate.

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

12.3.4 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.

12.3.5 Pressure tests are to be carried out in accordance with Table 2.9.1. Special consideration will be given where design or testing features may require modification of the test requirements.

12.3.6 Dynamic balancing and overspeed tests are to be carried out, *see* 10.3 and 10.4, 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 test unit.

12.3.7 A mechanical running test, *see* 10.5, 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.

12.4 Compliance and certificate

12.4.1 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 12.2.4 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 13* Type testing procedure for crankcase explosion relief valves

13.1 Scope

13.1.1 This test procedure identifies standard conditions by which crankcase explosion relief valves intended to be fitted to diesel engines can be tested to demonstrate that they satisfy LR requirements for type testing to a defined standard.

13.1.2 This test procedure is also applicable to explosion relief valves intended for gear cases.

13.1.3 Standard repeatable test conditions have been established using a methane gas and air mixture.

13.1.4 The test procedure is only applicable to explosion relief valves fitted with flame arresters.

13.2 Purpose

13.2.1 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 over-pressure protection provided by the valve.

13.3 Test facilities

13.3.1 The test facilities for carrying out type testing of crankcase explosion relief valves are to meet the following requirements:

(a) The test facilities where testing is carried out are to be accredited to a National or International Standard for the testing of explosion protection devices.
(b) The test facilities are to be acceptable to LR.
(c) The test facilities are to be equipped so that they can control 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 ± 0.1%.
(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. The result of each test is to be documented by video recording and if necessary by recording with a heat sensitive camera.
(g) The test vessel for explosion testing is to have documented dimensions that are to be such that its height or length between dished ends is approximately 2 times its diameter but not more than 2.5 times. The internal volume of the test vessel is to be determined from the vessel dimensions that include any standpipe arrangements.
(h) The test vessel for explosion testing is to be provided with a flange for mounting the explosion relief valve in an orientation consistent with how it will be installed in service, i.e., in the vertical plane or the horizontal plane. The flange arrangement is to be made approximately one third of the height or length of the test vessel.
(j) A circular flat plate having the following dimensions is to be provided for fitting between the pressure vessel flange and valve to be tested:
   (i) Outside diameter = 2 x *D* where *D* is the outer diameter of the valve top cover. The circular plate is to provide simulation of the crankcase surface.
   (ii) Internal bore having the same internal diameter as the valve to be tested.
(k) The test vessel for explosion testing is to have connections for measuring the methane in air mixture in at least two positions, i.e., top and bottom.
(l) The test vessel for explosion testing is to be provided a means of fitting an ignition source at a position approximately one third the height or length of the vessel, *see* 13.4.3.
(m) The test vessel volume is to be as far as practicable, related to the size of relief valve to be tested. In general, the volume is to correspond to the requirement in 6.3.1 for the free area of explosion relief valve to be not less than 115 cm^2/m^3 of crankcase gross volume, e.g., the testing of a valve having 1150 cm^2 of free area, would require a test vessel with a volume of 10 m^3. In no case is the volume of the test vessel to vary by more than +15 per cent to –10 per cent or from the 115 cm^2/m^3 volume ratio.

13.4 Explosion test process

13.4.1 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 methane concentration of 9,5 per cent ±0,5 per cent. The pressure in the test vessel is to be not less than atmospheric and not exceed 0,2 bar.

13.4.2 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.

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

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

13.5 Valves to be tested

13.5.1 The valves used for type testing are to be manufactured and tested in accordance with procedures acceptable to LR and selected from the manufacturer's usual production line for such valves by the LR Surveyor witnessing the tests.

13.5.2 For approval of a specific valve size, three valves of that specific size are to be tested. The valves are to have been tested at the manufacturer's works to demonstrate that the opening pressure is in accordance with that agreed by the engine builder and valve manufacturer within a tolerance of ±20 per cent and that the valve is air tight at a pressure below the opening pressure for at least 30 seconds.

13.5.3 The selection of valves for type testing is to recognize the orientation in which they are intended to be installed on the engine or gear case. Where it is intended that valves be installed in the vertical or near vertical or the horizontal or near horizontal position, then three valves of each size are to be tested for each intended orientation.

13.6 Method

13.6.1 The following requirements are to be satisfied at explosion testing:
(a) The explosion testing is to be witnessed by a LR Surveyor where type testing approval is required by LR.
(b) Valves are to be tested in the vertical or horizontal position consistent with the orientation in which they are intended to be installed on an engine or gear case, usually in the vertical position, *see* 13.5.3.
(c) 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.
(d) Type testing is to be carried out for each range of valves for which a manufacturer requires LR approval.
(e) Successive explosion testing to establish a valve's functionality is to be carried out as quickly as possible during stable weather conditions.
(f) The pressure rise and decay during all explosion testing is to be recorded.
(g) The external condition of the valves is to be monitored during each test. The test facility is to produce a report on the explosion test findings.

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

13.6.3 **Stage 1.** Two explosion tests are to be carried out with the flange opening fitted with the circular plate covered by a 0,05 mm thick polythene film. These tests establish a reference pressure level for determination of the effects of a relief valve in terms of pressure rise in the test vessel, *see* 13.7.1(f).

13.6.4 **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 13.3.1(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.

(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. During the second explosion test, the valve is to be visually monitored for any indication of combustion outside the flame arrester. 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.

13.6.5 **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, recognizing that the test vessel ambient conditions may have changed during the testing of the explosion relief valves in Stage 2.

13.7 Assessment

13.7.1 Assessment of the valves after explosion testing is to address the following:

(a) The valves to be tested are to have evidence of appraisal/approval by LR, *see also* 13.5.1.

(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 underpressure 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.

(g) The valve tightness is to be ascertained by verifying from records that an underpressure of at least 0,3 bar is held by the test vessel for at least 10 seconds following an explosion.

(h) After each explosion test in Stage 2, the external condition of the flame arrester is to be examined for signs of damage and/or deformation.

(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 is to be noted. Photographic records of the valve condition are to be taken and included in the report.

13.8 Design series qualification

13.8.1 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.

13.8.2 The quenching ability of a flame screen depends on the total mass of quenching lamellas/mesh. Provided the materials, thickness of materials, depth 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 arrestors subject to (a) and (b) being satisfied.

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

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

where

n_1 = number of lamellas of size 1 quenching device for a valve with a relief area equal to S_1

n_2 = number of lamella 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

13.9 The report

13.9.1 The test facility 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.

13.10 Approval

13.10.1 Approval of an explosion relief valve is the prerogative of LR based on the appraisal of plans and particulars and the test facility's report of the results of type testing.

■ *Section14* Type testing procedure for crankcase oil mist detection/monitoring and alarm arrangements

14.1 Scope

14.1.1 This test procedure identifies standard conditions by which crankcase oil mist detection/monitoring and alarm equipment and systems intended to be fitted to diesel engines can be tested to demonstrate that they satisfy LR requirements for type testing to a defined standard.

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

14.2 Purpose

14.2.1 The purpose of type testing crankcase oil mist detection/monitoring and alarm arrangements is seven fold:
(a) To verify the functionality of the system.
(b) To verify the effectiveness of the oil mist detectors.
(c) To verify the accuracy of oil mist detectors.
(d) To verify the alarm set points.
(e) To verify time delays between mist extraction from crankcase and alarm activation.
(f) To verify the operation of alarms to indicate functional failure in the equipment and associated arrangements.
(g) To verify that there is an indication when optical obscuration has reached a level that will affect the reliability of information and alarms.

14.3 Test facilities

14.3.1 The test house carrying out type testing of crankcase oil mist detection/monitoring and alarm equipment and arrangements is to satisfy the following criteria:
(a) The test facilities are to have the full range of facilities for carrying the type and functionality tests required by this procedure and be acceptable to LR.
(b) The test house that verifies that the equipment ascertains the levels of oil mist concentration 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 ±10 per cent in accordance with this procedure.
(c) The type tests are to be witnessed by a LR Surveyor unless otherwise agreed.
(d) The oil mist concentrations are to be ascertained by the gravimetric deterministic method or equivalent. The gravimetric deterministic method is a laboratory process where the difference in weight of a millipore (typically 0,8 μm) filter is ascertained by weighing the filter before and after drawing 1*d*m^3 of oil mist through the filter.
(e) 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/monitoring 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.
(f) The filters are required to be weighed to a precision of 0,1 mg and the volume of air/oil mist sampled to a precision of 10 ml.

14.4 Equipment testing

14.4.1 The range of tests is to include the following for the alarm/monitoring panel:
(a) Functional tests described in 14.5.
(b) Electrical power supply failure test.
(c) Power supply variation test.
(d) Dry heat test.
(e) Damp heat test.
(f) Vibration test.
(g) EMC test.
(h) Insulation resistance test.
(j) High voltage test.
(k) Static and dynamic inclinations, if moving parts are contained.

14.4.2 The range of tests is to include the following for the detectors:
(a) Functional tests described in 14.5.
(b) Electrical power supply failure test.
(c) Power supply variation test.
(d) Dry heat test.
(e) Damp heat test.
(f) Vibration test.
(g) Insulation resistance test.
(h) High voltage test.
(j) Static and dynamic inclinations, if moving parts are contained.

14.5 Functional test process

14.5.1 All tests to verify the functionality of crankcase oil mist detection/monitoring devices are to be carried out in accordance with 14.5.2 to 14.5.6 with an oil mist concentration in air, known in terms of mg/l to an accuracy of ±10 per cent.

14.5.2 The concentration of oil mist in the test vessel is to be measured in the top and bottom of the vessel and these concentrations are not to differ by more than 10 per cent.

14.5.3 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).

14.5.4 The operation of the alarm indicators for oil mist concentration in air are to be verified and are to provide an alarm at a maximum setting corresponding to 5 per cent of the LEL or approximately 2,5 mg/l.

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

14.5.6 Where oil mist is drawn into a detector/monitor 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.

14.6 Detectors/monitors and equipment to be tested

14.6.1 The detectors/monitors and equipment used in type testing are to be manufactured and tested in accordance with procedures acceptable to LR and selected from the manufacturer's usual production line for such equipment by the LR Surveyor witnessing the tests.

14.6.2 Two sets of detectors/monitors requiring approval are to be tested. One set is to be tested in the clean condition and the other in a condition that represents the maximum degree of lens obscuration that is stated as being acceptable by the manufacturer.

14.7 Method

14.7.1 The following requirements are to be satisfied at type testing:
(a) The testing is to be witnessed by a LR surveyor where type testing approval is required by LR.
(b) Oil mist detection/monitoring devices are to be tested in the orientation in which they intended to be installed on an engine or gear case.
(c) Type testing is to be carried out for each range of oil mist detection/monitoring devices that a manufacturer requires LR approval.
(d) The test house is to produce a test report.

14.8 Assessment

14.8.1 Assessment of oil mist detection/monitoring devices after testing is to address the following:
(a) The devices to be tested are to have evidence of appraisal/approval by LR, *See also* 14.6.1.
(b) The details of the detection/monitoring devices to be tested are to be recorded. This is to include manufacturer, type designation, oil mist concentration assessment capability and alarm settings.
(c) After completing the tests, the detection/monitoring devices are to be examined and the condition of all components ascertained and documented. Photographic records of the monitoring devices condition are to be taken and included in the report.

14.9 Design series qualification

14.9.1 The approval of one detection/monitoring device may be used to qualify other devices having identical construction details. Proposals are to be submitted for consideration.

14.10 The Report

14.10.1 The test house is to provide a full report which includes the following information and documents:
(a) Test specification.
(b) Details of devices tested.
(c) Results of tests.

14.11 Acceptance

14.11.1 Acceptance of crankcase oil mist detection/monitoring devices is the prerogative of LR based on the appraisal of plans and particulars and the test house report of the results of type testing.

14.11.2 The following information is to be submitted to LR for acceptance of oil mist detection/monitoring and alarm arrangements:
(a) Description of oil mist detection/monitoring equipment and system including alarms.
(b) Copy of the test house report identified in 14.10.
(c) Schematic layout of engine oil mist detection/monitoring 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.
- 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.

■ *Section 15* Electronically controlled engines

15.1 Scope

15.1.1 The requirements of this section are applicable to engines for propulsion, auxiliary and emergency power purposes with software-based electronic control of fuel, air and exhaust systems.

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

15.1.3 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 one or more electronic control systems to provide the services essential for the operation of the engine such as fuel injection, air inlet, exhaust and speed control.

15.1.4 Deviation from Rule requirements are to be submitted and will be considered on the basis of technical justification by the engine builder.

15.1.5 During the life of the engine any changes to hardware, software, control and monitoring systems which may affect the safety and reliable operation of the engine are to be submitted and approved by LR.

15.2 Plans and particulars

15.2.1 In addition to the plans and particulars required by Section 1 the following 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 electronic control 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 can be controlled by electronic control systems.

(b) Details of hydraulic systems for actuation of sub-systems (fuel injection, air inlet and 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.

(c) Failure Modes and Effects Analysis (FMEA) of the mechanical, pressure containing and electrical systems and arrangements that support the operation of the engine. The analysis is to demonstrate that suitable risk mitigation has been achieved so that a system will tolerate a single failure in equipment or loss of an associated sub-system such that operation of the engine will not be lost or degraded beyond acceptable performance criteria of the engine. *See* 13.5.

(d) A schedule of testing and trials to demonstrate that the engine is capable of operating as described in the design statement, and any testing required to verify the conclusions of the FMEA.

(e) Operating manuals which describe the particulars of each system and, together with maintenance instructions, include reference to the arrangements for making modifications and changes to electronic control systems and for the functioning of sub-systems.

(f) 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.

(g) 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.

(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 all intended engine operating modes.

(j) Evidence of type testing of the engine with electronic controls, or a proposed test plan at the engine builders with the electronic controls functioning, to verify the functionality and behaviour under fault conditions of the electronic control system.

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

(a) System requirements specification.
(b) Description of operation with explanatory diagrams.
(c) Line diagrams of control circuits.
(d) List of monitored points.
(e) List of control points.
(f) List of alarm points.
(g) List of safety functions and details of any overrides, including consequences of use.
(h) Details of hardware configuration.
(j) Hardware certification details.
(k) Software quality plan.
(l) System integration plan.
(m) Failure Mode and Effects Analysis (FMEA). *See* Pt 5, Ch 2,1.1.4.
(n) Factory acceptance, integration, harbour and sea trials/test schedules for hardware and software.
(o) Software certification details.
(p) Quality plan for sourcing, design installation and testing of all components used in the control, alarm, monitoring and safety systems installed with the engine for engine operation.

15.3 Oil fuel and hydraulic oil systems

15.3.1 Oil fuel and hydraulic oil piping systems arrangements are to comply with Chapters 2, 11, 12, 13 and 14 as applicable.

15.3.2 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.

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

15.3.4 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.

15.3.5 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.

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

15.3.7 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.

15.3.8 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.

15.3.9 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.

15.3.10 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.

15.3.11 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.

15.3.12 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.

15.4 Electronic control systems

15.4.1 Plans and details of electronic control systems are to comply with Pt 6, Ch 1 and Ch 2 as applicable.

15.4.2 For electronic control systems and electrical actuating systems, the quality plan for sourcing, design, installation and testing of components 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 engine.
(f) Details of arrangements for software upgrades.

15.4.3 The system integration plan is required 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 for safe and reliable operation of the engine within stated performance criteria.

15.5 FMEA analysis

15.5.1 A Failure Mode and Effects Analysis (FMEA) is to demonstrate that a failure of the functioning of an electronic control system:

(a) 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 2.12.2);
(b) 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 1,2.13.4 and 2.13.5); and
(c) 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 1,2.3.12, 2.4.6, 2.5.4, 2.10.3, 2.13.5).

15.5.2 Where FMEA analysis is required to be carried out the reports submitted are to address the following issues:

(a) Identify the standards used for analysis and system design.
(b) Identify the 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. This may be through system design, provision of redundant systems and/or quality control procedures for sourcing, manufacture and testing.
(h) Identify trials and testing necessary to prove conclusions.

15.5.3 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.

15.5.4 In an electronically controlled engine it is necessary to define the essential services on which the operation of the engine relies and the control functions, alarm functions and safety functions for the equipment and machinery providing these services. Examples of essential services are:

(a) Starting arrangements.
(b) Fuel supply arrangements.
(c) Lubricating oil arrangements.
(d) Hydraulic oil arrangements.
(e) Cooling arrangements.
(f) Power supply arrangements.

■ *Section 16* Alarms and safeguards for emergency diesel engines

16.1 Application

16.1.1 These requirements apply to emergency diesel engines required to be immediately available in an emergency and capable of being controlled remotely or automatically.

16.2 Plans and information

16.2.1 Plans, information and test schedules to be submitted for design appraisal are to be in accordance with Pt 6, Ch 1.

16.3 Alarms and safeguards

16.3.1 Alarm and safety systems are to comply with the requirements of Pt 6, Ch 1.

16.3.2 Alarms and safeguards are to be fitted in accordance with Table 2.16.1.

Table 2.16.1 Alarms and safeguards for emergency diesel engines

Item	Alarm	Alarm	Note
Emergency Diesel Engine	≥ 220 kW	<220 kW	
Fuel oil leakage from pressure pipes	Leakage	Leakage	*See* 7.1.2
Lubricating oil temperature	High	—	—
Lubricating oil pressure	Low	Low	—
Oil mist concentration in crankcase	High	—	See Note
Coolant pressure or flow	Low	—	—
Coolant Temperature (can be air)	High	High	—
Overspeed	High	—	Automatic shutdown
NOTE For engines having a power of more than 2250 kW or a cylinder bore of more than 300 mm.			

16.3.3 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.

16.3.4 Regardless of the engine output, if shutdowns additional to those specified in Table 2.14.1 are provided except for the overspeed shutdown, they are to be automatically overridden when the engine is in automatic or remote control mode during navigation.

16.3.5 Grouped alarms of at least those items listed in Table 2.14.1 are to be arranged on the bridge.

16.3.6 In addition to the fuel oil control from outside the space, a local means of engine shutdown is to be provided.

16.3.7 Local indications of at least those items listed in Table 2.14.1 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.

■ *Section 17* General requirements

17.1 Turning gear

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

17.1.2 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.

17.1.3 The turning gear for auxiliary engines may be hand operated (manual) except where this is not practicable, in which case the provision of 17.1.2 is to be complied with.

17.1.4 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.*1*

7.1.5 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.

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

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

■ *Section 18* Program for trials of diesel engines to assess operational capability

18.1 Works trials (acceptance test)

18.1.1 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 18.1.2 to 18.1.9. 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.

18.1.2 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.

18.1.3 In each case given in Table 2.18.1, 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.

18.1.4 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.

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

18.1.6 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.

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

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

18.1.9 For all stages that the engine is to be tested and where no duration is specified in Table 2.18.1, 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.

18.2 Shipboard trials

18.2.1 After the conclusion of the running-in programme prescribed by the engine manufacturer, engines are to undergo shipboard trials as specified in Table 2.18.2. The scope of the trials is to be agreed between the LR Surveyor and the Shipyard prior to testing.

18.2.2 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.

18.2.3 In addition to 18.2.2, 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.

Table 2.18.1 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*	≥ 60 minutes	After having reached steady conditions
110% power at engine speed corresponding to 1,032**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* 5.2
Shut down device	—	*See* 5.4
Engines driving generators		
Trial condition	Duration	Note
100% power (rated power) at rated engine speed, *R*	≥ 50 minutes	After having reached steady conditions (2)
110% power	15 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* 5.3
Shut-down device	—	*See* 5.4

NOTES
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.

18.2.4 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.

18.2.5 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

■ *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 16.

Table 2.18.2 Scope of shipboard trials for diesel engines

Main engines driving fixed-pitch propellers (1) (2)		
Trial condition	Duration	Note
At rated engine speed, *R*	≥ 4 hours	—
At engine speed corresponding to normal continuous power	≥ 2 hours	—
At engine speed corresponding to 1,032**R*	30 minutes	Where the engine adjustment permits, *see* 18.1.6
At minimum on-load speed	—	—
Starting and reversing manoeuvres	—	*See* Section 8
In reverse direction of propeller rotation during the dock or sea trials at a minimum engine speed of 0,7**R*	10 minutes	—
Monitoring, alarms and safety systems	—	—
Where imposed, test to ensure engine can pass safely through barred speed range	—	—
Engines driving generators for propulsion		
Trial condition	Duration	Note
100% power (rated power) see 18.2.3	≥ 4 hours	(3) (4)
At normal continuous power	≥ 4 hours	(3) (4)
In reverse direction of propeller rotation at a minimum speed of 70% of the nominal propeller speed	10 minutes	(3) (4)
Starting manoeuvres	—	—
Monitoring, alarm and safety systems	—	—

NOTES
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 driven generators.

■ *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^2 (41 and 61 kgf/mm^2). For alloy steel rotor forgings, the specified minimum tensile strength is to be selected within the limits of 500 and 800 N/mm^2 (51 and 82 kgf/mm^2). 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^2 (51 and 102 kgf/mm^2).

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 minimizing 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.

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 8.

3.2.2 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.

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

3.2.4 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.

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

3.2.6 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.

3.2.7 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 17,8.2.

3.2.8 The heat treatment of welded rotors is to be carried out as approved.

3.2.9 Surveyors are to be satisfied that the desired quality of welding is attainable with the proposed welding equipment and procedure and, for this purpose, test specimens representative of the welded joints are to be provided for radiographic examination and mechanical tests.

3.2.10 For cylinders, the mechanical tests of butt joints are to include tensile, bend and macro-tests as detailed in Chapter 17, Sections 1 to 8.

3.2.11 For diaphragms, nozzle plates, etc., representative samples are to be sectioned and macro-etched.

3.2.12 For rotors, the mechanical tests are to include tensile (all weld metal), tensile (joint), bend (transverse), bend (longitudinal) and macro-tests as detailed in Chapter 17, Sections 1 to 8, or such other tests as may be approved.

3.2.13 In subsequent production, check tests of the quality of the welding are to be carried out at the discretion of the Surveyors.

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.

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 Ch1,3.9. 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 Overspeed protective devices

4.1.1 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.

4.1.2 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.

4.2 Speed governors

4.2.1 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.

4.2.2 Auxiliary turbines intended for driving electric generators are to be fitted with speed governors which, with fixed setting, 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 equalize within a tolerance of ±0,5 per cent.

4.3 Low vacuum and overpressure protective devices

4.3.1 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.

4.3.2 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.

4.4 Bled steam connections

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

4.5 Steam strainers

4.5.1 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* Tests and equipment

6.1 Stability testing of turbine rotors

6.1.1 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 stabilizing 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.

6.1.2 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.

6.2 Balancing

6.2.1 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.

6.3 Hydraulic tests

6.3.1 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.

6.3.2 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^2), whichever is the greater.

6.3.3 For test purposes, the cylinders may be sub-divided with temporary diaphragms for distribution of test pressures.

6.3.4 Condensers are to be tested in the steam space to 1,0 bar (1,0 kgf/cm^2). 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^2), with a minimum test pressure of 2,0 bar (2,0 kgf/cm^2). Where the operating conditions are not known, the test pressure is to be not less than 3,4 bar (3,5 kgf/cm^2), *see* Chapter 14.

6.4 Indicators for movement

6.4.1 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.

6.5 Weardown gauges

6.5.1 Main and auxiliary turbines are to be provided with bridge weardown gauges for testing the alignment of the rotors.

■ *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 16.

■ *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.

■ *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):
- 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 GT98*.

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 of Chapter 1.

■ *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 (Part 2)).

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.

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 minimize 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 minimize the risk of fire and prevent damage by heat to adjacent components, *see* 5.1.5.

4.9 Welded construction

4.9.1 Full strength welds are to be used for all major joints and be designed so as to ensure complete fusion of the joint.

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.

■ *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 for Ships for 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.

5.1.5 The gas turbine design and construction are to minimize 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 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.

8.2 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 overtemperature 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.

Section 9
Planned maintenance and condition monitoring procedures, and 'upkeep by exchange'

9.1 Planned maintenance approach

9.1.1 Suitable gas turbine installation Planned Maintenance and Condition Monitoring Schemes (MPMS, MCM) will be accepted as part of LR's Continuous Survey Machinery (CSM) cycle provided the principles defined in 9.2 to 9.4 are satisfied (*see also* Pt 5, Ch 21).

9.2 Preventive maintenance

9.2.1 Preventive maintenance requires items to be opened out for inspection and overhaul at specified time periods or after a specified number of running hours.

9.2.2 Maintenance is normally carried out irrespective of the condition of the gas turbine in order to retain it in a satisfactory operational condition.

9.3 Unscheduled maintenance

9.3.1 The planned maintenance scheme is to be capable of dealing effectively with breakdown or corrective maintenance, i.e. unscheduled maintenance.

9.4 Condition monitoring

9.4.1 Condition monitoring requires the use of instrumentation to make regular or continuous measurements of certain parameters, in order to indicate the physical state of the gas turbine, without disturbing its normal operation.

9.4.2 The data collected is to be used to determine the actual condition of the gas turbine at any given time or, based on the trend characteristics of the condition, used for predicting the remaining useful life before complete deterioration or loss of performance terminates its ability to carry out its required function.

9.5 Condition monitoring techniques

9.5.1 The condition monitoring techniques, to support the trend away from preventive maintenance, listed in Table 4.9.1 are considered the minimum acceptable to obviate the need for a fully opened out inspection of engine components at Periodical Survey.

9.5.2 Alternative arrangements to those in Table 4.9.1, which provide an equivalent level of confidence in the condition of the gas turbine installation, will be considered.

Table 4.9.1 Condition monitoring techniques

Method	Requirement
Visual inspection	Periodic inspection of intakes and exhaust ducts, inlet guide vanes, compressor 1st stage, compressor and gas generator casings and auxiliary components and systems. The running clearances and dimensional changes, where practicable
Visual inspection by borescope/endoscope	Periodic inspection of compressor stators, guide vanes and blades, combustion chambers, turbine nozzles and blades and power turbine
Vibration monitoring	Continuous monitoring and trend analysis of gas generator and power turbine rotor vibration. The equipment used for vibration measurement should be capable of determining vibration throughout the operating range of the gas turbine
Lubrication, oil trend analysis programme	• Periodic inspection of magnetic particle detectors (manual records and/or automatic recording via debris counters in oil scavenge lines) • Periodic inspection of oil filters • Periodic sampling and laboratory analysis of lubricant quality
Fuel quality	• Maintenance of fuel bunker/marine gas oil analysis records • Periodic sampling and laboratory analysis of fuel quality
Performance monitoring	Continuous monitoring and trend analysis of critical gas turbine operating parameters including: • Compressor conditions (inlet and exit temperature, delivery pressure and speed) • Power turbine (inlet entry temperature and speed) • Engine breather temperature • Low cycle fatigue counter *See* Note.
NOTE Manual recording and trend analysis methods may also be acceptable.	

9.6 Upkeep by exchange

9.6.1 Where the gas turbine is maintained using an 'upkeep by exchange' policy, details of the system are to be submitted to LR for approval.

9.6.2 Where an 'upkeep by exchange' system has been approved, details of units that can be changed independently of each other are not required to be submitted provided there have been no changes since the original approval. The manufacture and testing of the replacement units are to be in accordance with relevant Rule requirements.

9.6.3 Records of each 'upkeep by exchange' are to be kept on board the ship and LR Surveyors are to witness running tests on load after each exchange. A record history is to be maintained for each exchange unit in the engine logbook.

Section

■ *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. 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_γ will be specially 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:

- Shaft power and revolution for each pinion.
- Number of teeth in each gear.
- Reference diameters.
- Helix angles at reference diameters.
- Normal pitches of teeth at reference diameters.
- Tip diameters.
- Root diameters.
- Face widths and gaps, where applicable.
- Pressure angles of teeth (normal or transverse) at reference diameters.
- Accuracy grade Q in accordance with ISO 1328 or an equivalent standard.
- Surface texture of tooth flanks and roots.
- Minimum backlash.
- Centre distance.
- Basic rack tooth form.
- Protuberance and final machining allowance.
- Details of post hobbing processes, if any.
- Details of tooth flank corrections, if adopted.
- Case depth for surface-hardened teeth.
- Shrinkage allowance for shrunk-on rims and hubs.
- 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. carburized, 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^2 (56 to 107 kgf/mm^2)
Gear wheels and rims	400 to 850 N/mm^2 (41 to 87 kgf/mm^2)

A tensile strength range is also to be specified and is not to exceed 120 N/mm^2 (12 kgf/mm^2) when the specified minimum tensile strength is 600 N/mm^2 (61 kgf/mm^2) or less. For higher strength steels, the range is not to exceed 150 N/mm^2 (15 kgf/mm^2).

2.1.3 Unless otherwise agreed, the full specified minimum tensile strength of the core is to be 800 N/mm^2 (82 kgf/mm^2) for induction-hardened or nitrided gearing and 750 N/mm^2 (76 kgf/mm^2) for carburized 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 µm
f_{pb} = maximum base pitch deviation of wheel, in µm
f_{Sh} = tooth flank misalignment due to wheel and pinion deflections, in µm
f_{Sho} = intermediary factor for the determination of f_{Sh}
g_α = 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
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_γ
u = gear ratio = $\dfrac{\text{Number of teeth in wheel}}{\text{Number of teeth in pinion}} \geq 1$
v = linear speed at pitch circle, in m/s
x = addendum modification coefficient
y_α = running in allowance, in µm
y_β = running in allowance, in µm
z = number of teeth
z_n = virtual number of teeth

$$= \frac{z}{\cos^2 \beta_b \cos \beta}$$

C_γ = tooth mesh stiffness (mean total mesh stiffness per unit face width), in N/mm µm
F_t = nominal tangential tooth load, in N

$$= \frac{P}{nd}\ 19{,}098 \times 10^6$$

F_β = total tooth alignment deviation (maximum value specified), in µm
$F_{\beta x}$ = actual longitudinal tooth flank deviation before running in, in µm
$F_{\beta y}$ = actual longitudinal tooth flank deviation after running in, in µm
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_γ = load sharing factor
P = transmitted power, in kW
P_r = radial pressure at shrinkage surface, in N/mm^2
P_{ro} = protuberance of tool, in mm
Q = accuracy grade from ISO 1328 – 1975
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 µm
S_{pr} = residual undercut left by protuberance in mm
$S_{F\,min}$ = minimum factor of safety for bending stress
S_{Fn} = tooth root chord in the critical section, in mm
$S_{H\,min}$ = minimum factor of safety for Hertzian contact stress
Y_D = design factor
Y_F = tooth form factor
$Y_{R\,rel\,T}$ = relative surface finish factor
Y_S = stress concentration factor
Y_{ST} = stress correction factor
Y_x = size factor
Y_β = helix angle factor
$Y_{\delta\,rel\,T}$ = 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_β = helix angle factor
Z_ε = contact ratio factor
α_{en} = pressure angle at the highest point of single tooth contact, in degrees
α_n = normal pressure angle at reference diameter, in degrees
α_t = transverse pressure angle at reference diameter, in degrees
α_{tw} = transverse pressure angle at pitch circle diameter, in degrees
α_{Fen} = angle for application of load at the highest point of single tooth contact, in degrees
β = helix angle at reference diameter, in degrees
β_b = helix angle at base diameter, in degrees
γ = intermediary factor for the determination of f_{Sh}
ε_α = transverse contact ratio

$$= \frac{g_\alpha \cos \beta}{\pi\, m_n \cos \alpha_t}$$

$\varepsilon_{\alpha n}$ = virtual transverse contact ratio
ε_β = overlap ratio

$$= \frac{b \sin \beta}{\pi\, m_n}$$

ε_γ = total contact ratio
ρ_{ao} = tip radius of tool, in mm
ρ_c = relative radius of curvature at pitch point, in mm

$$= \frac{a \sin \alpha_{tw}\, u}{\cos \beta_b\, (1 + u)^2}$$

ρ_F = tooth root fillet radius at the contact of the 30° tangent, in mm
σ_y = yield or 0,2 per cent proof stress, in N/mm^2
σ_B = ultimate tensile strength, in N/mm^2
σ_F = bending stress at tooth root, in N/mm^2
$\sigma_{F\,lim}$ = endurance limit for bending stress in N/mm^2
σ_{FP} = allowable bending stress at the tooth root, in N/mm^2
σ_H = Hertzian contact stress at the pitch circle, in N/mm^2
$\sigma_{H\,lim}$ = endurance limit for Hertzian contact stress, in N/mm^2
σ_{HP} = allowable Hertzian contact stress, in N/mm^2

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_γ. The value for K_γ is to be taken as 1,15 for multi-engine drives or split torque arrangements. Otherwise K_γ 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 $\dfrac{v z_1}{100} > 14$ for helic gears, and

where $\dfrac{v z_1}{100} > 10$ 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

$F_{\beta y} = F_{\beta x} - y_\beta$ and
$F_{\beta x} = 1{,}33\, f_{Sh} + f_{ma}$
$f_{ma} = 2/3\, F_\beta$ at the design stage, or
$f_{ma} = 1/3\, F_\beta$ where helix correction has been applied

$$f_{Sh} = f_{Sho} \frac{F_t\, K_A\, K_\gamma\, K_v}{b} \quad \text{where}$$

f_{Sho} = $23\gamma 10^{-3}$ µm mm/N for gears without helix correction and without end relief, or
= $16\gamma 10^{-3}$ µm 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 x 10^{-3} µm mm/N for helical gears, or
= 5 x 10^{-3} µm mm/N for spur gears

For through-hardened steels and surface hardened steels running on through-hardened steels:

$$y_\beta = \frac{320}{\sigma_{H\,lim}} F_{\beta x} \text{ when}$$

$$y_\beta \leq \frac{12800}{\sigma_{H\,lim}} \ \mu\text{m, and}$$

For surface hardened steels, when

$y_\beta = 0{,}15 F_{\beta x}$
$y_\beta \leq 6$ µm
$K_{F\beta} = K_{H\beta}{}^n$

where

$$n = \frac{\left(\frac{b}{h}\right)^2}{1 + \frac{b}{h} + \left(\frac{b}{h}\right)^2}$$

NOTES

1. $\dfrac{b}{h}$ is to be taken as the smaller of $\dfrac{b_1}{h_1}$ or $\dfrac{b_2}{h_2}$

2. For double helical gears $\dfrac{b}{2}$ 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:

$$y_\alpha = \frac{160}{\sigma_{H\,lim}}\,f_{pb} \text{ for through-hardened steels, when}$$

$$y_\alpha \leq \frac{6400}{\sigma_{H\,lim}}\ \mu\text{m and}$$

$y_\alpha = 0{,}075 f_{pb}$ for surface hardened steels, when

$y_\alpha \leq 3\ \mu$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_γ:

$$C_\gamma = \frac{0{,}8}{q'}\cos\beta\,(0{,}75\varepsilon_a + 0{,}25)\ \text{N/mm}\ \mu\text{m}$$

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_γ will be specially considered.

3.4 Tooth loading for surface stress

3.4.1 The Hertzian contact stress, σ_H, at the pitch circle is not to exceed the allowable Hertzian contact stress, σ_{HP}.

$$\sigma_H = Z_H\,Z_E\,Z_\varepsilon\,Z_\beta\sqrt{\frac{F_t\,(u+1)}{d_1\,b\,u}\,K_A\,K_\gamma\,K_v\,K_{H\beta}\,K_{H\alpha}} \text{ and}$$

$$\sigma_{HP} = \frac{\sigma_{H\,lim}\,Z_R\,Z_V\,Z_X}{S_{H\,min}} \text{ for the pinion/wheel combination}$$

where

$$Z_H = \sqrt{\frac{2\cos\beta_b\cos\alpha_{tw}}{\cos^2\alpha_t\,\sin\alpha_{tw}}}$$

$Z_E = 189{,}8$ 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

$\sigma_{H\,lim}$, *see* Table 5.3.3

$S_{H\,lim}$, *see* Table 5.3.4.

Table 5.3.2 Values of Z_x

Pinion heat treatment		Z_x
Carburized and induction-hardened	$m_n \leq 10$ $10 < m_n < 30$ $30 \leq m_n$	1,00 $1{,}05 - 0{,}005m_n$ 0,9
Nitrided	$m_n < 7{,}5$ $7{,}5 < m_n < 30$ $30 \leq m_n$	1,00 $1{,}08 - 0{,}011m_n$ 0,75
Through-hardened	All modules	1,00

Table 5.3.3 Values of endurance limit for Hertzian contact stress, $\sigma_{H\,lim}$

Heat treatment Pinion	Heat treatment Wheel	$\sigma_{H\,lim}$ N/mm^2
Through-hardened	Through-hardened	$0{,}46\sigma_{B2} + 255$
Surface-hardened	Through-hardened	$0{,}42\sigma_{B2} + 415$
Carburized, nitrided or induction-hardened	Soft bath nitrided (Tufftrided)	1000
Carburized, nitrided or induction-hardened	Induction-hardened	$0{,}88\ HV_2 + 675$
Carburized or nitrided	Nitrided	1300
Carburized	Carburized	1500

Table 5.3.4 Factors of safety

	$S_{H\,min}$	$S_{F\,min}$
Main propulsion gears	1,4	1,8
Main propulsion gears for yachts and small craft, single screw	1,25	1,50
Main propulsion gears for yachts and small craft, multiple screw	1,20	1,45
Auxiliary gears	1,15	1,40
NOTE For the purposes of the above, yachts and small craft are considered to be pleasure craft not engaged in trade, passenger carrying or intended for charter service. Small craft are considered to be generally not greater than 24 m in length.		

3.5 Tooth loading for bending stress

3.5.1 The bending stress at the tooth root, σ_F is not to exceed the allowable tooth root bending stress σ_{FP}

$$\sigma_F = \frac{F_t}{b\,m_n} Y_F\, Y_S\, Y_\beta\, K_A\, K_\gamma\, K_v\, K_{F\beta}\, K_{F\alpha} \quad \text{N/mm}^2$$

$$\sigma_{FP} = \frac{\sigma_{F\,lim}\, Y_{ST}\, Y_{\delta\,rel\,T}\, Y_{R\,rel\,T}\, Y_x}{S_{F\,min}\, Y_D} \quad \text{N/mm}^2$$

For values of $S_{F\,min}$, *see* Table 5.3.4
$\sigma_{F\,lim}$, *see* Table 5.3.5
Stress correction factor Y_{ST} = 2.

3.5.2 Tooth form factor, Y_F:

$$Y_F = \frac{6\,\dfrac{h_F}{m_n}\cos\alpha_{F\,en}}{\left(\dfrac{S_{Fn}}{m_n}\right)^2 \cos\alpha_n}$$

where h_F, $\alpha_{F\,en}$ and S_{Fn} are shown in Fig. 5.3.1.

$$\frac{S_{Fn}}{m_n} = z_n \sin\left(\frac{\pi}{3} - \nu\right) + \sqrt{3}\left(\frac{G}{\cos\nu} - \frac{\rho_{ao}}{m_n}\right)$$

where

$$\nu = \frac{2G}{z_n}\tan\nu - H$$

$$G = \frac{\rho_{ao}}{m_n} - \frac{h_{ao}}{m_n} + x$$

$$H = \frac{2}{z_n}\left(\frac{\pi}{2} - \frac{E}{m_n}\right) - \frac{\pi}{3}$$

$$E = \frac{\pi}{4} m_n - h_{ao}\tan\alpha_n + \frac{S_{pr}}{\cos\alpha_n} - (1 - \sin\alpha_n)\,\frac{\rho_{ao}}{\cos\alpha_n}$$

E, h_{ao}, α_n, S_{pr} and ρ_{ao} are shown in Fig. 5.3.2

$$\frac{\rho_F}{m_n} = \frac{\rho_{ao}}{m_n} + \frac{2G^2}{\cos\nu\,(z_n\cos^2\nu - 2G)}$$

$$d_{en} = \frac{2z}{|z|}\left\{\left[\sqrt{\left(\frac{d_{an}}{2}\right)^2 - \left(\frac{d_{bn}}{2}\right)^2} - \frac{\pi d\cos\beta\cos\alpha_n}{|z|}(\varepsilon_{an} - 1)\right]^2 + \left(\frac{d_{bn}}{2}\right)^2\right\}^{1/2}$$

where

$$d_{an} = d_n + d_a - d$$

$$d_n = \frac{d}{\cos^2\beta_b}$$

$$d_{bn} = d_n\cos\alpha_n$$

$$\varepsilon_{an} = \frac{\varepsilon_a}{\cos^2\beta_b}$$

$$\gamma_e = \frac{\dfrac{\pi}{2} + 2x\tan\alpha_n}{z_n} + \text{inv.}\,\alpha_n - \text{inv.}\,\alpha_{en}$$

where

$$\alpha_{en} = \arccos\frac{d_{bn}}{d_{en}}$$

$$\frac{h_F}{m_n} = \frac{1}{2}\left[(\cos\gamma_e - \sin\gamma_e\tan\alpha_{F\,en})\frac{d_{en}}{m_n} - z_n\cos\left(\frac{\pi}{3} - \nu\right) - \frac{G}{\cos\nu} + \frac{\rho_{ao}}{m_n}\right]$$

where

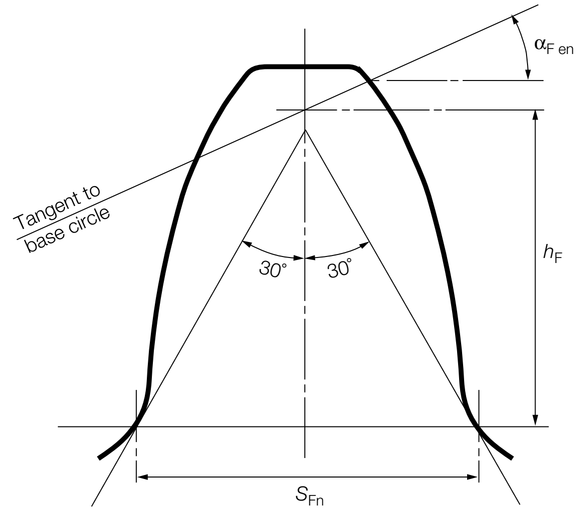
$$\alpha_{F\,en} = \alpha_{en} - \gamma_e.$$

Table 5.3.5 Values of endurance limit for bending stress, $\sigma_{F\,lim}$

Heat treatment	$\sigma_{F\,lim}$ 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 HV + 125
Gas nitrided	390
Carburized A	450
Carburized B	410
NOTES 1. A is applicable for Cr Ni Mo carburizing steels. 2. B is applicable for other carburizing steels.	

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:

$$\frac{S_{Fn2}}{m_n} = 2\left[\frac{\pi}{4} + \tan\alpha\left(\frac{h_{ao2} - \rho_{ao2}}{m_n}\right) + \left(\frac{\rho_{ao2} - S_{pr}}{m_n\cos\alpha_n}\right) - \frac{\rho_{ao2}}{m_n}\cos\frac{\pi}{6}\right], \text{ and}$$



NOTE
For helical gears the normal section is taken with the virtual number of teeth

Fig. 5.3.1 Normal tooth section

$$\frac{h_{F2}}{m_n} = \frac{d_{en2} - d_{fn2}}{2m_n} - \left[\frac{\pi}{4} + \left(\frac{h_{ao2}}{m_n} - \frac{d_{en2} - d_{fn2}}{2m_n}\right)\tan\alpha_n\right]\tan\alpha_n - \frac{\rho_{ao2}}{m_n}\left(1 - \sin\frac{\pi}{6}\right)$$

where $\alpha_{F\ en}$ is taken as being equal to α_n

$$\rho_{F2} = \frac{\rho_{ao2}}{2}$$

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

$$L = \frac{S_{Fn}}{h_F}$$

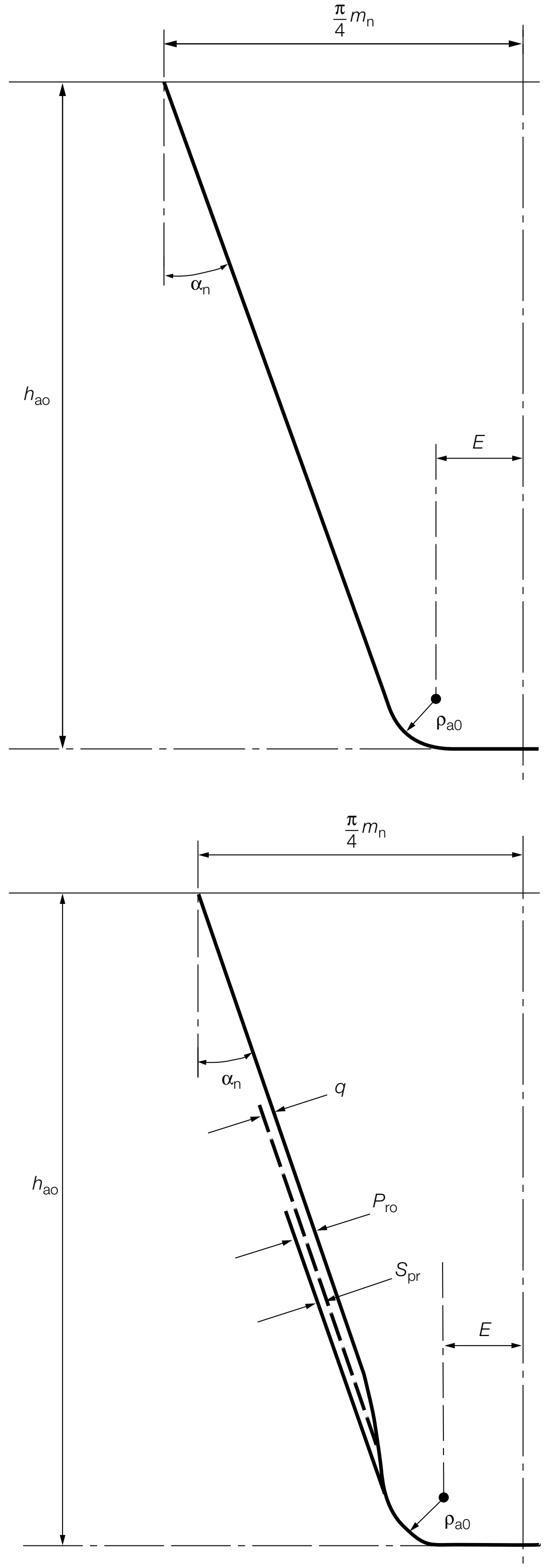
$$q_s = \frac{S_{Fn}}{2\rho_F}$$

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 α_n = 20° but may be used as an approximation for other pressure angles and internal gears.

3.5.5 Helix angle factor Y_β

$$Y_\beta = 1 - \left(\varepsilon_\beta \frac{\beta}{120}\right), \text{ if } \varepsilon_\beta > 1 \text{ let } \varepsilon_\beta = 1$$

but $Y_b \geq 1 - 0{,}25\varepsilon_b \geq 0{,}75$.



NOTES
1. Dimensions shown on rack profile of tooth
2. $S_{pr} = P_{ro} - q$

Fig. 5.3.2 External tooth forms

3.5.6 Relative notch sensitivity factor, $Y_{\delta \text{ rel T}}$

$Y_{\delta \text{ rel T}} = 1 + 0{,}036\,(q_s - 2{,}5)\left(1 - \frac{\sigma_y}{1200}\right)$ for through-hardened steels

$Y_{\delta \text{ rel T}} = 1 + 0{,}008\,(q_s - 2{,}5)$ for carburized and induction-hardened steels, and

$Y_{\delta \text{ rel T}} = 1 + 0{,}04\,(q_s - 2{,}5)$ for nitrided steels.

3.5.7 Relative surface finish factor, $Y_{\text{R rel T}}$

$Y_{\text{R rel T}} = 1{,}674 - 0{,}529\,(6R_a + 1)^{0,1}$ for through-hardened, carburized and induction hardened steels, and

$Y_{\text{R rel T}} = 4{,}299 - 3{,}259\,(6R_a + 1)^{0,005}$ for nitrided steels.

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

$$Y_D = 1 + \frac{0{,}2d_s^2\, d\, P_r\, b}{F_t\, \sigma_{\text{F lim}}\, (d_f^2 - d_s^2)}, \text{ otherwise}$$

$Y_D = 1{,}00$.

3.6 Factors of safety

3.6.1 Factors of safety are shown in Table 5.3.4.

■ *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.

4.3.3 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.

4.3.4 Gearcases are to be stress relief heat treated on completion of all welding.

4.3.5 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 ≤ 5	40% h_W for 50% *b* and 20% h_W for a further 40% *b*
Q ≥ 6	40% h_W for 35% *b* and 20% h_W for a further 35% *b*

NOTES
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 ≤ 5	70% h_W for 60% *b* and 50% h_W for a further 30% *b*
Q ≥ 6	60% h_W for 45% *b* and 40% h_W for a further 35% *b*

NOTES
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 Alignment

5.3.1 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.

5.3.2 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.

5.3.3 Further requirements are given in Ch 8,5.

Cross-reference

For lubricating oil systems, *see* Chapter 14.

■ *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^2 (41 to 77,5 kgf/mm^2). *See also* 3.5.1.

(b) Alloy steel – not exceeding 800 N/mm^2 (82 kgf/mm^2).

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^2 (51 kgf/mm^2).

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.

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 0,0125*d*

= 1,10 for shafts with transverse or radial holes where the diameter of the hole (d_h) is not greater than 0,3*d*

= 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)

σ_u = specified minimum tensile strength of the shaft material, in N/mm^2 (kgf/mm^2), *see* 2.1.3

After a length of 0,2*d* from the end of a keyway, transverse hole or radial hole and 0,3*d* 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 0,8*d* and a width of not more than 0,1*d* and a diameter of central hole d_i of not more than 0,8*d*, *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:

$$\text{Diameter of quill shaft} = 101 \sqrt[3]{\frac{P\,400}{R\,\sigma_u}} \text{ mm}$$

$$\left(91 \sqrt[3]{\frac{H\,41}{R\,\sigma_u}} \text{ mm}\right)$$

where *P* (*H*) and *R* are as defined in Ch 1,3.3.

σ_u = specified minimum tensile strength of the material, in N/mm^2 (kgf/mm^2) but is not to exceed 1100 N/mm^2 (112 kgf/mm^2).

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 σ_u is to be taken as the specified minimum tensile strength of the final wheel shaft material, in N/mm^2 (kgf/mm^2).

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, σ_u is to be taken as the minimum tensile strength of the thrust shaft material, in N/mm^2 (kgf/mm^2).

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)

σ_u = specified minimum tensile strength of the shaft material, in N/mm^2 (kgf/mm^2) but is not to be taken as greater than 600 N/mm^2 (61 kgf/mm^2). *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 σ_u taken as 400 N/mm^2 (41 kgf/mm^2).

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.

3.8 Coupling bolts

3.8.1 The diameter of the bolts at the joining faces of the couplings is to be 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
σ_u = specified minimum tensile strength of bolts, in N/mm^2
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 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.

3.9 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 0,75t.

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^2) 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.

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^2

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^2 (41 kgf/mm^2) 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^2). 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^2). 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 weardown, 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. Means for ascertaining the temperature of the oil in the sterntube are also to be provided.

3.12.9 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.

3.12.10 Screwshafts which are grease lubricated are not eligible for the **OG** notation.

3.12.11 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.

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.

Section

■ *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.
(j) 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) θ_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°, 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:

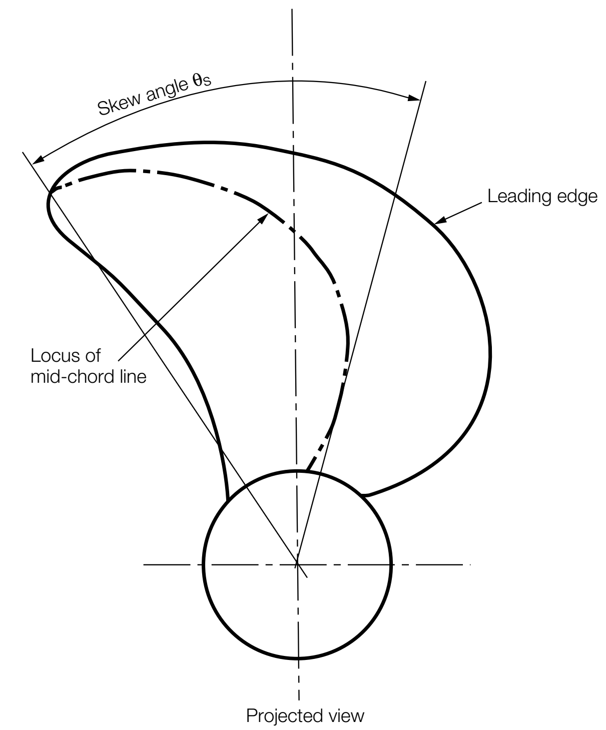


Fig. 7.1.1 Definition of skew angle

(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° 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.

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 Materials (Part 2). 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 contro lable 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 less than 25°, 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 = $L_{0,25}$, $L_{0,35}$, or $L_{0,6}$, as appropriate

$K = \frac{GBD^3R^2}{675}$

G = density, in g/cm^3, *see* Table 7.2.1

U = allowable stress, in N/mm^2 (kgf/mm^2) *see* 3.1.2, 3.1.3, 3.1.4, and Table 7.2.1

$E = \frac{\text{actual face modulus}}{0{,}09T^2 L}$

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^2	*G* Density g/cm^3	*U* Allowable stress N/mm^2	Specified minimum tensile strength kgf/mm^2	*G* Density g/cm^3	*U* Allowable stress kgf/mm^2
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

$C = 1,0$

$F = \dfrac{P_{0,25}}{D} + 0,8$

$M = 1,0 + \dfrac{3,75D}{P_{0,7}} + 2,8\,\dfrac{P_{0,25}}{D}$

for solid propellers at 25 per cent radius

$C = 1,4$

$F = \dfrac{P_{0,35}}{D} + 1,6$

$M = 1,35 + \dfrac{5D}{P_{0,7}} + 2,6\,\dfrac{P_{0,35}}{D}$

for controllable pitch propellers at 35 per cent radius

$C = 1,6$

$F = \dfrac{P_{0,6}}{D} + 4,5$

$M = 1,35 + \dfrac{5D}{P_{0,7}} + 1,35\,\dfrac{P_{0,6}}{D}$

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 $\left(\dfrac{r}{T}\right)^{0,2}$

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 25° or greater, 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

θ_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^2

A_2 = contact area of fitting at outside of sleeve, in mm^2

$$B_1 = \frac{1}{E_2}\left(\frac{k_1^2 + 1}{k_1^2 - 1} + \nu_2\right) + \frac{1}{E_1}\left(\frac{1 + l^2}{1 - l^2} - \nu_1\right)$$

$$B_2 = \frac{1}{E_3}\left(\frac{k_2^2+1}{k_2^2-1}+\nu_3\right)+\frac{1}{E_2}\left(\frac{k_1^2+1}{k_1^2-1}-\nu_2\right)$$

$$B_3 = \frac{1}{E_3}\left(\frac{k_3^2+1}{k_3^2-1}+\nu_3\right)+\frac{1}{E_1}\left(\frac{1+l^2}{1-l^2}-\nu_1\right)$$

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^2 (kgf/mm^2)

E_2 = modulus of elasticity of sleeve material, in N/mm^2 (kgf/mm^2)

E_3 = modulus of elasticity of propeller material, in N/mm^2 (kgf/mm^2)

$$F_1 = \frac{2Q}{d_1}(1+C)$$

$$F_2 = \frac{2Q}{d_2}(1+C)$$

$$F_{10} = \frac{2Q}{d_1}\left(1+C+\frac{I_f}{100}\right)$$

$$F_{20} = \frac{2Q}{d_2}\left(1+C+\frac{I_f}{100}\right)$$

I_f = percentage increase for Ice Class 1D, obtained from Ch 9,3.2.1

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

$$V_1 = 0{,}51\left(\frac{\mu_1}{\theta_1}\right)^2 - 1$$

$$V_2 = 0{,}51\left(\frac{\mu_2}{\theta_2}\right)^2 - 1$$

$Y = B_1 B_2 - h^2 k_1^2$

α_1 = coefficient of linear expansion of screwshaft material, in mm/mm/°C

α_2 = coefficient of linear expansion of sleeve material, in mm/mm/°C

α_3 = coefficient of linear expansion of propeller material, in mm/mm/°C

θ_1 = taper of the screwshaft cone, but is not to exceed $\frac{1}{15}$ on the diameter, i.e. $\theta_1 \leq \frac{1}{15}$

θ_2 = taper of the outside of the sleeve

μ_1 = coefficient of friction for fitting of boss assembly on shaft

= 0,13 for oil injection method of fitting

μ_2 = coefficient of friction for fitting sleeve into the boss

ν_1 = Poisson's ratio for screwshaft material

ν_2 = Poisson's ratio for sleeve material

ν_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, δ on the screwshaft is to be not less than:

$$\delta_T = \frac{d_1}{\theta_1}\left(p_1 B_3 + (\alpha_3-\alpha_1)(35-T_1)\right) \text{ mm}$$

or, where Ice Class notation is required, the greater of δ_T or δ_O, where

$$\delta_O = \frac{d_1}{\theta_1}\left(p_{10} B_3 - (\alpha_3-\alpha_1)\,T_1\right) \text{ mm}$$

The yield stress or 0,2 per cent proof stress, σ_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

δ_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:

$$W = A_1\left(0{,}002+\frac{\theta_1}{20}\right)\left(p_1+\frac{18}{B_3}(\alpha_3-\alpha_1)\right) \text{ N (kgf)}$$

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:

$$W_{2T} = \frac{A_2}{B_2}\left(\mu_2+\frac{\theta_2}{2}\right)\left(B_2 p_2 - hp_1 + (\alpha_3-\alpha_2)(35-T_2)\right) \text{ N (kgf)}$$

or, where Ice Class notation is required, the greater of W_{2T} or W_{20}

where

$$W_{20} = \frac{A_2}{B_2}\left(\mu_2+\frac{\theta_2}{2}\right)\left(B_2 p_{20} - hp_{10} - (\alpha_3-\alpha_2)\,T_2\right) \text{ N (kgf)}$$

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:

$$W_{1T} = A_1\left(\mu_1+\frac{\theta_1}{2}\right)\left(p_1+\frac{hk_1^2}{Y}(\alpha_3-\alpha_2)(35-T_1)\right) \text{ N (kgf)}$$

or where Ice Class notation is required, the greater of W_{1T} or W_{10} where

$$W_{10} = A_1\left(\mu_1+\frac{\theta_1}{2}\right)\left(p_{10}-\frac{hk_1^2}{Y}(\alpha_3-\alpha_2)T_1\right) \text{ N (kgf)}$$

The push-up distance of the combined boss and sleeve on a steel screwshaft is to be in accordance with the following formula:

$$\delta_1 = \frac{W_1 d_1 Y}{A_1 B_2 \theta_1\left(\mu_1+\frac{\theta_1}{2}\right)} \text{ mm}$$

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:

$$W_2 = A_2 \left(0{,}25 + \frac{\theta_2}{2}\right)\left(p_A + \frac{(\alpha_3 - \alpha_2)(18 - T_2)}{B_2}\right) \text{ N (kgf)}$$

where

p_A = 3,5 N/mm^2
(p_A = 0,35 kgf/mm^2)

3.2.5 For the triple element keyless propeller, the yield stress or 0,2 per cent proof stress of the propeller material, σ_o is to be not less than:

$$\sigma_o = 1{,}4 p_3 \sqrt{\frac{3k_2^4 + 1}{k_2^2 - 1}} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

where

$$p_3 = \frac{W_1\, h}{A_1\, B_2 \left(\mu_1 + \frac{\theta_1}{2}\right)} + \frac{W_2}{A_2 \left(\mu_2 + \frac{\theta_2}{2}\right)} + \frac{\alpha_3 - \alpha_2}{B_2}\left(T_2 + \frac{h^2\, k_1^2}{Y}\, T_1\right)$$

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, σ_o is to be not less than:

$$\sigma_o = \frac{1{,}6}{k_1^2 - 1}\sqrt{3k_1^4 (p_3 - p_5)^2 + (p_3\, k_1^2 - p_5)^2} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

or

$$\sigma_o = \frac{1{,}6}{k_1^2 - 1}\sqrt{3k_1^4 (p_4 - p_6)^2 + (p_4\, k_1^2 - p_6)^2} \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

where

$$p_4 = p_3 - \frac{35B_1}{Y}(\alpha_3 - \alpha_2)$$

$$p_5 = \frac{W_1}{A_1 \left(\mu_1 + \frac{\theta_1}{2}\right)} + \frac{h\, k_1^2}{Y}(\alpha_3 - \alpha_2)\, T_1$$

$$p_6 = p_5 - \frac{35h\, k_1^2}{Y}(\alpha_3 - \alpha_2)$$

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 σ_u, based on the ruling section, is to be not less than:

$$\sigma_u = \frac{2{,}4}{k_1^2 - 1}\left(p_5\left(\frac{5k_1^2 + 3}{4}\right) - 2p_3\, k_1^2\right) \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

or

$$\sigma_u = \frac{2{,}4}{k_1^2 - 1}\left(p_6\left(\frac{5k_1^2 + 3}{4}\right) - 2p_4\, k_1^2\right) \text{ N/mm}^2 \text{ (kgf/mm}^2\text{)}$$

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 equalize 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 minimize stress raising effects.

4.3.3 The outside of the propeller boss is to be hard stamped with the following details:

(a) For the oil injection method of fitting, the start point load and the axial pull-up at 0°C and 35°C.
(b) 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

■ *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 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.

1.2 Resilient mountings

1.2.1 For resilient mountings, *see* Ch 1,4.3.

■ *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 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.

2.2.4 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.

2.2.5 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.

2.2.6 Details of vibration or performance monitoring proposals where required.

2.3 Scope of calculations

2.3.1 Calculations are to be carried out, by recognized 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 (on request, Lloyd's Register (hereinafter referred to as 'LR') can provide a table of generalized harmonic torque components for use where appropriate). 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
- 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
- σ_u = specified minimum tensile strength of the shaft material, in N/mm^2
- τ_c = permissible stress due to torsional vibrations for continuous operation, in N/mm^2
- τ_t = permissible stress due to torsional vibrations for transient operation, in N/mm^2
- e = slot width, in mm
- l = slot length, in mm.

Table 8.2.1 C_k factors

Intermediate shafts with	
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)
Thrust shafts external to engines	
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
Propeller shafts	
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
NOTE The determination of C_k – factors for shafts other than shown in this Table will be specially considered by LR.	

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).

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:

$$scf = \alpha_{t(hole)} + 0{,}57 \frac{\frac{(l - e)}{d}}{\sqrt{\left(1 - \frac{d_i}{d}\right)\frac{e}{d}}}$$

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 sea-water. 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 τ_c for continuous operation, and τ_t for transient running, given by the following formulae:

$$\tau_c = \frac{\sigma_u + 160}{18} C_k C_d \left(3 - 2r^2\right) \text{ for } r < 0,9 \quad \text{N/mm}^2$$

$$\tau_c = \frac{\sigma_u + 160}{18} C_k C_d \, 1,38 \text{ for } 0,9 \leq r \leq 1,05 \quad \text{N/mm}^2$$

$$\tau_t = \pm\, 1,7\tau_c \frac{1}{\sqrt{C_k}} \text{ for } r \leq 0,8 \quad \text{N/mm}^2$$

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, σ_u is not to be taken as more than 800 N/mm^2 in the case of alloy steel intermediate shafts, or 600 N/mm^2 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 $0,95N_s$ and $1,05N_s$ the vibration stresses in the transmission shafting are not to exceed the values given by the following formula:

$$\tau_c = \pm\,(21 - 0,014d) \quad \text{N/mm}^2.$$

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 $0,95N_s$ to $1,05N_s$. Below $0,95N_s$ 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 $0,95N_s$ to $1,05N_s$, 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 ±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 $0,95N_s$ to $1,10N_s$.

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 $0,85N_s$ and $1,05N_s$ 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.

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, τ_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 τ_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 τ_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 τ_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 τ_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, τ_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.

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 ± 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:

$$\frac{0{,}98}{N}\left(\frac{ab}{a+b}\right)^{1/2} \quad \text{rev/min}$$

where

$a = \dfrac{E}{G\,l^2}\,(66{,}2 + 97{,}5A - 8{,}88A^2)^2 \quad (\text{c/min})^2$

$b = 91{,}2\,\dfrac{k}{M_e} \quad (\text{c/min})^2$

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
= $0{,}785\,(D^2 - d^2)\,G\,l$
$A = \dfrac{m}{M}$
D = outside diameter of shaft, taken as an average over length l, in mm
E = modulus of elasticity of shaft material, in N/mm^2
G = density of shaft material, in kg/mm^3
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.

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 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 ± 20 per cent of the M.C.R. speed, measurements using an appropriate recognized 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 The Builder is to carry out shaft alignment calculations for all installations and to prepare alignment procedures detailing the proposed alignment method and the alignment checks to demonstrate compliance with requirements of this section.

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 where the screwshaft has a diameter of 250 mm or greater in way of the aftermost sterntube bearing:

(a) All geared installations.
(b) Installations with one shaftline bearing, or less, inboard of the sterntube bearing/seal.
(c) Where prime movers or shaftline bearings are installed on resilient mountings.

5.2.2 The shaft alignment calculations are to take into account the:

(a) thermal displacements of the bearings between cold static and hot dynamic machinery conditions;
(b) buoyancy effect of the propeller immersion due to the ship's operating draughts;
(c) effect of predicted hull deformations over the range of the ship's operating draughts, where known;
(d) effect of filling the aft peak ballast tank upon the bearing loads, where known;
(e) gear forces, where appropriate, due to prime-mover engagement on multiple-input single-output installations;
(f) propeller offset thrust effects;
(g) maximum allowed bearing weardown, for water or grease-lubricated sterntube 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 sterntube 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 weardown rates for water or grease-lubricated sterntube 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 Particulars to be submitted for review – shaft alignment procedure

5.3.1 A shaft alignment procedure is to be submitted for all main propulsion installations detailing, as a minimum, 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) 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 sterntube bearing;
(g) details of slope-bore of the aftermost sterntube 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 minimize 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 sterntube bearing is, in general, not to exceed 3×10^{-4} rad in the static condition.
(c) Sterntube 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 ovalilty and straightness, circumferentially and longitudinally, after installation.
(f) The sterntube 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.

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.

■ *Section 1* General

1.1 Class notations

1.1.1 For ships where ice class notation **Ice Class 1AS FS, Ice Class 1A FS, Ice Class 1B FS** or **Ice Class 1C FS** is requested, the requirements of this Chapter, as applicable, in addition to the Finnish Swedish Ice Class Rules in force at the time of contract, are to be complied with. Section 2 of this Chapter replaces Section 6 of the Finnish Swedish Ice Class Rules.

1.1.2 Ships strengthened in accordance with the requirements of **Ice Class 1D** are not intended for operation in the northern part of the Baltic in the winter season. For ships where **Ice Class 1D** is requested, the requirements of Section 3 are to be complied with.

1.1.3 Offshore supply ships strengthened in accordance with the requirements of Ice Class **1E** are only intended for navigation in very light first-year ice conditions. The requirements of Section 3 are to be complied with.

1.1.4 For ships where the ice class notation **Ice Class 1AS FS(+), Ice Class 1A FS(+), Ice Class 1B FS(+)** or **Ice Class 1C FS(+)** is requested, the requirements of Sections 2 and 4 of this Chapter, in addition to the Finnish Swedish Ice Class Rules, in force at the time of contract, are to be complied with. The Finnish Swedish Ice Class Rules may be obtained from the following website:

www.fma.fi

1.2 Materials for shafting

1.2.1 All components of the main propulsion system are to be of steel or other approved ductile material.

1.2.2 For screwshafts in ships intended for the notation **Ice Class 1AS FS** or **Ice Class 1A FS** and where the connection between the propeller and the screwshaft is by means of a key, Charpy impact tests are to be made in accordance with the requirements of Ch 5,3.4.12 of the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

1.3 Materials for propellers

1.3.1 Propellers and propeller blades are to be of cast steel or copper alloys and are to be manufactured, tested and certified in accordance with Ch 4,1, Ch 4,5 and Ch 9,1 of the Rules for Materials respectively.

1.3.2 For steel propellers, the elongation of the material used is to be not less than 19 per cent for a test piece length of 5*d*. Charpy impact tests are to be carried out in accordance with the requirements of the Rules for Materials.

1.3.3 Cast steel load transmitting components of controllable pitch mechanisms are to be manufactured, tested and certified in accordance with the requirements of Ch 4,5 of the Rules for Materials.

1.3.4 Forged steel load transmitting components of controllable pitch propellers are to be manufactured, tested, and certified in accordance with Ch 5,1 and Ch 5,2 of the Rules for Materials. Impact tests are to be carried out at minus 10°C and the average energy value is to be not less than 27J.

1.3.5 Spheroidal cast iron load transmitting-components of controllable-pitch mechanisms are to be manufactured, tested and certified in accordance with the requirements of Table 7.3.2 in Ch 7,3 of the Rules for Materials.

■ *Section 2* Ice Classes 1AS FS, 1A FS, 1B FS and 1C FS

2.1 General

2.1.1 Where the notation **Ice Class 1AS FS**, **Ice Class 1A FS**, **Ice Class 1B FS** or **Ice Class 1C FS** is desired, the requirements of this Section, in addition to those for open water service, are to be complied with, so far as these are applicable.

2.2 Determination of ice torque

2.2.1 Dimensions of propellers, shafting and gearing are determined by formulae taking into account the impact when a propeller blade hits ice. The ensuing load is hereinafter defined by ice torque, M.

$M = m D^2$ kN m (tonne-f m)

where

m = 21,10 (2,15) for **Ice Class 1AS FS**
= 15,69 (1,60) for **Ice Class 1A FS**
= 13,04 (1,33) for **Ice Class 1B FS**
= 11,96 (1,22) for **Ice Class 1C FS**

D = diameter of propeller, in metres.

2.2.2 If the propeller is not fully submerged when the ship is in ballast condition, the ice torque for **Ice Class 1A FS** is to be used for **Ice Class 1B FS** and **Ice Class 1C FS**.

2.3 Propeller blade sections

2.3.1 The width, *L*, and thickness, *T*, of propeller blade sections are to be determined so that:

(a) at the radius 0,25*D*/2, for solid propellers

$$LT^2 \geq \frac{26\,478\,000}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(27{,}2\,\frac{P}{NR} + 2{,}24M\right)$$

$$\left(LT^2 \geq \frac{2\,700\,000}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(20\,\frac{H}{NR} + 22M\right)\right)$$

(b) at radius 0,35*D*/2 for controllable pitch propellers

$$LT^2 \geq \frac{21\,084\,300}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(27{,}2\,\frac{P}{NR} + 2{,}35M\right)$$

$$\left(LT^2 \geq \frac{2\,150\,000}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(20\,\frac{H}{NR} + 23M\right)\right)$$

(c) at the radius 0,6*D*/2

$$LT^2 \geq \frac{9\,316\,320}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(27{,}2\,\frac{P}{NR} + 2{,}86M\right)$$

$$\left(LT^2 \geq \frac{950\,000}{\sigma_u\,(0{,}65 + 0{,}7p_r/D)}\left(20\,\frac{H}{NR} + 28M\right)\right)$$

where

D = diameter of propeller, in metres
L = length of the expanded cylindrical section of the blade, at the radius in question, in mm
M = ice torque as defined in 2.2
N = number of blades
p_r = propeller pitch at the radius in question, for solid propellers, in metres
= 0,7 nominal pitch for controllable pitch propellers, in metres
$P(H)$ = shaft power as defined in Ch 1,3.3
R = propeller speed, in rev/min
T = the corresponding maximum blade thickness, in mm
σ_u = specified minimum tensile strength of the material, in N/mm^2 (kgf/mm^2).

2.3.2 Where the blade thickness derived from these formulae is less than the blade thickness derived by Ch 7,3.1 the latter is to apply.

2.4 Propeller blade minimum tip thickness

2.4.1 The blade tip thickness, *t*, at the radius *D*/2 is to be determined by the following formulae:

Ice Class 1AS FS

$$t = (20 + 2D)\sqrt{\frac{490}{\sigma_u}} \text{ mm}$$

$$\left(t = (20 + 2D)\sqrt{\frac{50}{\sigma_u}} \text{ mm}\right)$$

Ice Classes 1A FS, **1B FS** and **1C FS**

$$t = (15 + 2D)\sqrt{\frac{490}{\sigma_u}} \text{ mm}$$

$$\left(t = (15 + 2D)\sqrt{\frac{50}{\sigma_u}} \text{ mm}\right)$$

where D and σ_u are as defined in 2.3.

2.5 Intermediate blade sections

2.5.1 The thickness of other sections is to conform to a smooth curve connecting the section thicknesses as determined by 2.3 and 2.4.

2.6 Blade edge thickness

2.6.1 The thickness of blade edges is to be not less than 50 per cent of the derived tip thickness, *t*, measured at 1,25*t* from edge. For controllable pitch propellers this applies only to the leading edge.

2.7 Mechanisms for controllable pitch propellers

2.7.1 The strength of mechanisms in the boss of a controllable pitch propeller is to be 1,5 times that of the blade when a load is applied at the radius 0,9*D*/2 in the weakest direction of the blade.

2.8 Keyless propellers

2.8.1 When it is proposed to use keyless propellers, the fit of the propeller boss to the screwshaft will be specially considered.

2.9 Screwshafts

2.9.1 The diameter d_s at the aft bearing of the screwshaft fitted in conjunction with a solid propeller is to be not less than:

$$d_s = 1{,}08\sqrt[3]{\frac{\sigma_u\,LT^2}{\sigma_o}} \text{ mm}$$

where

L and T = proposed width and thickness respectively of the propeller blade section at 0,25*D*/2, in mm
σ_o = specified minimum yield stress of the material of the screwshaft, in N/mm^2 (kgf/mm^2)
σ_u = specified minimum tensile strength of the blade material, in N/mm^2 (kgf/mm^2).

2.9.2 The diameter, d_s at the aft bearing of the screwshaft fitted in conjunction with a controllable pitch propeller is to be not less than:

$$d_s = 1{,}15\sqrt[3]{\frac{\sigma_u\,LT^2}{\sigma_o}} \text{ mm}$$

where

L and T = proposed width and thickness respectively of the propeller blade section at 0,35*D*/2, in mm

σ_o = specified minimum yield stress of the material of the screwshaft, in N/mm^2 (kgf/mm^2)
σ_u = specified minimum tensile strength of the blade material, in N/mm^2 (kgf/mm^2).

2.9.3 Where the screwshaft diameter as derived by 2.9.1 or 2.9.2 is less than the diameter derived by Ch 6,3.5.1, the latter is to apply.

2.9.4 The shaft may be tapered at the forward end in accordance with Ch 6,3.5.4.

2.10 Intermediate and thrust shafts

2.10.1 The diameters of intermediate shafts and thrust shafts in external bearings are to comply with Ch 6,3.1 and Ch 6,3.4 respectively, except for **Ice Class 1AS FS** ice strengthening where these diameters are to be increased by 10 per cent.

2.11 Reduction gearing

2.11.1 Where gearing is fitted between the engine and the propeller shafting, the gearing is to be in accordance with Chapter 5, and is to be designed to transmit a torque, Y_i, determined by the following formula:

$$Y_i = Y + \frac{M\, I_h\, u^2}{I_l + I_h\, u^2} \quad \text{kN m (tonne-f m)}$$

where

u = gear ratio = $\dfrac{\text{pinion speed}}{\text{wheel speed}}$

I_h = mass moment of inertia of machinery components rotating at higher speed
I_l = mass moment of inertia of machinery components rotating at lower speed, including propeller with an addition of 30 per cent of entrained water
(I_h and I_l are to be expressed in the same units)
M = ice torque as defined in 2.2

$$Y = 9{,}55\,\frac{P}{R}$$

$$\left(Y = 0{,}716\,\frac{H}{R}\right)$$

P (*H*) and *R* are as defined in 2.3.

2.12 Fire pumps in motor ships

2.12.1 In motor ships where clearing steam is not available, fire pumps are to be provided with suctions from the cooling water inlet chest.

Section 3
Ice Class 1D and 1E

3.1 General

3.1.1 Where the notation Ice Class **1D** or Ice Class **1E** is desired, the requirements of this Section, in addition to those for open water service, are to be complied with.

3.1.2 For Ice Class **1D** or Ice Class **1E**, the total engine output is to be not less than determined by the following formula:

$$P = 0{,}72LB \text{ kW}$$
$$(H = 0{,}98LB) \text{ Hp}$$

where
L = Rule length, in metres, *see* Pt 3, Ch 1,6.1.1
B = moulded breadth of ship, in metres, *see* Pt 3, Ch 1,6.1.3

3.2 Main engine shafting, gearing and propellers

3.2.1 The diameters of the shafting and propeller blade thickness as required by the Rules for open water service are to be increased by the following percentages. No increase in the diameter of crankshafts, thrustshafts or intermediate shafts is required.

Screwshaft, increase in diameter as required by Ch 6,3.5	5%
Propeller, increase in blade thickness at root and at 60 per cent radius as required by Ch 7,3.1	8%
Keyless propeller fitting, increase in mean torque *Q* as defined in Ch 7,3.2.	15%

3.2.2 The screwshaft may be tapered at the forward end in accordance with Ch 6,3.5.4.

3.3 Minimum propeller blade tip thickness

3.3.1 The tip thickness, *t*, of the blade at 95 per cent radius is to be not less than that obtained by the following formula:

$$t = 0{,}14\,(T + 57\,\sqrt[3]{\frac{430}{\sigma_u}} \text{ mm}$$

$$\left(t = 0{,}14\,(T + 57)\,\sqrt[3]{\frac{44}{\sigma_u}} \text{ mm}\right)$$

where
T = blade root thickness required by 3.2.1, in mm
σ_u = specified minimum tensile strength of material, in N/mm^2 (kgf/ mm^2).

3.4 Blade edge thickness

3.4.1 The edges of the blades are to be suitably thickened for the operating conditions but are to be not less than 50 per cent of the required tip thickness, *t*, measured at 1,25 times tip thickness, *t*, from the edge. For controllable pitch propellers, this requirement need only be applied to the leading edges of the blades.

3.5 Ship-side valves

3.5.1 The sea inlet and overboard discharge valves which are situated at or below the maximum Load Line, are to be provided with low pressure steam or compressed air connection for clearing purposes, *see* Chapter 13.

3.5.2 When steam is not available for clearing, it is recommended that arrangements be made for supplying water for machinery cooling purposes by circulating from ballast tanks(s) of adequate capacity, preferably situated in the double bottom. Such tank(s) must be used only for storage of water ballast or fresh water.

3.6 Cooling water lines

3.6.1 Connections are to be fitted between the cooling water overboard discharge lines and sea inlets for main and/or auxiliary engine cooling water systems so that warm water may be used to assist in maintaining the suction pipes free from ice.

3.6.2 Where the cooling water inlet valves are fitted to a common water box, the connections from the cooling water discharge lines may be led to the water box in a position as near as possible to the inlet valves.

3.7 Fire pumps in motor ships

3.7.1 In motor ships where clearing steam is not available, fire pumps are to be provided with suctions from the main cooling water inlet pipe.

■ *Section 4* Ice Classes 1AS FS(+), 1A FS(+), 1B FS(+) and 1C FS(+)

4.1 Powering of ice strengthened ships

4.1.1 For ships that require additional strengthening in ice the total shaft power installed is to be calculated using the following sections, but is not to be less than required by the Finnish Swedish Ice Class Rules in force at the time of contract.

4.1.2 Ice strengthened ships which are to be considered to have an icebreaking capability are to be able to develop sufficient thrust to permit continuous mode icebreaking at a speed of at least five knots in ice having a thickness equal to the nominal value for the desired Ice Class and a snow cover of at least 0,3 m.

4.1.3 The shaft power necessary to provide an icebreaking capability can be determined by the equation:

$$P_1 = 0{,}736 C_1 C_2 C_3 C_4 \left[240 B h (1 + h + 0{,}035 v^2) + 70 S_c \sqrt{L}\right]$$

$$\left(H_1 = C_1 C_2 C_3 C_4 \left[240 B h (1 + h + 0{,}035 v^2) + 70 S_c \sqrt{L}\right]\right)$$

where

B = moulded breath of ship, in metres, *see* Pt 3, Ch 1,6.1.3
L = Rule length, in metres, *see* Pt 3, Ch 1,6.1.1.
Δ = displacement, in tonnes, *see* Pt 3, Ch 9,7.2.1
$C_1 = \dfrac{1{,}2B}{\sqrt[3]{\Delta}}$, but is not to be taken as less than 1,0
C_2 = 0,9 if the ship is fitted with a controllable pitch propeller, otherwise 1,0
C_3 = 0,9 if the rake of the stem is 45° or less, otherwise 1,0. The product $C_2 C_3$ is not to be taken as less than 0,85
C_4 = 1,1 if the ship is fitted with a bulbous bow, otherwise 1,0
h = ice thickness
S_c = depth of snow cover
v = ship speed, in knots, when breaking ice of thickness h.

■ *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 pressurized hot water above 120°C.
(c) Heating of pressurized 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).

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.

1.2 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
σ = allowable stress, *see* 1.8, in N/mm^2.

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, σ, 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.

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 economizer 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 pressurized hot water above 120°C or the heating of pressurized 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 Heat treatment, non-destructive examinations and routine tests, where required, for the three classes of fusion welded pressure vessels are indicated in Table 10.1.1. Details are given in Chapter 17.

1.6 Plans

1.6.1 Plans of boilers, superheaters and economizers 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.

Table 10.1.1 Heat treatment, non-destructive examination and testing requirements

Class	Radiographic examination	Heat treatment	Routine weld tests	Hydraulic test
1	Required, *see* Chapter 17	*See* Chapter 17	Required	Required
2/1	Spot required, *see* Chapter 17	*See* Chapter 17	Required	Required
2/2	—	*See* Chapter 17	Required	Required

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 6, Ch 1,3.5 and 3.6.

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.

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^2.

(b) For boiler furnaces, combustion chambers and flanged plates:
400 to 520 N/mm^2.

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^2 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^2.

(b) Low alloy steels:
400 to 500 N/mm^2.

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', σ, is the stress to be used in the formulae for the calculation of scantlings of pressure parts.

1.8.2 The allowable stress, σ, is to be the lowest of the following values:

$$\sigma = \frac{E_t}{1,5} \qquad \sigma = \frac{R_{20}}{2,7} \qquad \sigma = \frac{S_R}{1,5}$$

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.

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.

■ *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 σ 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:

(a) 6,0 mm for cylindrical shell plates.
(b) 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.

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, counterboring or recessing, or the compensating effect of the tube stub. *See* 2.3 and 2.4.
s = pitch of tube holes, in mm.

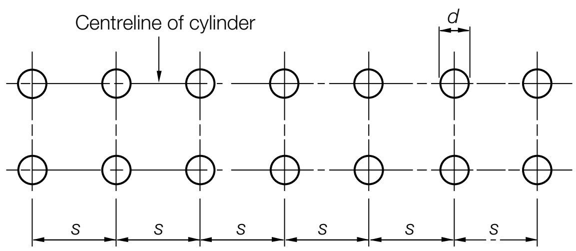


Fig. 10.2.1 Regular drilling

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.

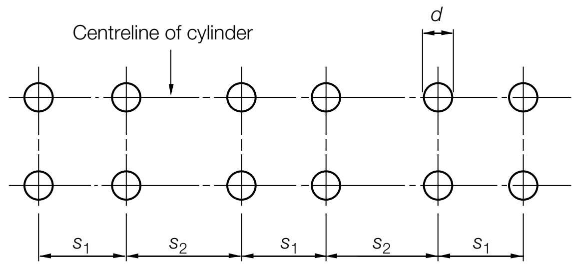


Fig. 10.2.2 Irregular drilling

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.

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.

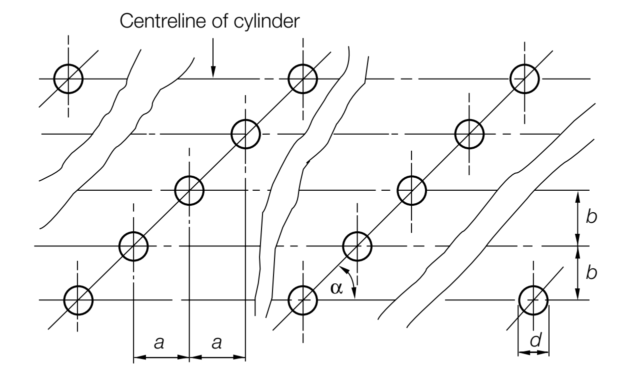


Fig. 10.2.3 Spacing of holes on a diagonal line

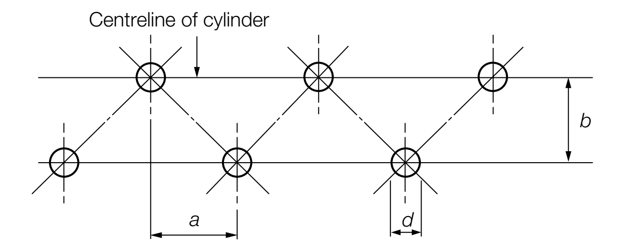


Fig. 10.2.4 Regular saw-tooth pattern of holes

2.2.8 For tube holes on a diagonal line:

$$J = \frac{2}{A + B + \sqrt{(A - B)^2 + 4C^2}}$$

where

$$A = \frac{\cos^2 \alpha + 1}{2\left(1 - \frac{d \cos \alpha}{a}\right)}$$

$$B = 0,5\left(1 - \frac{d \cos \alpha}{a}\right)(\sin^2 \alpha + 1)$$

$$C = \frac{\sin \alpha \cos \alpha}{2\left(1 - \frac{d \cos \alpha}{a}\right)}$$

$$\cos \alpha = \frac{1}{\sqrt{1 + \frac{b^2}{a^2}}}$$

$$\sin \alpha = \frac{1}{\sqrt{1 + \frac{a^2}{b^2}}}$$

α = 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.

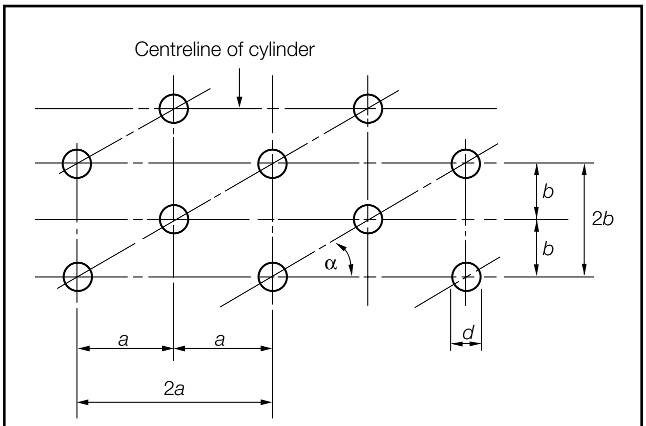


Fig. 10.2.5 Regular staggering of holes

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.

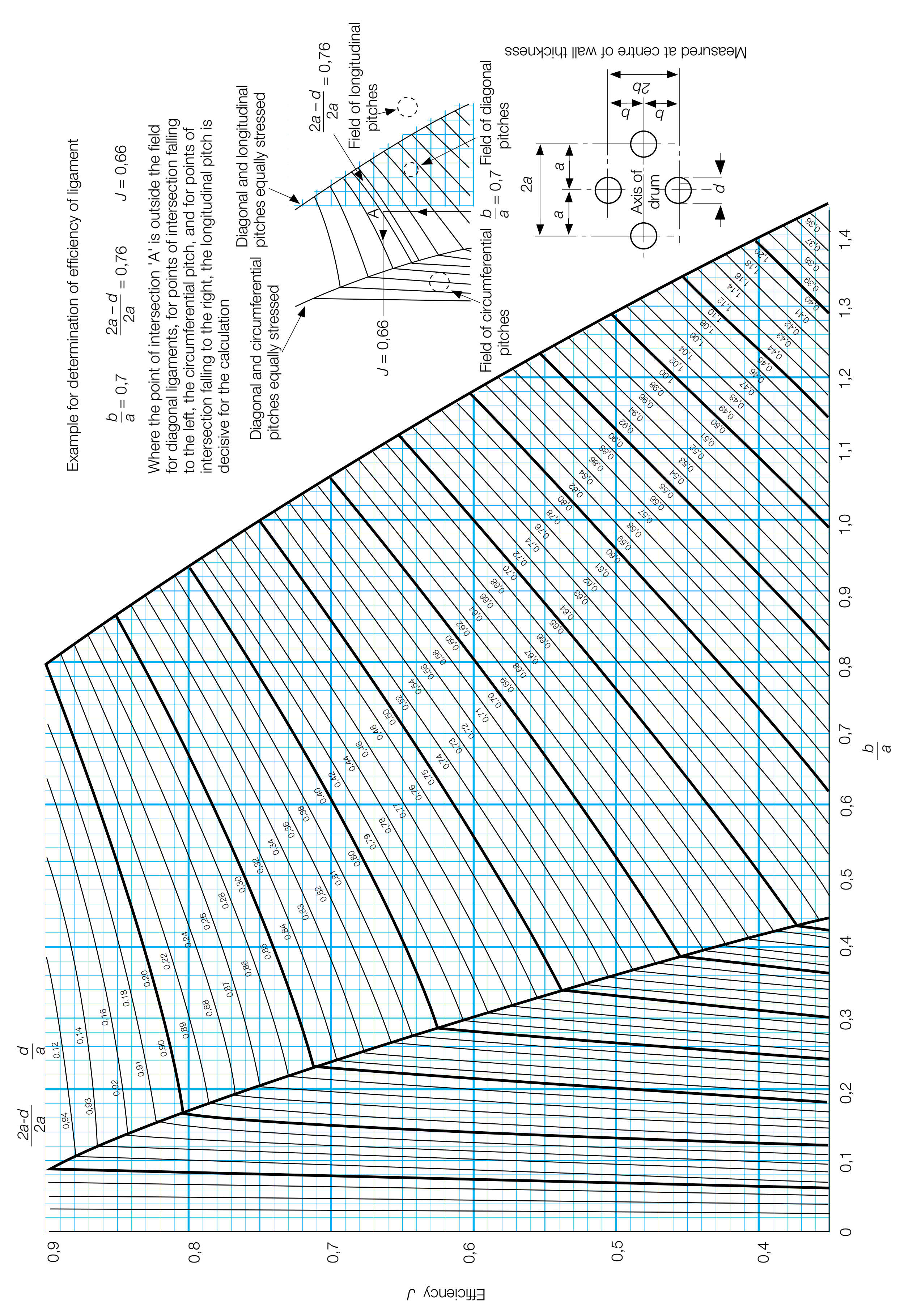


Fig. 10.2.6 Efficiency of ligaments between holes

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

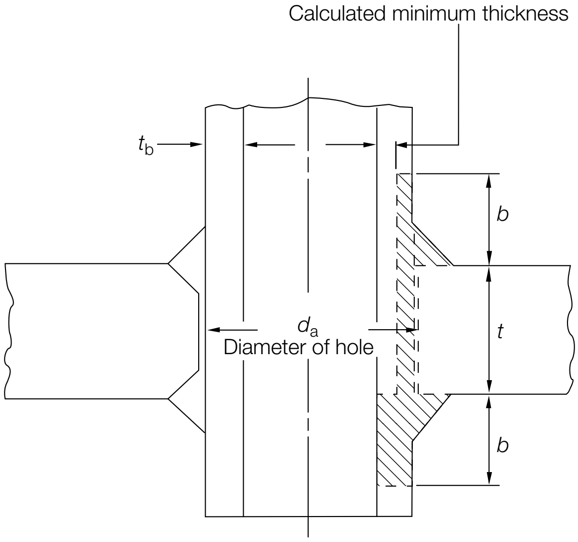
d_e = the equivalent diameter of the hole, in mm
d_a = the actual diameter of the hole, in mm
t = the thickness of the shell, in mm
A = the compensating area provided by each tube stub and its welding fillets, in mm^2.

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;

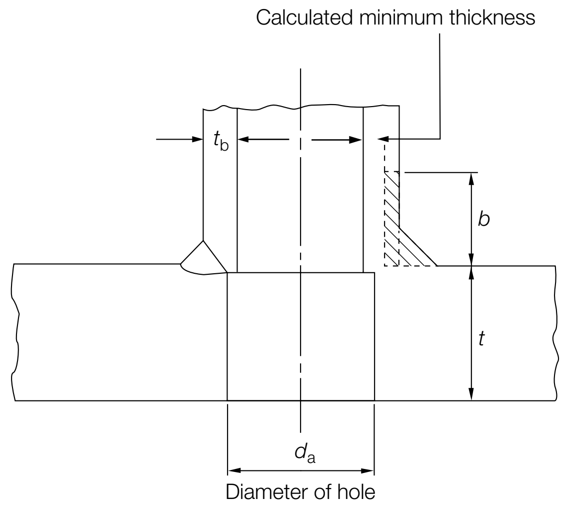
where

$b = \sqrt{d_a t_b}$
t_b = actual thickness of tube stub, in mm.



The area shown hatched is half the area A

Fig. 10.2.7
Compensation of welded tube stubs
The calculated minimum thickness is to satisfy 7.1.



The area shown hatched is half the area A

Fig.10.2.8
Compensation of welded tube stubs
The calculated minimum thickness is to satisfy 7.1.

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:

$$K = \frac{p\,D_o}{18{,}2\,\sigma\,t}$$ but is not to be taken as greater than 0,99

where

p, D_o and σ 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.

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:

$d + 1{,}1\sqrt{D\,t}$ 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 = $\sqrt{d_o\,t_b}$ in mm

D = $\sqrt{D_i\,t_a}$ and is not to exceed $0{,}5d_o$, in mm

σ = shell plate allowable stress, N/mm^2

σ_p = standpipe allowable stress, N/mm^2

σ_r = added reinforcement allowable stress, N/mm^2

σ_w = weld metal allowable stress, N/mm^2

NOTE

σ_p, σ_r and σ_w are not to be taken as greater than σ.

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.

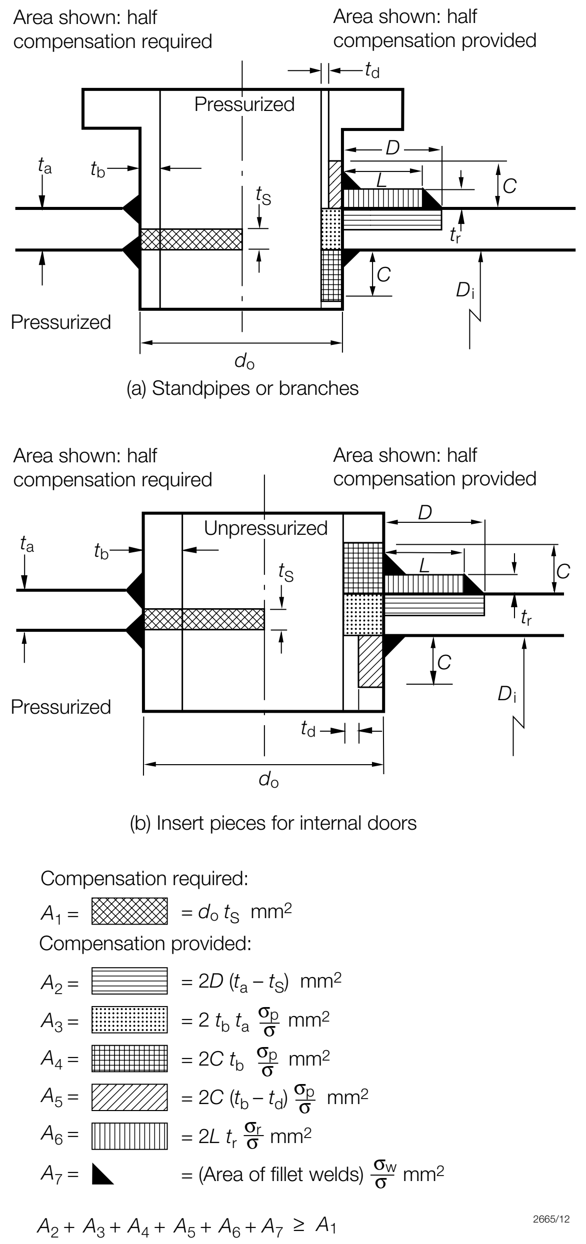


Fig. 10.2.9
Compensation for welded standpipes or branches in cylindrical shells

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, σ 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 hemi-spherical 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, σ 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, σ 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, *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.

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.

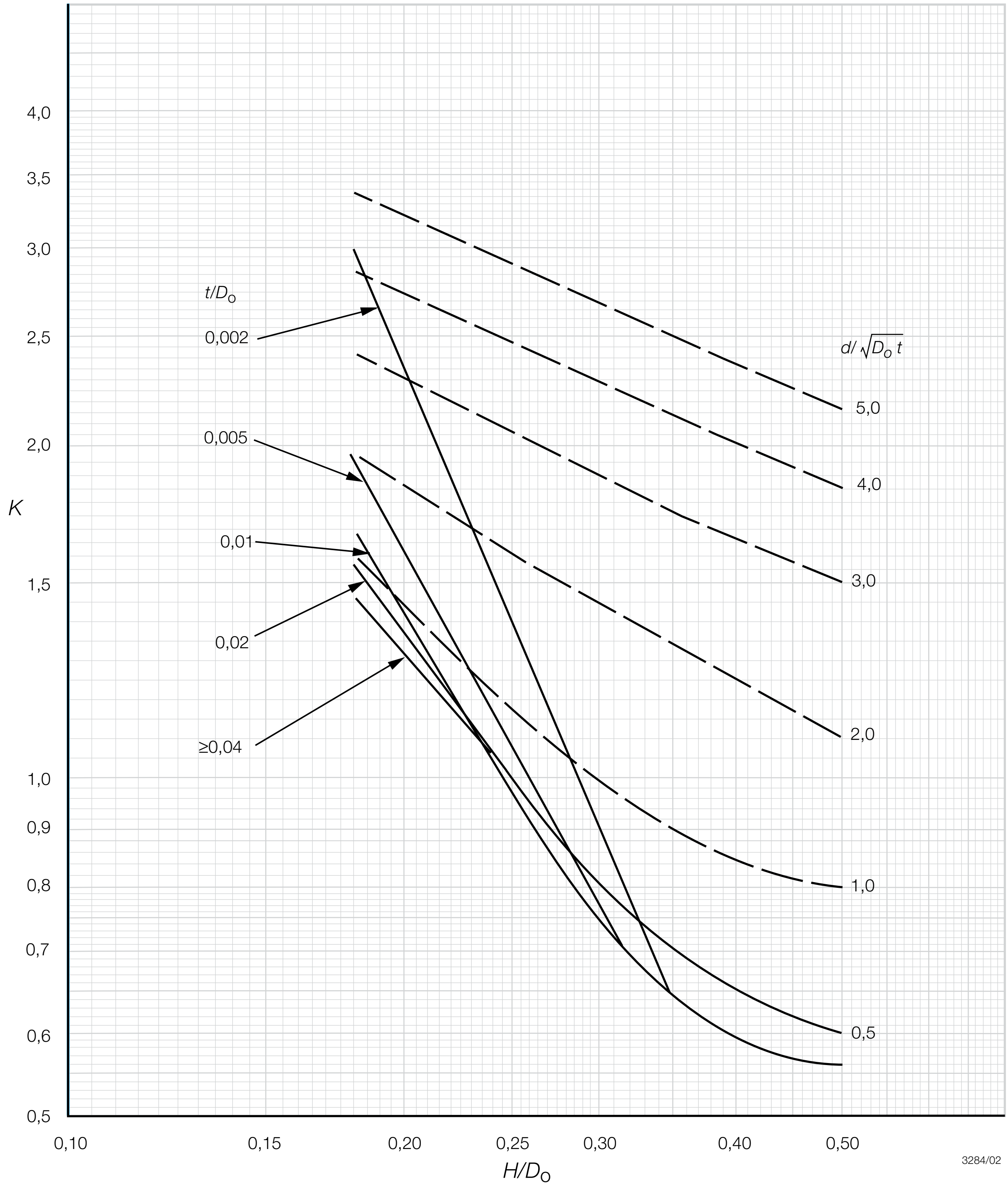


Fig. 10.4.1 Shape factor

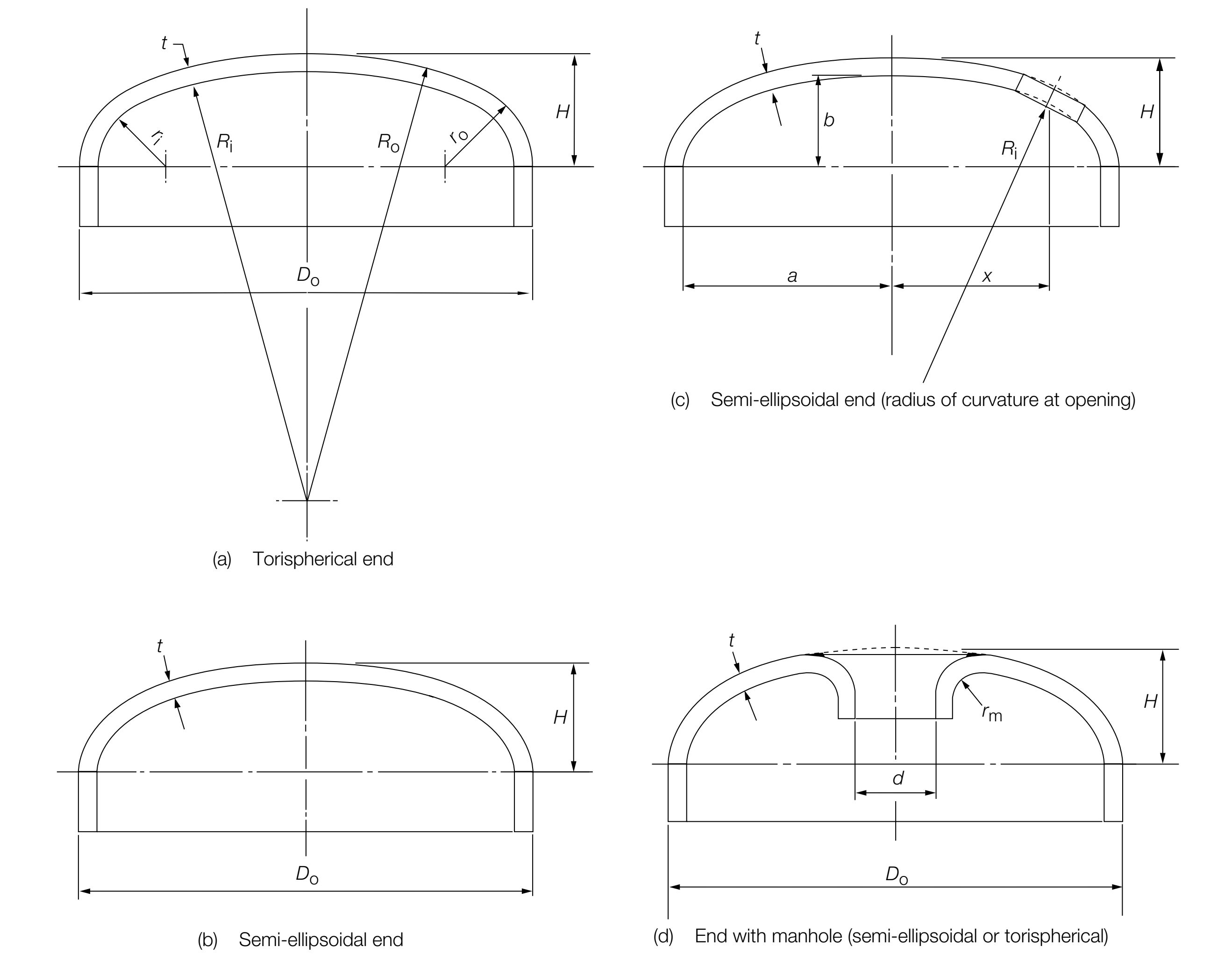


Fig. 10.4.2 Typical dished ends

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.

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.

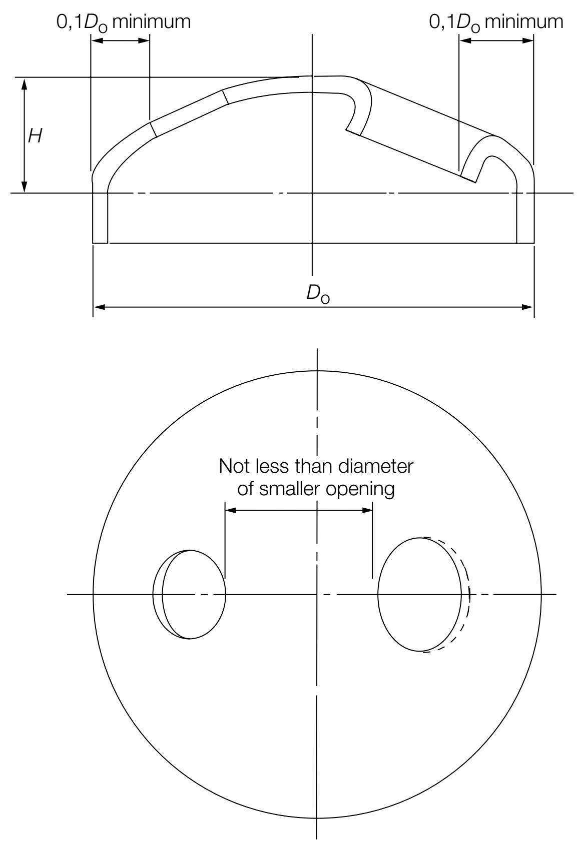


Fig. 10.4.3 Opening in dished ends

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.

4.6.2 Reinforcing material with the following limits may be taken as effective reinforcement:

(a) The effective width, l_1 of reinforcement is not to exceed $\sqrt{2R_i\,t}$ or 0,5d_o whichever is the lesser.

(b) 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:

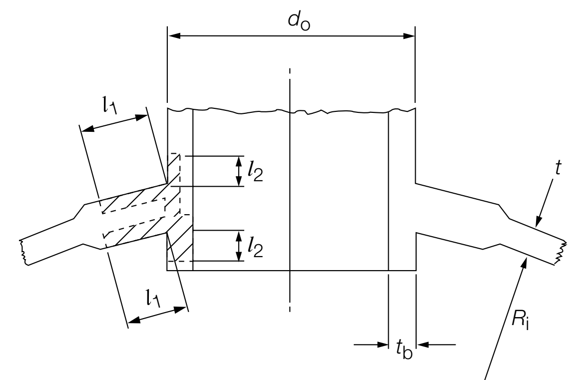
$$\frac{[a^4 - x^2\,(a^2 - b^2)]^{3/2}}{a^4\,b}$$

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.



$l_1 = \sqrt{2R_i t}$ or 0,5d_o whichever is the lesser

l_2 is not to exceed $\sqrt{d_o t_b}$

Fig. 10.4.4 Limits of reinforcement

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:

$$\frac{d_o - \dfrac{A}{t}}{\sqrt{D_o\,t}} \quad \text{instead of from} \quad \frac{d}{\sqrt{D_o\,t}}$$

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
- 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.

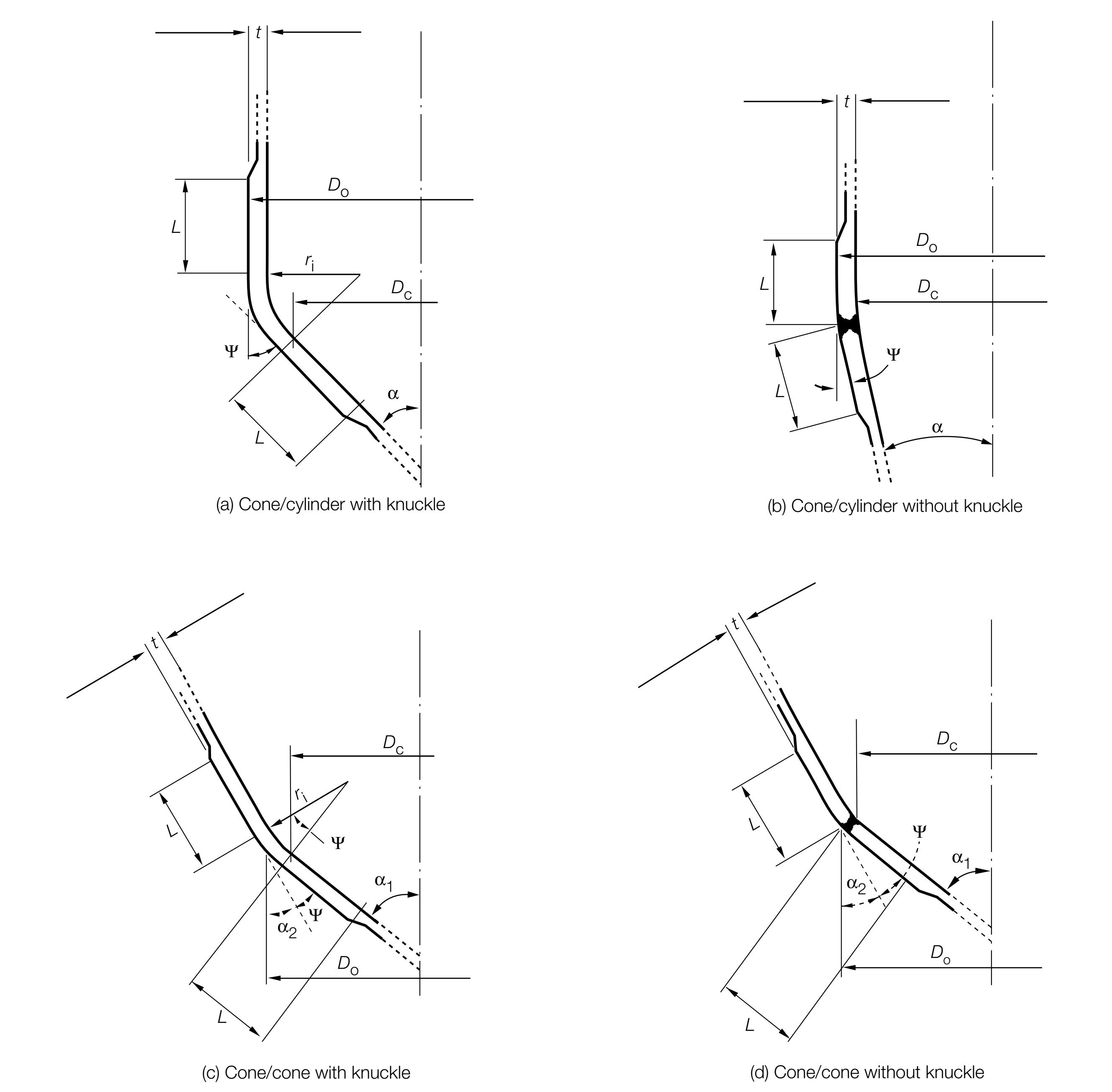


Fig. 10.5.1 Conical ends and conical reducing sections

Table 10.5.1 Values of K as a function of ψ and r_i/D_o

ψ	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

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, ψ, 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, σ 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

$= 0{,}5\sqrt{\dfrac{D_o\,t}{\cos\psi}}$

r_i = inside radius of transition knuckle, in mm, which is to be taken as $0{,}01D_c$ in the case of conical sections without knuckle transition.

ψ = 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.

5.2.5 The thickness of conical sections having an angle of inclination to the vessel axis of more than 75° is to be determined as for a flat plate.

■ 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 σ 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 minimized.

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 economizer 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 σ 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
≤ 38	1,75
> 38 > 50	2,16
≤ 50 ≤ 70	2,40
> 70 ≤ 75	2,67
> 75 ≤ 95	3,05
> 95 ≤ 100	3,28
> 100 ≤ 125	3,50

7.1.2 The minimum thickness of boiler, superheater, reheater and economizer 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 σ 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 economizer tubes is to be taken as not less than 35°C in excess of the maximum temperature of the internal fluid.

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 economizer 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:

$$t = \frac{pn}{20\sigma J} + \sqrt{\frac{0{,}4Y p}{\sigma J_1}} + 0{,}75 \text{ mm}$$

where t, p and σ 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.

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 centreline 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

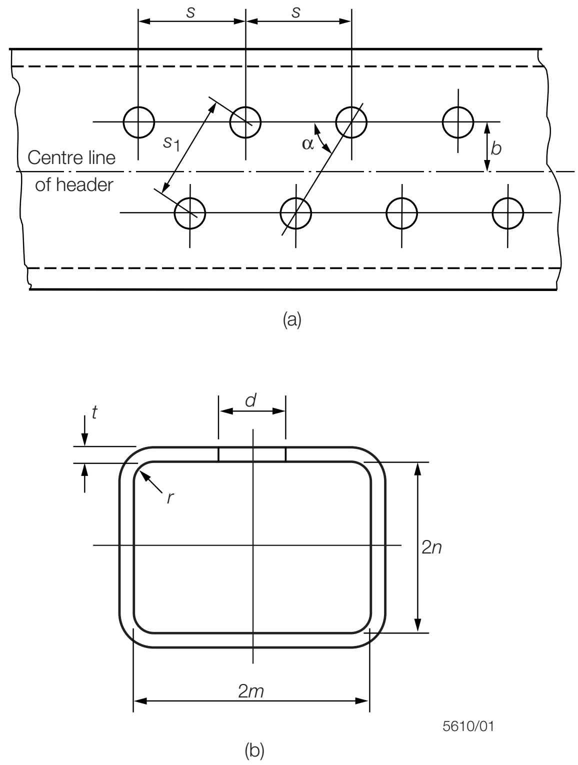


Fig. 10.8.1 Rectangular section headers

α = the angle subtended by the diagonal ligament on the longitudinal ligament, *see* Fig.10.8.1(a)

(d) at the corners:

$$Y = \frac{1}{3}\left(\frac{m^3 + n^3}{m + n}\right)$$

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:

$$J_1 = \frac{s - d}{s} \quad \text{when } d < 0{,}6m$$

or

$$J_1 = \frac{s - 0{,}6m}{s} \quad \text{when } d \geq 0{,}6m$$

Symbols are as defined in 8.2.4.

(d) for the diagonals:

$$J_1 = \frac{s_1 - d}{s_1} \quad \text{when } d < 0{,}6m$$

or

$$J_1 = \frac{s_1 - 0{,}6m}{s_1} \quad \text{when } d \geq 0{,}6m$$

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 σ 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

$$M = \frac{Wr}{3} - \frac{pd^2\,r}{40} \text{ Nmm}$$

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.

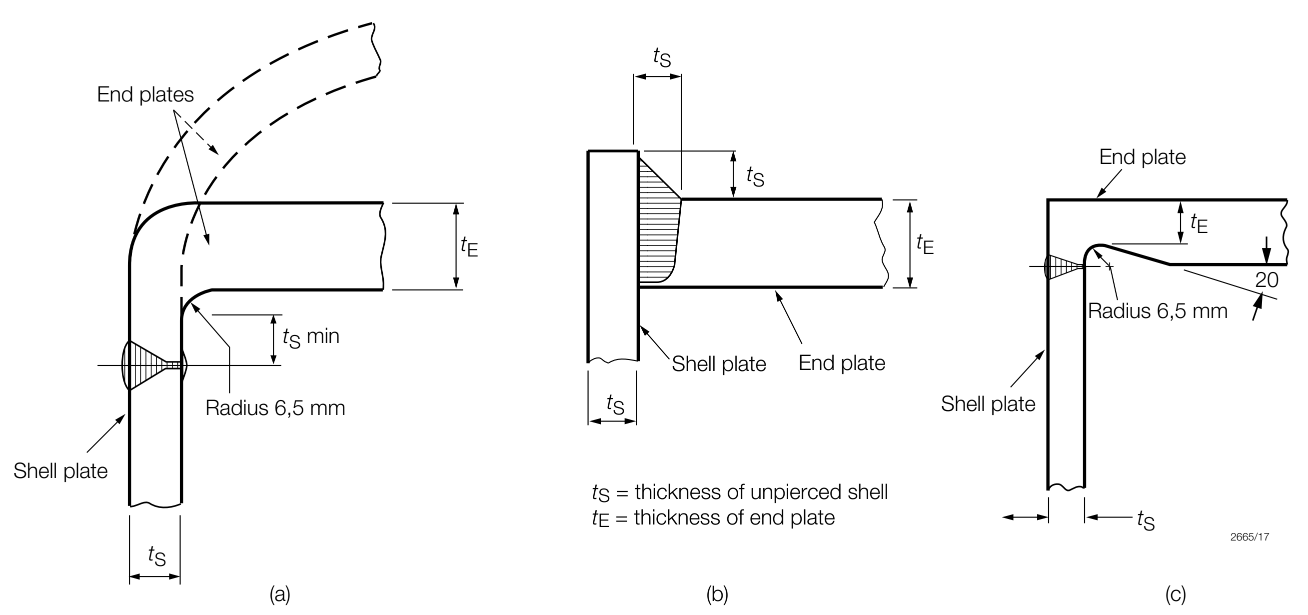


Fig. 10.8.2 Typical methods of attachment of header end closures

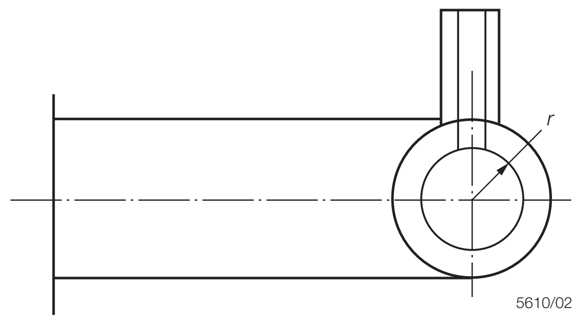


Fig. 10.8.3 Toroidal furnace headers

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 σ 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

= 0,032 for rectangular headers.

- For end plates welded as shown in Figs. 10.8.2(b) and (c):

C = 0,028 circular headers

= 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 recognized 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.

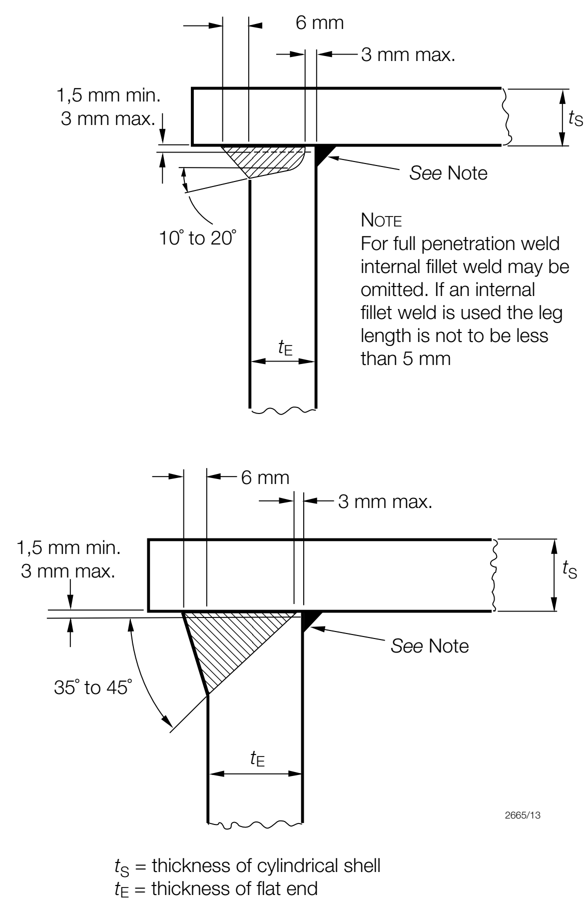


Fig. 10.9.1
Typical attachment of unflanged flat end plates to shell

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 *t*, *p* and σ 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.

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.

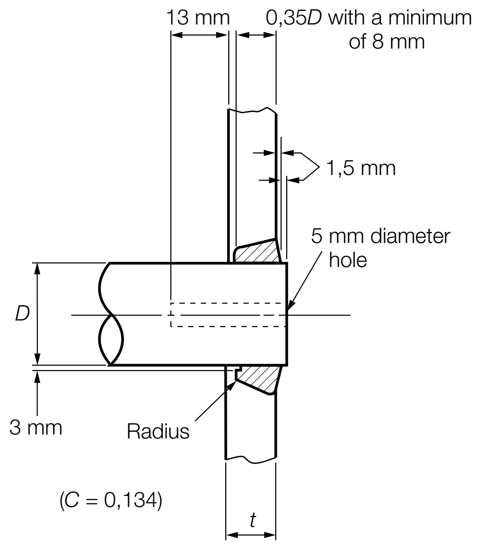
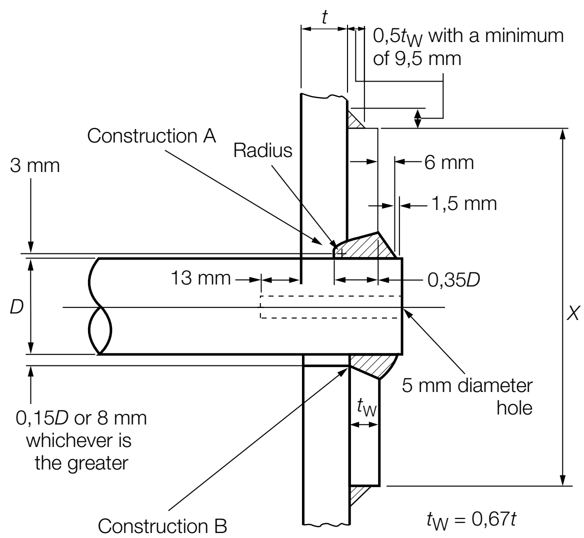


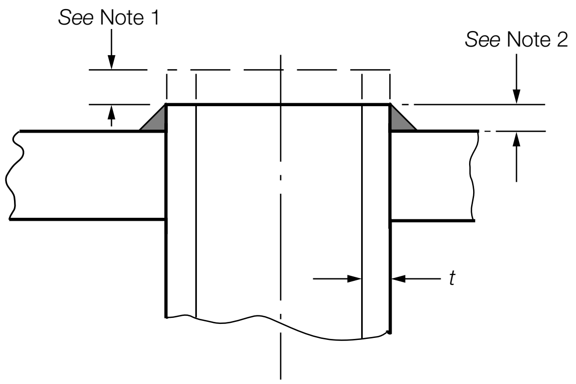
Fig. 10.9.2
Typical attachment of firebox, combustion chamber stays and bar stays



Method of construction 'A' or 'B' may be used, except where $t_W < 0{,}35D$, construction 'A' is to be used.

where *X* = 3,5*D*, *C* = 0,12;
where *X* = 0,67 x pitch of stays, *C* = 0,113

Fig. 10.9.3 Typical attachment of bar stays



NOTE
1. The ends of the tubes are to be dressed flush with the welds when exposed to flame. When not exposed to flame the ends of the tubes may extend a maximum of 10 mm beyond the weld.
2. 3 mm minimum, but stress in weld due to nominal flat plate load carried by the tube not to exceed 70 N/mm^2. An equivalent recessed weld may be used.
3. Weld stress area is to be based on the weld throat area.

2665/14

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^2, 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:

(a) 12,5 mm where the diameter of the tube hole does not exceed 50 mm, or

(b) 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:

$b = 0{,}125d + 12{,}5$ mm

for welded tubes:

$b = 0{,}125d + 8$ 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:

$$H = \sqrt{t\,W}$$

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^2 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.

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^2.

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:

$$b = C(t - 0{,}75)\sqrt{\frac{\sigma}{p}} \text{ mm}$$

where p and σ 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:

$$D = \sqrt{\frac{345A}{p} + d^2}$$

where p 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^2.

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^2
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:

$$C = \frac{AD_i\,p}{t}$$

where
p = 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.

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^2).

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:

$$t = \frac{pR_i}{13\sigma} + 0,75 \quad \text{mm}$$

where *t*, *p*, R_i and σ 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:

$$H = \sqrt{t\,W}$$

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:

$$t = \frac{pD_o}{C} + 0,75 \quad \text{mm}$$

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:

$$t = \sqrt{\frac{pD_o\,(L + 610)}{102\,400}} + 0,75 \quad \text{mm}$$

$$t = \frac{C\,p\,D_o}{1100} + \frac{L}{320} + 0,75 \quad \text{mm}$$

where
t and *p* are as defined in 1.2

$C = \dfrac{2x}{x + \sigma}$ or 0,85 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 σ 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:

$$I = \frac{pD_o^3 L}{13{,}3 \times 10^6} \text{ mm}^4$$

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.

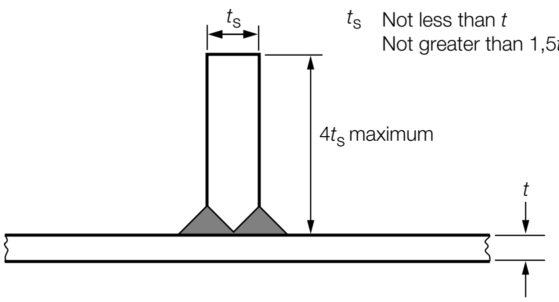
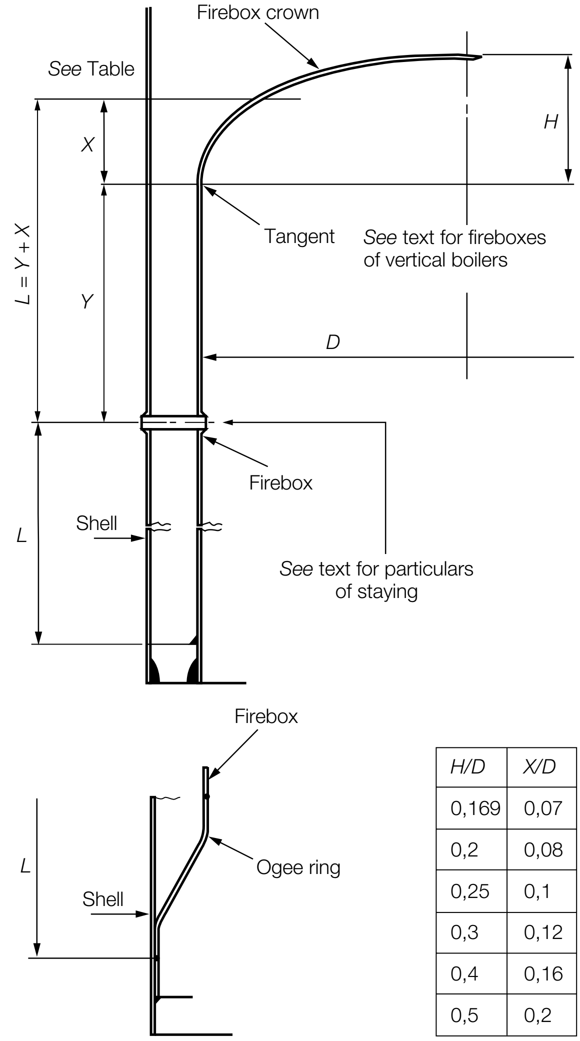


Fig. 10.11.1
Furnace, flue and combustion chamber stiffeners



H/D	X/D
0,169	0,07
0,2	0,08
0,25	0,1
0,3	0,12
0,4	0,16
0,5	0,2

Fig. 10.11.2 Effective length, *L*, for use in 11.4

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.

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 σ are as defined in 11.7.1

$C = \dfrac{2x}{x + \sigma}$ or 0,85 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 $\dfrac{R_o}{t - 0{,}75}$ 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 σ 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:

$$t = \frac{CpR_o}{660} + 0{,}75 \text{ mm}$$

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^2 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^2

$C = \dfrac{2x}{x + \sigma}$ or 0,85 whichever is the greater

R_o = outside radius of the crown plate, in mm

$\left(\text{in no case is } \dfrac{R_o}{t} \text{ to exceed } 88\right)$

σ = specified minimum lower yield stress or 0,2 per cent proof stress in N/mm^2 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.

■ *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.

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

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^2, 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^2.

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^2, 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^2, and the diameter of this type of bar stay is not to be less than 25 mm.

■ *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 economizers, 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 recognized 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.

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 recognized standards will be accepted.

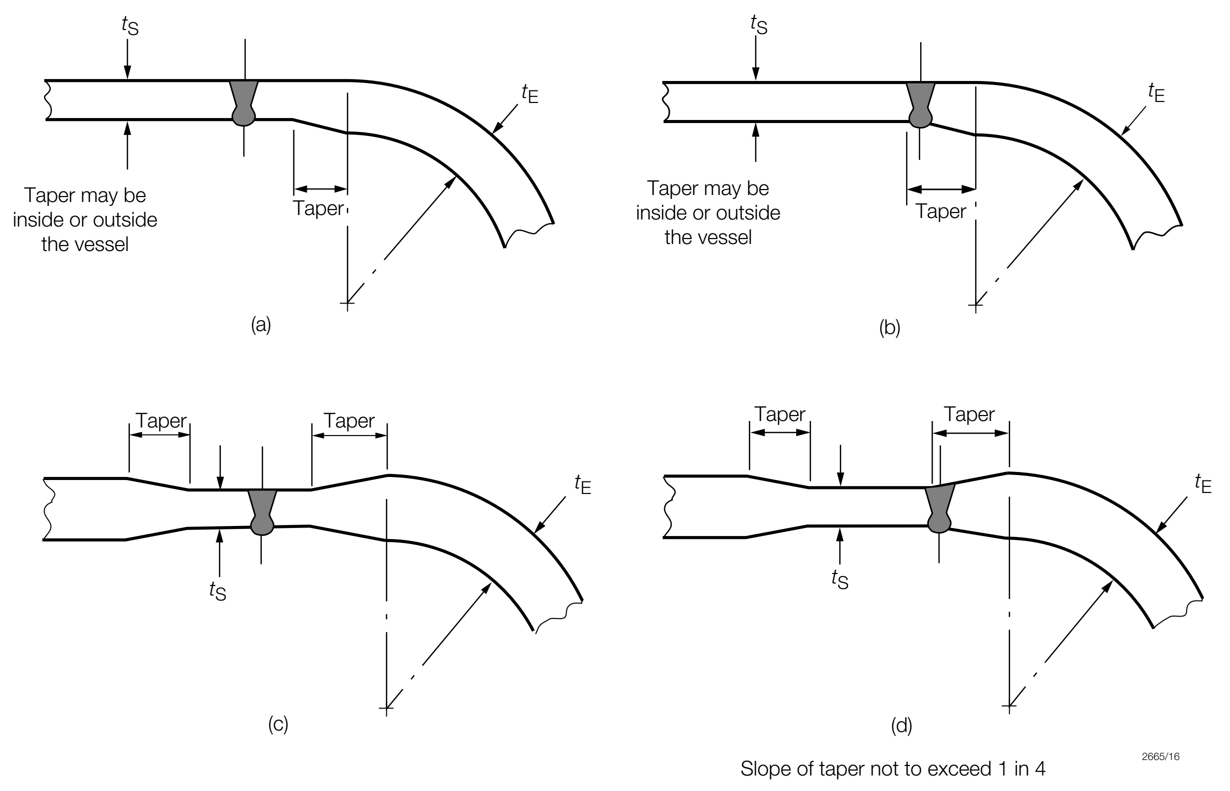


Fig. 10.14.1 Typical attachments of dished ends to cylindrical shells

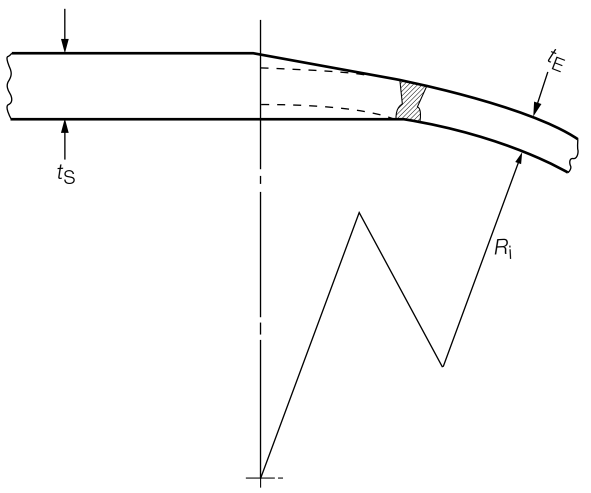


Fig. 10.14.2
Attachment of hemispherical end to cylindrical shell

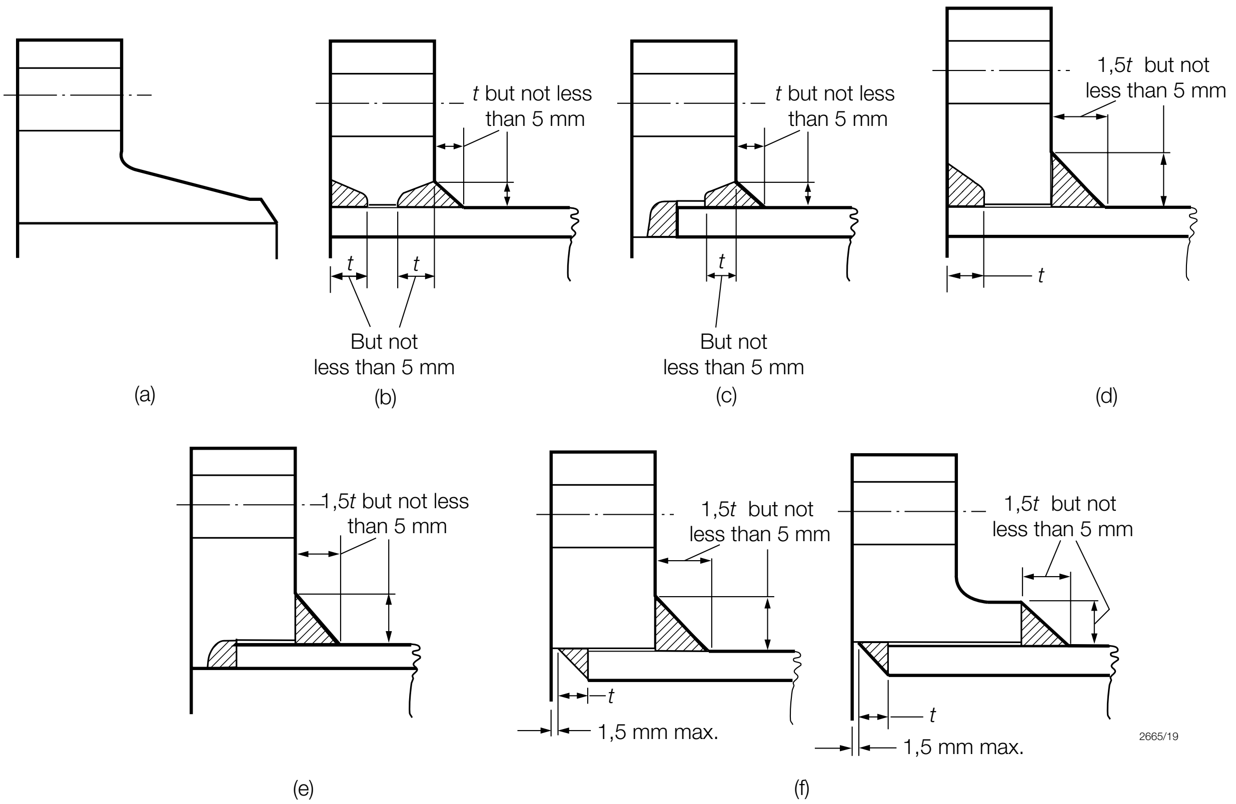
14.4.4 Typical examples of welded-on flange connections are shown in Fig. 10.14.3(a) to (f), and limiting design conditions for the flange types are shown in Table 10.14.1. In Fig. 10.14.3 *t* is the minimum Rule thickness of the standpipe or branch.

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.



'*t*' is the minimum Rule thickness of standpipe or branch

Fig. 10.14.3 Typical examples of welded flange connections

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 recognized 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

14.4.9 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 minimize 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.

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 (l). 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.

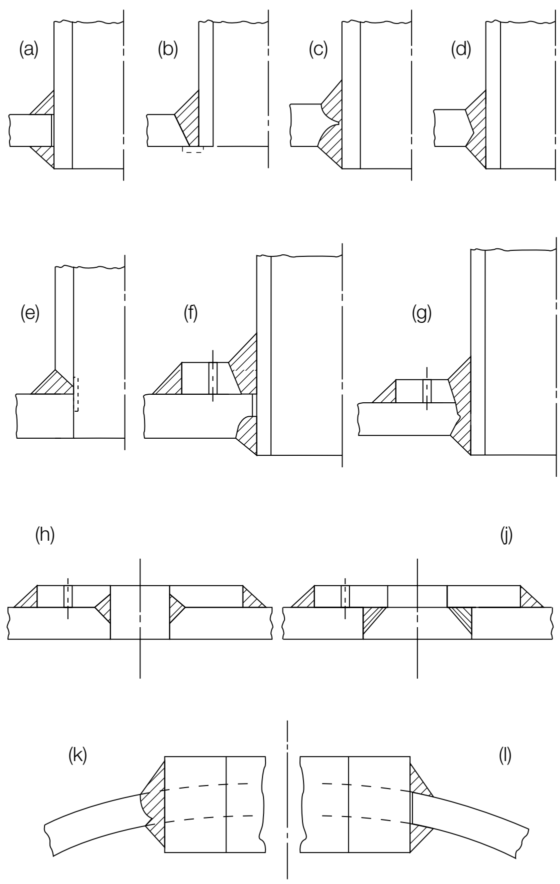


Fig. 10.14.4
Typical acceptable methods of attaching branches and pads

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.

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, pressurized thermal liquid and pressurized 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 super-heater 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^2 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 15.2.11.

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* 15.2.11.

15.2.8 Each safety valve chest is to be drained by a pipe fitted to the lowest part and led with a continuous fall to the bilge or to a tank, clear of the boilers. No valves or cocks are to be fitted to these drain pipes. It is recommended that the bore of the drain pipes be not less than 19 mm.

15.2.9 Safety valves for shell type exhaust gas steaming economizers are to incorporate fail safe features which will ensure operation of the valve even with solid matter deposits on the valve and guide. Alternatively, a bursting disc discharging to a suitable waste steam pipe is to be fitted. These emergency devices are to function at a pressure not exceeding 1,5 times the economizer approved design pressure. Full particulars of the proposed arrangements are to be submitted for consideration.

15.2.10 Where the receiver is fitted with safety valves to relieve the steam output of the economizer and the economizer cannot be isolated from the receiver the require-ments of 15.2.9 may be waived.

15.2.11 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^2, 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^2, through the seats after deducting the area of the guides or other obstructions when the valves are fully lifted

C = 4,8 for valves of ordinary type having a minimum lift of $\frac{D}{24}$

= 7,2 for valves of high lift type, having a minimum lift of $\frac{D}{16}$

= 9,6 for valves of improved high lift type having a minimum lift of $\frac{D}{12}$

= 19,2 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 economizers and other heating surfaces in direct communication with the boiler)

V_H = specific volume of superheated steam (m^3/kg)

V_S = specific volume of saturated steam (m^3/kg).

15.2.12 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 recognized 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.

15.2.13 Pressurized thermal liquid and pressurized hot water heaters are to be provided with a safety relief device.

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 15.2.11. 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.

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 economizer and exhaust gas heated boiler which may be used as an economizer 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.

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 Salinometer valve or cock

15.11.1 Each boiler is to be provided with a salinometer 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.

■ *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 minimize 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.

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.

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 economizer which forms an integral part of the boiler.

16.8.2 Where the arrangements necessitate the use of a common inlet pipe on the economizer 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 minimizing 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:

(a) boilers are to be tested on completion to a pressure 1,5 times the approved design pressure, or
(b) 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

■ *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
σ = allowable stress, *see* 1.8, in N/mm^2.

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, σ, 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.

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 Heat treatment, non-destructive and routine tests where required, for the four Classes of fusion welded pressure vessel are indicated in Table 11.1.1. Details of these requirements are given in Chapter 17.

1.5.8 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_2 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, for fire-fighting or flammable liquids, and

$p > 7$
$V > 100$
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 LR's 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^2.

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^2, 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 Lloyd's Register (hereinafter referred to as LR).

Table 11.1.1 Heat treatment, non-destructive examination and testing requirements

Class	Radiographic examination	Heat treatment	Routine weld tests	Hydraulic test
1	Required *see* Chapter 17	*see* Chapter 17	Required	Required
2/1	Spot required *see* Chapter 17	*see* Chapter 17	Required	Required
2/2	—	*see* Chapter17	Required	Required
3	—	—	—	Required

1.8 Allowable stress

1.8.1 The term 'allowable stress', σ, is the stress to be used in the formulae for the calculation of scantlings of pressure parts.

1.8.2 The allowable stress, σ, is to be the lowest of the following values:

$$\sigma = \frac{E_t}{1,5} \qquad \sigma = \frac{R_{20}}{2,7} \qquad \sigma = \frac{S_R}{1,5}$$

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 σ 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.

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:

$$t = \frac{p\,R_i}{20\sigma\,J - 0{,}5p} + 0{,}75 \quad \text{mm}$$

where t, p, R_i, σ 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:

$$t = \frac{p\,D_o\,K}{20\sigma\,J} + 0{,}75 \quad \text{mm}$$

where
t, p, D_o, σ 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:

$$t = \frac{p\,R_i}{20\sigma\,J - 0{,}5p} + 0{,}75 \quad \text{mm}$$

where t, p, R_i, σ, 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:

$$H = t_1 W$$

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, ψ, between the two sections under consideration does not exceed 30°.

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:

$$t = \frac{p D_o K}{20\sigma J} + 0{,}75 \quad \text{mm}$$

where

t, p, σ 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 $0{,}01D_c$ 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

$$= 0{,}5\sqrt{\frac{D_o t}{\cos\psi}}$$

ψ = 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:

$$t = \frac{p D_c}{20\sigma J - p}\;\frac{1}{\cos\alpha} + 0{,}75 \quad \text{mm}$$

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° 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 σ 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 recognized standard.

8.2 Torispherical and semi-ellipsoidal ends

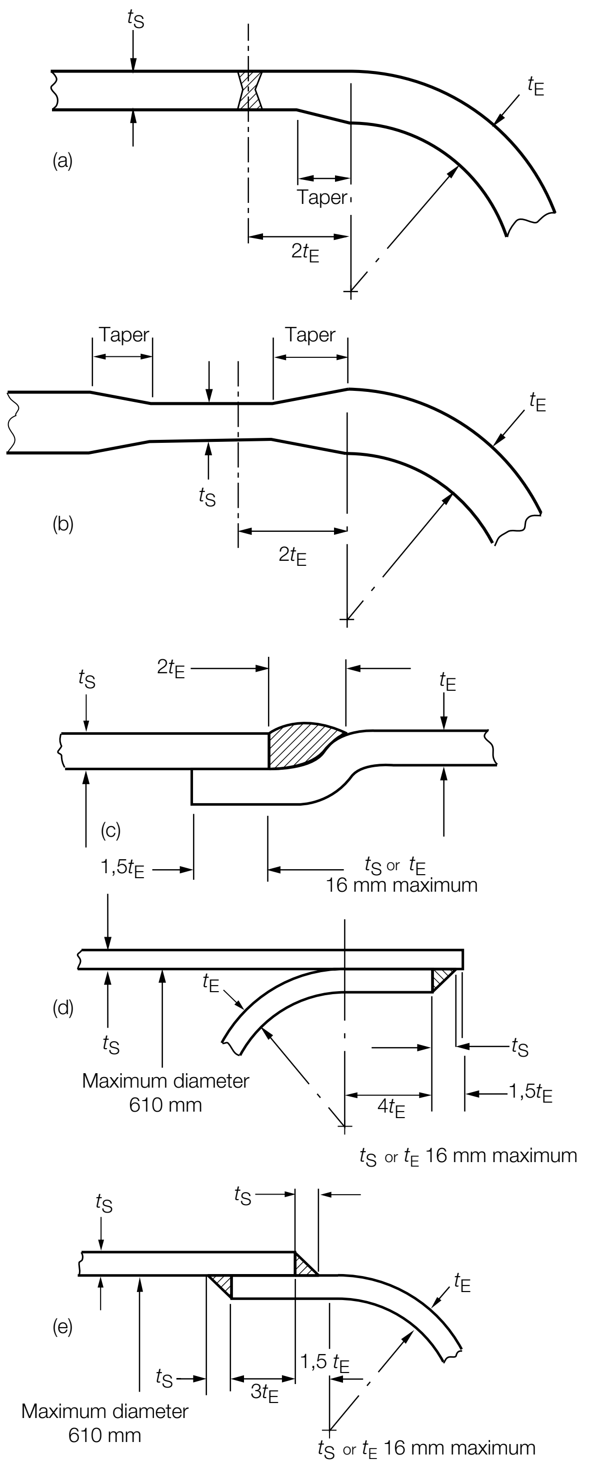
8.2.1 For typical acceptance types of attachment for dished ends to cylindrical shells, *see* Fig. 11.8.1. Types (d) and (e) are to be made a tight fit in the cylindrical shell.

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.



Type of end attachment	Acceptable for
(a) and (b)	All classes
(c)	2/1, 2/2 and 3
(d) and (e)	Class 3 only

2665/23

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 pressurized 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 utilizing 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 2,7.
For mountings for liquefied gas vessels, *see* the Rules for Ships for Liquefied Gases.

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

σ_T = allowable stress at design temperature, in N/mm^2

σ_{50} = allowable stress at 50°C, in N/mm^2.

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.

Section

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.

1.2 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^2), *see* 1.3
p_t = hydraulic test pressure, in bar (kgf/cm^2)
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
σ = maximum permissible design stress, in N/mm^2 (kgf/cm^2).

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.

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

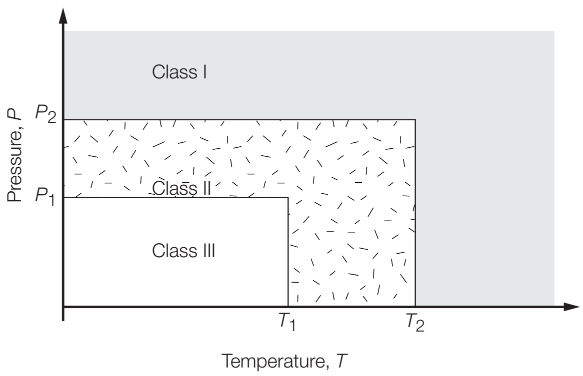
1.5.1 Pressure piping systems are divided into three classes for the purpose of assigning appropriate testing requirements, types of joints to be adopted, heat treatment and weld procedure.

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

NOTE
1. Flammable liquids include: oil fuel, lubricating oil and flammable hydraulic oil.
2. For grey cast iron, see also 4.2.2.



NOTE
T_1 and P_1 correspond to the maximum temperatures and pressures for a Class III piping system and T_2 and P_2 to those for a Class II piping system depending on the service.

Fig. 12.1.1 Classes of piping system

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 Materials.

1.6.2 The manufacturer's test 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 shown in Table 12.1.2.

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 Spheroidal or nodular cast iron	< 300	*DN* < 50 or p_W x *DN* < 2500
Copper alloy	< 200	*DN* < 50 or p_W x *DN* < 1500

1.6.3 The manufacturer's test certificate 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 recognized National Standard applicable to the intended application and are manufactured and tested in accordance with the appropriate requirements of the Rules for Materials.

■ *Section 2*
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/cm²). The manufacturer's test certificate will be acceptable and is to be provided for each consignment of material.

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, σ, is to be taken as the lowest of the following values:

$$\sigma = \frac{E_t}{1,6} \qquad \sigma = \frac{R_{20}}{2,7} \qquad \sigma = \frac{S_R}{1,6}$$

where

E_t = specified minimum lower yield or 0,2 per cent proof stress at the design temperature

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, σ, 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

σ 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.

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

σ and c are as defined in 2.2.3. In general, R is to be not less than $3D$.

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, or reduction in thickness due to bending on this nominal thickness. For larger diameters, the minimum thickness will be specially 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.

Table 12.2.1 Carbon and carbon-manganese steel pipes

Specified minimum tensile strength, N/mm^2 (kgf/mm^2)	Maximum permissible stress, N/mm^2 (kgf/cm^2)												
	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)

Table 12.2.2 Alloy steel pipes

Type of steel	Specified minimum tensile strength, N/mm^2 (kgf/mm^2)	Maximum permissible stress, N/mm^2 (kgf/cm^2)									
		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 normalized 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 normalized 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 normalized 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 normalized 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
1. Maximum permissible stress values applicable when the tempering temperature does not exceed 750°C.
2. Maximum permissible stress values applicable when the tempering temperature exceeds 750°C.

Table 12.2.3 Values of *c* for steel pipes

Piping service	*c* 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

2.2.7 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.

Table 12.2.4 Minimum thickness for steel pipes

External diameter, *D*, 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 and sounding pipes through ballast and fuel tanks, ballast lines through fuel tanks and fuel lines through ballast tanks, 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
70	2,6	4,5	4,0	6,3
76,1–82,5	2,6	4,5	4,5	6,3
88,9–108	2,9	4,5	4,5	7,1
114,3–127	3,2	4,5	4,5	8,0
133–139,7	3,6	4,5	4,5	8,0
152,4–168,3	4,0	4,5	4,5	8,8
177,8	4,5	5,0	5,0	8,8
193,7	4,5	5,4	5,4	8,8
219,1	4,5	5,9	5,9	8,8
244,5–273	5,0	6,3	6,3	8,8
298,5–368	5,6	6,3	6,3	8,8
406,4–457,2	6,3	6,3	6,3	8,8

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.

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 recognized National Standard which is applicable to the intended service and media conveyed.

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.

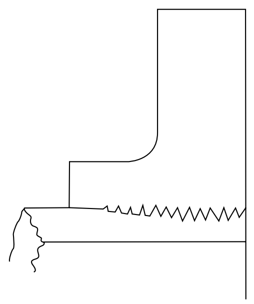


Fig. 12.2.1 Screwed-on flange

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^2) and a maximum design temperature of 370°C and for feed for a maximum design pressure of 50 bar (51 kgf/cm^2).

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.

2.6.3 Butt welded joints are generally to be of the full penetration type and are to meet the requirements of Chapter 17.

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.

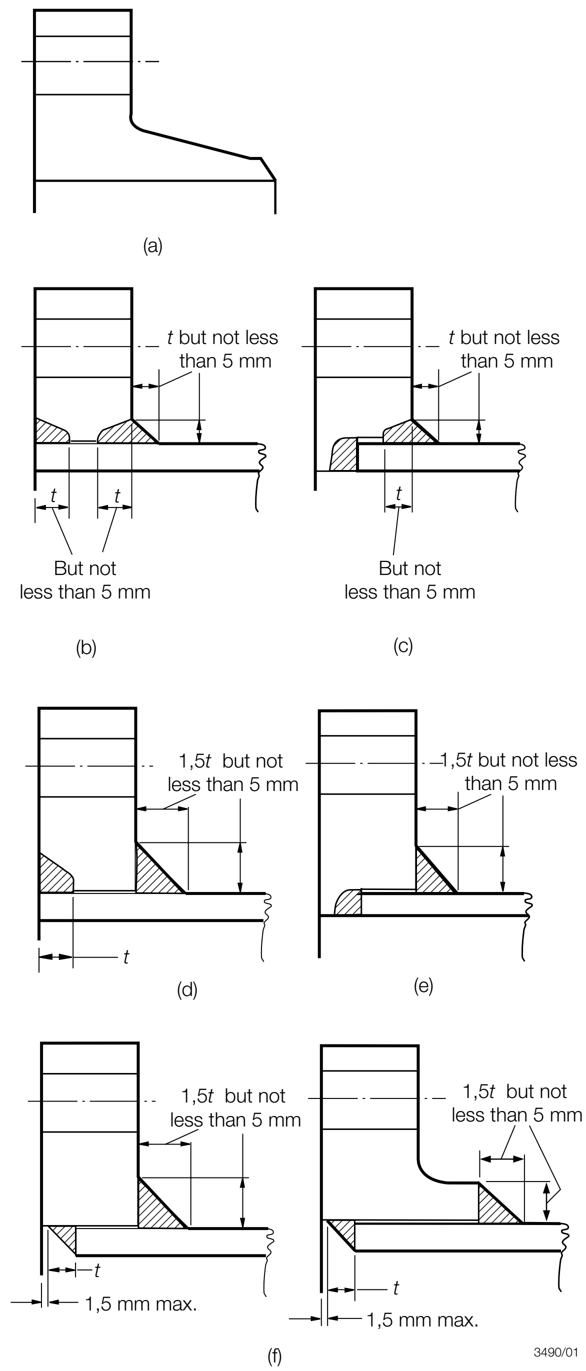


Fig. 12.2.2 Typical welded-on flanges

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.

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 recognized 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

2.6.8 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 recognized National or International Standard.

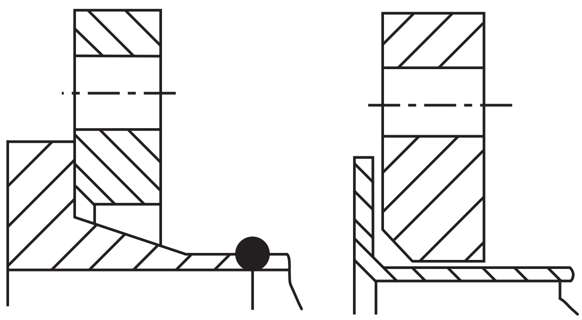


Fig. 12.2.3 Loose flange arrangements

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 17,6.2.3.

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.

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* Pt 5, 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 the nominal thickness of the pipe. 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.

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 Table12.2.7 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.

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 on the weather decks of oil and chemical tankers to accommodate axial pipe movement, *see* Ch 13,2.7.

2.13 Non-destructive testing

2.13.1 For details of non-destructive tests on piping systems, other than hydraulic tests, *see* Chapter 17.

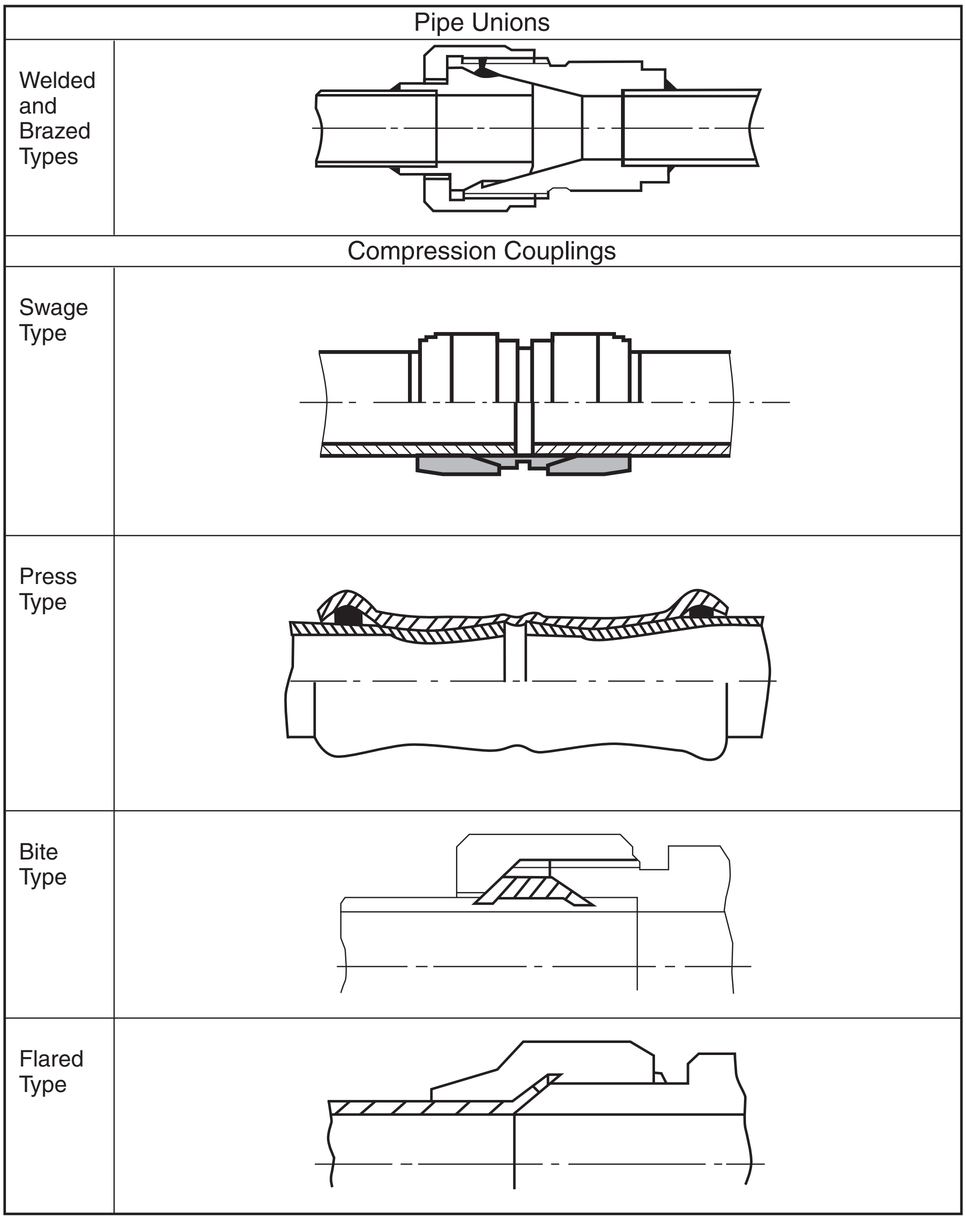


Fig. 12.2.4 Examples of mechanical joints (*see continuation*)

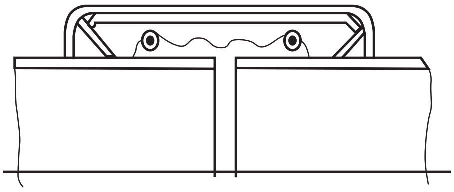
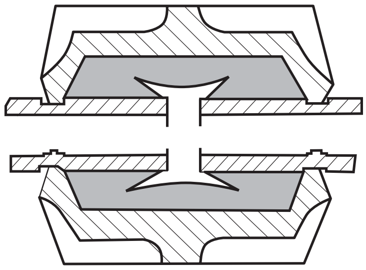
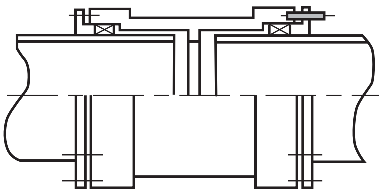
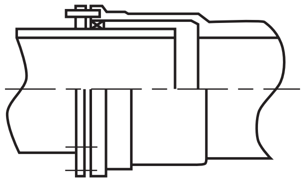
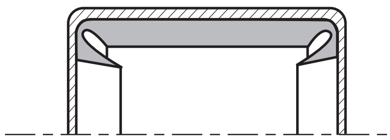
Slip-on Joints	
Grip Type	
Machine Grooved Type	
SlipType	  

Fig. 12.2.4 Examples of mechanical joints (*conclusion*)

Table 12.2.7 Application of mechanical joints

Systems	Kind of connections		
	Pipe unions	Compression couplings (6)	Slip-on joints
Flammable fluids (Flash point <60°)			
Cargo oil lines	+	+	+5
Crude oil washing lines	+	+	+5
Vent lines	+	+	+3
Inert gas			
Water seal effluent lines	+	+	+
Scrubber effluent lines	+	+	+
Main lines	+	+	+2,5
Distribution lines	+	+	+5
Flammable fluids (Flash point > 60°)			
Cargo oil lines	+	+	+5
Fuel oil lines	+	+	+2,3
Lubricating oil lines	+	+	+2,3
Hydraulic oil	+	+	+2,3
Thermal oil	+	+	+2,3
Sea-water			
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	+	+	+
Fresh water			
Cooling water system	+	+	+1
Condensate return	+	+	+1
Non-essential system	+	+	+
Sanitary/Drains/Scuppers			
Deck drains (internal)	+	+	+4
Sanitary drains	+	+	+
Scuppers and discharge (overboard)	+	+	—
Sounding/vent			
Water tanks/Dry spaces	+	+	+
Oil tanks (f.p.> 60°C)	+	+	+2,3
Miscellaneous			
Starting/Control air (1)	+	+	—
Service air (non-essential)	+	+	+
Brine	+	+	+
CO_2 system	+	+	—
Steam	+	+	–7

KEY
+ Application is allowed
— Application is not allowed

NOTES
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.

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
Pipe unions			
Welded and brazed type	+(OD ≤ 60,3 mm)	+(OD ≤ 60,3 mm)	+
Compression couplings			
Swage type	–	–	+
Bite type	+(OD ≤ 60,3 mm)	+(OD ≤ 60,3 mm)	+
Flared type	+(OD ≤ 60,3 mm)	+(OD ≤ 60,3 mm)	+
Press type	–	–	+
Slip-on joints			
Machine grooved type	+	+	+
Grip type	–	+	+
Slip type	–	+	+
KEY + 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 test certificate will be acceptable and is to be provided for each consignment of material.

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
σ = maximum permissible design stress, in N/mm² (kgf/cm²), 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
σ and c are as defined in 3.1.6. In general, R is to be not less than $3D$.

Table 12.3.1 Copper and copper alloy pipes

Pipe material	Condition of supply	Specified minimum tensile strength, N/mm^2 (kgf/mm^2)	Permissible stress, N/mm^2 (kgf/cm^2)										
			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.

■ *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.

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 $5{,}65\sqrt{S_o}$, where S_o 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. Castings for Class III systems are to comply with the requirements of acceptable national specifications. A manufacturer's test certificate will be accepted and is to be provided for each consignment of material for Class III systems, *see also* 1.6.

4.1.4 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.

4.1.5 Where the elongation is less than the minimum required by 4.1.1, 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.

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 2,7.4.3.

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 is to be electrically conductive when:

(a) carrying fluids capable of generating electrostatic charges.
(b) passing through dangerous 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 2,1.12.

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 recognized 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.

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.

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		7,5	6				
	16		12	9	6			
ABS	10	7,5	7,5	7	6			
	16	12	12	10,5	9	7,5	6	
HDPE	10	7,5	6					
	16	12	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

5.3.7 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 2,1.12. The resistance to earth from any point in the piping system is not to exceed 1 MΩ.

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.

Table 12.5.3 Fire endurance requirements (*see continuation*)

Piping systems	Location										
	A Machinery spaces of Category A	B Other machinery spaces and pump rooms	C Cargo pump rooms	D Ro–Ro cargo holds	E Other dry cargo holds	F Cargo tanks	G Fuel oil tanks	H Ballast water tanks	I Cofferdams void spaces pipe tunnel and ducts	J Accommodation service and control spaces	K Open decks
CARGO (FLAMMABLE CARGOES f.p. ≤ 60°C)											
1 Cargo lines	N/A	N/A	L1	N/A	N/A	0	N/A	0[10]	0	N/A	L1[2]
2 Crude oil washing lines	N/A	N/A	L1	N/A	N/A	0	N/A	0[10]	0	N/A	L1[2]
3 Vent lines	N/A	N/A	N/A	N/A	N/A	0	N/A	0[10]	0	N/A	X
INERT GAS											
4 Water seal effluent line	N/A	N/A	0[1]	N/A	N/A	0[1]	0[1]	0[1]	0[1]	N/A	0
5 Scrubber effluent line	0[1]	0[1]	N/A	N/A	N/A	N/A	N/A	0[1]	0[1]	N/A	0
6 Main line	0	0	L1	N/A	N/A	N/A	N/A	N/A	0	N/A	L1[6]
7 Distribution lines	N/A	N/A	L1	N/A	N/A	0	N/A	N/A	0	N/A	L1[2]
FLAMMABLE LIQUIDS (f.p. > 60°C)											
8 Cargo lines	X	X	L1	X	X	N/A[3]	0	0[10]	0	N/A	L1
9 Fuel oil	X	X	L1	X	X	N/A[3]	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
SEAWATER[1]											
12 Bilge main and branches	L1[7]	L1[7]	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

Table 12.5.3 Fire endurance requirements *(continued)*

Piping systems	Location: A Machinery spaces of Category A	B Other machinery spaces and pump rooms	C Cargo pump rooms	D Ro–Ro cargo holds	E Other dry cargo holds	F Cargo tanks	G Fuel oil tanks	H Ballast water tanks	I Cofferdams void spaces pipe tunnel and ducts	J Accommodation service and control spaces	K 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[10]	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[2]
19 Non-essential systems	0	0	0	0	0	N/A	0	0	0	0	0
FRESHWATER											
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[4]	L1[4]	N/A	L1[4]	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[1,8]	0[1,8]	0[1,8]	0[1,8]	0[1,8]	0	0	0	0	0[1,8]	0
SOUNDING/AIR											
26 Water tanks/dry spaces	0	0	0	0	0	0[10]	0	0	0	0	0[11]

Table 12.5.3 Fire endurance requirements *(continued)*

Piping systems	Location										
	A Machinery spaces of Category A	B Other machinery spaces and pump rooms	C Cargo pump rooms	D Ro–Ro cargo holds	E Other dry cargo holds	F Cargo tanks	G Fuel oil tanks	H Ballast water tanks	I Cofferdams void spaces pipe tunnel and ducts	J Accommodation service and control spaces	K Open decks
27 Oil tanks (f.p. > 60°C)	X	X	X	X	X	X[3]	0	0[10]	0	X	X
MISCELLANEOUS											
28 Control air	L1[5]	L1[5]	L1[5]	L1[5]	L1[5]	N/A	0	0	0	L1[5]	L1[5]
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[9]	0[9]	0[9]	0	0	0	0	0[9]	0[9]

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, stabilizing, 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.

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, '0' may replace 'N/A' or 'X'.
4. For drains serving only the space concerned, '0' may replace 'L1'.
5. When controlling functions are not required by the Rules or statutory requirements, '0' may replace 'L1'.
6. For pipe between machinery space and deck water seal, '0' 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 International Convention on Load Lines, 1966, 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 '0'.
10. For tankers where compliance with MARPOL Annex I, Regulation 19.3.6 is required, 'N/A' is to replace '0'.
11. Air and sounding pipes on open deck are to be of substantial construction, *see* Pt 5, Ch 13,10.2.2.

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.

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* Pt 5, 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 2,1.12.

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 2,20.2.3.

■ *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 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.

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 or plastics hoses, with single or double 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 oil systems. 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 assembles 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 – Hydraulic pressure impulse test without flexing*.
- ISO 6803 – *Rubber and plastics hoses and hose assemblies – Hydraulic pressure impulse test with 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 3,5 bar (3,6 kgf/cm^2). 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 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:
(a) For carbon and carbon-manganese steel pipes, the test pressure is to be twice the design pressure, as defined in 1.3.
(b) For alloy steel pipes, the test pressure is to be determined by the following formula, but need not exceed 2*p*:

$$p_t = 1,5 \frac{\sigma_{100}}{\sigma} p \quad \text{bar (kgf/cm}^2\text{)}$$

where
p_t and p are as defined in 1.2.1
σ = permissible stress for the design temperature, in N/mm^2 (kgf/cm^2), as stated in Table 12.2.2
σ_{100} = permissible stress for 100°C, in N/mm^2 (kgf/cm^2), as stated in Table 12.2.2.

8.1.4 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.

8.1.5 Consideration will be given to the reduction of the test pressure to not less than 1,5*p*, where it is necessary to avoid excessive stress in way of bends, branches, etc.

8.1.6 All valve bodies are to be tested by hydraulic pressure to 1,5 times the nominal pressure rating at ambient temperature. However, the test pressure need not be more than 70 bar (71 kgf/cm^2) above the design pressure specified for the design temperature.

8.1.7 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^2).

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.

■ *Cross-reference*

See also Ch 13,2.10 for testing after installation.

APPENDIX

■ *Section 9* Guidance notes on metal pipes for water services

9.1 General

9.1.1 These guidance notes, except where it is specifically stated, apply to sea-water piping systems.

9.1.2 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.

9.2 Materials

9.2.1 Materials used in sea-water piping systems include:
- Galvanized steel.
- Steel pipes lined with rubber, plastics or stoved coatings.
- Copper.
- 90/10 copper-nickel-iron.
- 70/30 copper-nickel.
- Aluminium brass.

9.2.2 Selection of materials should be based on:

- the ability to resist general and localized 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 minimize bimetallic corrosion);
- the ability to resist selective corrosion, e.g. dezincification of brass, dealuminification of aluminium brass and graphitization of cast iron;
- the ability to resist stress corrosion and corrosion fatigue; and
- the amenability to fabrication by normal practices.

9.3 Steel pipes

9.3.1 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.

9.3.2 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.

9.3.3 Galvanizing 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.

9.3.4 Austenitic stainless steel pipes are not recommended for salt-water services as they are prone to pitting, particularly in polluted waters.

9.3.5 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 specializing in this form of protection.

9.3.6 The foregoing comments on rubber lined pipes also apply to pipes lined with plastics.

9.3.7 Stove coating of pipes as protection against corrosion should only be used where the pipes will be efficiently protected against mechanical damage.

9.4 Copper and copper alloy pipes

9.4.1 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.

9.4.2 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.

9.4.3 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.

9.5 Flanges

9.5.1 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.

9.5.2 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.

9.5.3 Inert gas shielded arc welding is the preferred process but metal arc welding may be used on copper-nickel-iron alloy pipes.

9.5.4 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.

9.5.5 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.

9.5.6 The use of a copper-zinc brazing alloy is not permitted.

9.6 Water velocity

9.6.1 Water velocities should be carefully assessed at the design stage and the materials of pipes, valves, etc., selected to suit the conditions.

9.6.2 The water velocity in copper pipes should not exceed 1 m/s.

9.6.3 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:

- Galvanized 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

9.7 Fabrication and installation

9.7.1 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.

9.7.2 Pipe bores should be smooth and clean.

9.7.3 Jointing should be flush with the bore surfaces of pipes and misalignment of adjacent flange faces should be reduced to a minimum.

9.7.4 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.

9.7.5 The position of supports should be given special consideration in order to minimize vibration and ensure that excessive bending moments are not imposed on the pipes.

9.7.6 Systems should not be left idle for long periods, especially where the water is polluted.

9.7.7 Strainers should be provided at the inlet to sea-water systems.

9.8 Metal pipes for fresh water services

9.8.1 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.

9.8.2 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 galvanized, or pipes of suitable non-ferrous material used.

9.8.3 Copper alloy pipes should be treated to remove any carbonaceous films or deposits before the tubes are put into service.

9.8.4 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.

9.8.5 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.

Section

■ *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 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.

1.2 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 criterion 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.

(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.

(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 power transmission, control and heating systems.

(t) Arrangements of cooling water systems for main and auxiliary services.
(u) Oil fuel settling service and other oil fuel tanks not forming part of the ship's structure.
(v) Arrangements and dimensions of all steam pipes where the design pressure or temperature exceeds 16,0 bar (16,3 kgf/cm^2) 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.
(w) Details verifying compliance with the capacity of the oil fuel treatment plant required by Ch 14,3.9.1.
(x) Details verifying compliance of demands on low pressure air systems by essential users as required by Ch 14,10.1.3.

■ *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.

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.

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* Ch 9,2.13 and Ch 9,3.5.

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.

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 12,9.

■ *Section 3*
Drainage of compartments, other than machinery space

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.

3.2 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.

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 in passenger ships 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.

3.5.5 Where the fore peak (in passenger ships) 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.

3.5.6 In ships other than passenger ships, pipes piercing the collision bulkhead are to be fitted with suitable valves operable from above the freeboard deck and the valve chests are to be secured to the bulkhead inside the fore peak. 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.

3.6 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.

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 space

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 suctions when the ship is on an even keel, and is either upright or has a list of not more than 5°. One of these suctions 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 suctions are to be provided at the wings.

4.4 Additional bilge suctions

4.4.1 Additional bilge suctions 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 suctions 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 suctions 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 suctions, 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.

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'.

4.7 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, 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.

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 suctions 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 criterion numeral as derived from Regulation 6.3 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^3/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 suctions need not be of the self-priming type.

6.4.3 For requirements regarding emergency bilge suctions, *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.

6.6 Direct bilge suctions

6.6.1 The direct bilge suctions in the machinery space(s) are to be led to independent power pump(s), and the arrangements are to be such that these direct suctions can be used independently of the main bilge line suctions.

■ *Section 7*
Piping systems and their fittings

7.1 Main bilge line suctions

7.1.1 Suctions from the main bilge line, i.e. branch bilge suctions, are to be arranged to draw water from any hold or machinery compartment of the ship, excepting small spaces such as those mentioned in 3.5 and 3.6, where manual pump suctions are accepted, and are not to be of smaller diameter than that required by the formula in 5.2.1. 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 suctions 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 suctions – Mud boxes

7.4.1 Suctions for bilge drainage in machinery spaces and tunnels, other than emergency suctions, 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 suctions.

7.5 Hold suctions – Strum boxes

7.5.1 The open ends of bilge suctions in holds and other compartments outside machinery spaces and tunnels 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^3 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.

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 criterion 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 bulkhead 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.

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 underdeck cargo spaces, or fire-fighting by means of fixed spraying nozzles or by flooding of the cargo space with water are provided, the following provisions are to apply:

(a) 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.

(b) The drainage system valves are to be operable from outside the protected space at a position in the vicinity of the extinguishing system controls.

(c) Adequately sized bilge wells are to be located at the side shell of the ship at a distance of not more than 40 m in each watertight compartment, *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(a) and (b). 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.

■ *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

10.2 Ships with auxiliary power

10.2.1 In ships in which auxiliary power is available on board, power pump suctions are 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.

■ *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.

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 2,10.

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 12,3.3 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 recognized 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.

12.8 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.

12.12 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 60ºC) 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* Chapter 9.

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.

■ *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 In general, oil fuel in storage and service tanks is not to be heated to a temperature exceeding 10°C below its flash point. Higher temperatures will be considered 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) There is no source of ignition in the vicinity of the ventilation pipes or near the openings in the drainage systems or in the tanks themselves.

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 for Ships for the Carriage of Liquefied Gases* (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 methane tankers, the relevant requirements of the Rules for Ships for Liquefied Gases 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.

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* Pt 5, 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 minimize 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 2,7.

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 pressurized 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.

2.10 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 The piping arrangements for gas oil, distillate and diesel grades are to be separate and distinct from those intended for residual grades, up to the service tanks required by 4.18, to prevent cross-contamination. Cross-connection is permitted between separate arrangements in the event of failure of a designated item of equipment.

■ *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 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.

3.1.2 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.

3.1.3 Unit pressure pumps are to be entirely separate from the feed, bilge or ballast systems.

3.1.4 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.

3.1.5 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.

3.1.6 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.

3.1.7 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.

3.1.8 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.

3.1.9 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 6, Ch 1,3.5 to 3.8, as applicable.

3.1.10 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.

3.1.11 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.

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 2,8.1.

3.4 Steam connections to burners

3.4.1 Where burners are provided with steam purging and/or atomizing 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 Fuel valve cooling pumps

3.11.1 Where pumps are provided for fuel valve cooling, the arrangements are to be in accordance with 3.10.

3.12 Oil-fired galleys

3.12.1 The oil fuel tank is to be located outside the galley and is to be fitted with approved means of filling and venting.

3.12.2 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.

3.12.3 The galley is to be well ventilated.

3.12.4 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 close 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^2) 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.

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^2). 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^2) 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.

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.

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

4.17.4 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.

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.

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.

5.3 Pipes in way of holds

5.3.1 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.

5.3.2 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.

5.4 Reduced pressure lines

5.4.1 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.

5.5 Steam for fire-extinguishing in cargo holds

5.5.1 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.

5.5.2 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 and condensate 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 pumps

6.2.1 Two or more feed pumps are to 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.*6.2.4* Independent feed pumps required for feeding the main boilers are to be fitted with automatic regulators for controlling their output.

6.2.4 Independent feed pumps required for feeding the main boilers are to be fitted with automatic regulators for controlling their output.

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:

(a) Where only one main engine is fitted, the standby pump is to be connected ready for immediate use.
(b) Where more than one main engine is fitted, each with its own pump, a complete spare pump of each type may be accepted.
(c) 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.
(d) 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.
(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 3,6.3 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 12,9.

■ *Section 8* **Lubricating oil systems**

8.1 General requirements

8.1.1 In addition to the requirements detailed in this Section, the requirements of Sections 2 and 4 are to be complied with in so far as they are applicable. In all cases 2.9.1 to 2.9.3, 4.2, 4.3, 4.5, 4.8, 4.11 and 4.17 are to apply.

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:

(a) The lubricating oil pump is independently driven and the total output of the main engine(s) exceeds 370 kW (500 shp).
(b) One main engine with its own pump is fitted and the output of the engine exceeds 370 kW (500 shp).
(c) 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 Alarms

8.3.1 All main and auxiliary engines and turbines intended for essential services are to be provided with means of indicating the lubricating oil pressure supply to them. Where such engines and 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.

8.4 Emergency supply for propulsion turbines and propulsion turbo-generators

8.4.1 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.

8.4.2 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.

8.4.3 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.

8.4.4 For automatic shutdown arrangements of main turbines in the event of failure of the lubrication system, *see* Ch 3,5.1 and Pt 6, Ch 1,3.4.

8.5 Maintenance of bearing lubrication

8.5.1 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.

8.5.2 For details of the requirements relating to the lubrication of bearings of electric generators and motors, *see* Pt 6, Ch 2,1.9.

8.6 Filters

8.6.1 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.

8.6.2 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.

8.7 Cleanliness of pipes and fittings

8.7.1 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.

8.8 Lubricating oil drain tank

8.8.1 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.

8.9 Lubricating oil contamination

8.9.1 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.

8.9.2 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.

8.9.3 For prevention of ingress of water into lubricating oil tanks via air pipes, *see* Ch 13,12.5.4.

8.9.4 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.

8.9.5 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.

8.9.6 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.

8.10 Deep tank valves and their control arrangements

8.10.1 The requirements for remote operation of valves on deep tank suction pipes may be waived where the valves are closed during normal operation.

8.10.2 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.

■ *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 arrangements for storage, distribution and utilisation of hydraulic and other flammable oils employed under pressure in power transmission systems, control and actuating systems and heating systems in locations where means of ignition are present are to comply with the provisions of 2.9.1 to 2.9.3, 4.3, 4.5, 4.11 and 4.17 where applicable.

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 Over-pressure protection is to be provided on the discharge side of all pumps. Where relief valves are fitted for this purpose they are to be fitted in closed circuit, i.e. arranged to discharge back to the system oil tank.

9.2.4 Provision is to be made for hand operation of the systems in an emergency, unless an acceptable alternative is available.

9.2.5 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.

9.2.6 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.

9.2.7 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.

9.2.8 Suitable oil collecting arrangements for leaks shall be fitted below hydraulic valves and cylinders.

■ *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 which are essential for pneumatic control and instrumentation purposes.

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.

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 users 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 2,8 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 recognized 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. To ensure that LP compressed air users do not cause the starting air compressors to operate the starting air system is to be fitted with an auxiliary compressor which is to be capable of continuous running and which can maintain the stored capacity of starting compressed air in the air receivers as required by Ch 2,8 and Ch 4,6 as applicable, whilst supplying essential LP users.

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.

■ *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

■ *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 Dangerous 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 dangerous zones or spaces and requirements for electrical equipment within such spaces, *see* Pt 6, Ch 2,13.4.

1.5.3 For the requirements for earthing and bonding of pipework for the control of static electricity, *see* Pt 6, Ch 2,1.12.

1.6 Cargo pump room

1.6.1 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.

1.6.2 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.

1.6.3 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.

1.6.4 Alarms and safety arrangements are to be provided as indicated in 1.6.5 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* 1.6.6.

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

NOTES
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.

1.6.5 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:

(a) sampling lines do not pass through gas safe spaces, except where permitted by (e);

(b) 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;

(c) 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;

(d) 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 shutdown; and

(e) 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.

1.6.6 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 Cargo pump room ventilation

1.7.1 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.

1.7.2 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.

1.7.3 The ventilation systems are to be capable of 20 air changes per hour, based on the gross volume of the pump room or space.

1.7.4 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 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.

1.7.5 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 minimize the possibility of re-cycling hazardous vapours from any ventilation discharge opening. Vent exits are to be arranged to discharge upwards.

1.7.6 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.

1.7.7 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.

1.8 Non-sparking fans for hazardous areas

1.8.1 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 1.8.2(e). Generally, however, the air gap need be no more than 13 mm.

1.8.2 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.

1.8.3 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 1.8.2(c).

1.8.4 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 5×10^4 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.

1.8.6 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.

1.8.7 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.

1.9 Slop tanks

1.9.1 The requirements in 1.9.2 to 1.9.7 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.

1.9.2 Slop tanks are to be provided with an approved independent venting system, *see* Section 4.

1.9.3 At least two portable instruments are to be available on board for gas detection.

1.9.4 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.

1.9.5 Adequate ventilation is to be provided for spaces surrounding slop tanks, *see also* Pt 4, Ch 9,11.3.

1.9.6 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.

1.9.7 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.

1.10 Steam connections to cargo tanks

1.10.1 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 dangerous 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 dangerous 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.

2.2 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 suctions. The cargo pumps or cargo stripping pumps may be used for this purpose, provided that the bilge suctions are 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 suctions are 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 suctions are 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.

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 deadweight, 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.

■ *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 close-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^2) before fitting.

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 3 m of discharge manifolds are to be considered as dangerous spaces with regard to electrical or incendive equipment, *see also* Pt 6, Ch 2,13.9.

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 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.

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 dangerous spaces are to be intrinsically-safe.

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 minimize 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 overpressure or underpressure 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 overpressure or underpressure protection as required in 4.1.2(c).

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 recognized 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. overfill 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^2) above atmospheric and a negative pressure of not more than 0,07 bar (0,07 kgf/cm^2) below atmospheric. Higher positive pressures not exceeding 0,7 bar (0,7 kgf/cm^2) 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 minimize 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.

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 paragraph 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 % 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 minimize 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.

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). Any proposal to use an inert gas other than flue gas, e.g. nitrogen, will be specially considered.

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.

7.2 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;

(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.

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 minimize 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 stabilized 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.

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 overpressure 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 minimized 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.

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 shutdown 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 shutdown 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.

■ *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.*

Section

Section 1
General

1.1 Application

1.1.1 Adequate spare parts for the propelling and essential auxiliary machinery together with the necessary tools for maintenance and repair shall be readily available for use.

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

1.2 Tables of spare parts

1.2.1 For general guidance purposes, spare parts for main and auxiliary machinery installations are shown in the following Tables:

Table 16.1.1	Spare parts for main oil engines
Table 16.1.2	Spare parts for auxiliary oil engines
Table 16.1.3	Spare parts for main steam turbines
Table 16.1.4	Spare parts for auxiliary steam turbines
Table 16.1.5	Spare parts for auxiliary air compressors
Table 16.1.6	Spare parts for boilers supplying steam propulsion and for essential services.

Table 16.1.1 Spare parts for main oil engines (*see continuation*)

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Main bearings	Main bearings or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1	–
Main thrust block	Pads for one face of Michell-type thrust block Inner and outer race with rollers where roller thrust bearings are fitted	1 set or 1	1 set 1
Cylinder liner	Cylinder liner complete with joint rings and gaskets	1	—
Cylinder cover	Cylinder cover, complete with valves, joint rings and gaskets. For engines without covers, the respective valves for one cylinder unit Cylinder cover studs or bolts, with nuts, as applicable for one cylinder	1 $^{1}/_{2}$ set	— —
Cylinder valves	Exhaust valves, complete with casings, seats, springs and other fittings for one cylinder Air inlet valves, complete with casings, seats, springs and other fittings for one cylinder Starting air valve, complete with casing, seat, springs and other fittings Relief valve, complete Fuel injection valves of each size and type fitted, complete with all fittings, for one engine	2 sets 1 set 1 1 1 set, *see* Note	1 set 1 set 1 1 $^{1}/_{4}$ set
Connecting rod bearings	Bottom end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinder Top end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinder	1 set 1 set	— —
Pistons	Crosshead type, piston of each type fitted, complete with piston rod, stuffing box, skirt, rings, studs and nuts Trunk piston type, piston of each type fitted, complete with skirt, rings, studs, nuts, gudgeon pin and connecting rod	1 1	— —
Piston rings	Piston rings, for one cylinder	1 set	—
Piston cooling	Telescopic cooling pipes and fittings or their equivalent, for one cylinder unit	1 set	—

NOTE
1. Engines with three or more fuel injection valves per cylinder: two fuel injection valves complete per cylinder and a sufficient number of valve parts, excluding the body, to provide, with those fitted, a full engine set.

Table 16.1.1 Spare parts for main oil engines *(conclusion)*

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Gear and chain for camshaft drives	Chain drive: separate links with pins and rollers of each size and type fitted	6	—
	Bearing bushes of each type fitted	1 set	—
Cylinder lubricators	Lubricator complete, of the largest size, with its chain drive or gear wheels	1	—
Fuel injection pumps	Fuel pump complete, or, when replacement at sea is practicable, a complete set of working parts for one pump (plunger, sleeve, valves, springs, etc.)	1	—
Fuel injection piping	High pressure fuel pipe of each size and shape fitted, complete with couplings	1	—
Scavenge blowers (including turbo-chargers)	Rotors, rotor shafts, bearings, nozzle rings and gear wheels or equivalent working parts if of other types, *see* Note 2	1 set	—
Scavenging system	Suction and delivery valves for one pump of each type fitted	1 set	—
Reduction and/or reverse gear	Complete bearing bush, of each size fitted in the gearcase assembly	1 set	—
	Roller or ball race, of each size fitted in the gearcase assembly	1 set	—
Main engine-driven air compressors	Piston rings of each size fitted	1 set	—
	Suction and delivery valves complete of each size fitted	1/2 set	
Gaskets and packings	Special gaskets and packings of each size and type fitted for cylinder covers and cylinder liners for one cylinder	1 set	—

NOTE
2. The spare parts may be omitted where it has been demonstrated at the Enginebuilder's Works, or during sea trials, for an engine of the type concerned, that the engine can be manoeuvred satisfactorily with one blower out of action. The requisite blanking and/or blocking arrangements, applicable for running with one blower out of action as demonstrated, are to be available on board.

Table 16.1.2 Spare parts for auxiliary oil engines

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Main bearings	Main bearing or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1	–
Cylinder valves	Exhaust valves, complete with casings, seats, springs and other fittings for one cylinder	2 sets	–
	Air inlet valves, complete with casings, seats, springs and other fittings for one cylinder	1 set	–
	Starting air valve, complete with casing, seat, springs and other fittings	1	–
	Relief valve, complete	1	–
	Fuel valves of each size and type fitted, complete with all fittings, for one engine	$^1/_2$ set	–
Connecting rod bearings	Bottom end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinder	1 set	–
	Top end bearings or shells of each size and type fitted, complete with shims, bolts and nuts for one cylinder	1 set	–
	Trunk piston type: gudgeon pin with bush for one cylinder	1 set	–
Piston rings	Piston rings, for one cylinder	1 set	–
Piston cooling	Piston cooling fittings, for one cylinder unit	1 set	–
Fuel injection pumps	Fuel pump complete, or, when replacement at sea is practicable, a complete set of working parts for one pump (plunger, sleeve, valve springs, etc.)	1	–
Fuel injection piping	High pressure fuel pipe of each size and shape fitted, complete with couplings	1	–
Gaskets and packings	Special gaskets and packings of each size and type fitted, for cylinder covers and cylinder liners for one cylinder	1 set	–

Table 16.1.3 Spare parts for main steam turbines

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Main bearings	Complete bearing bush, of each size and type fitted, for the rotor, pinion and gear wheel shafts, for one engine	1	—
Turbine thrust	Pads of each size for one face of Michell-type thrust, or rings for turbine adjusting block, of each size for one engine Assorted liners for one block where fitted	1 set	1 set
Main thrust block	Pads for one face of Michell-type thrust block or Inner and outer race with rollers where roller thrust bearings are fitted	1 set 1	1 set 1
Turbine shaft sealing rings	Carbon sealing rings, where fitted, with springs, for each size and type of gland, for one engine	1 set	—
Oil filters	Disposable filter elements of each type and size fitted	1 set	—

Table 16.1.4 Spare parts for auxiliary steam turbines

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Main bearings	Complete bearing bush, of each size and type fitted, for the rotor, pinion and gear wheel shafts, for one engine	1	—
Turbine thrust	Pads of each size for one face of Michell-type thrust, or rings for turbine adjusting block, of each size for one engine Assorted liners for one block where fitted	1 set	1 set
Turbine shaft sealing rings	Carbon sealing rings, where fitted, with springs, for each size and type of gland, for one engine	1 set	—
Oil filters	Disposable filter elements of each type and size fitted	1 set	—

Table 16.1.5 Spare parts for auxiliary air compressors

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Piston rings	Rings, of each size fitted, for one piston	1 set	1 set
Valves	Suction and delivery valves, complete, of each size fitted	$1/2$ set	$1/2$ set

Table 16.1.6 Spare parts for boilers supplying steam propulsion and for essential services

Item	Spare parts	Number	
		Ships for unrestricted service	Ships for restricted service
Tube stoppers or plugs	Tube stoppers or plugs, of each size used, for boiler, superheater and economizer tubes	10	6
Oil fuel burners	Oil fuel burners complete or a complete set of wearing parts for the burners, for one boiler	1 set	1 set
Gauge glasses	Gauge glasses of round type	2 sets per boiler	2 sets per boiler
	Gauge glasses of flat type	1 set for every two boilers	1 set for every two boilers

Section

■ *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. 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 The term ‘fusion weld’, for the purpose of these requirements, is applicable to welded joints made by manual, semi-automatic or automatic electric arc welding processes. Special consideration will be given to the proposed use of other fusion welding processes, *see* Section 6 for oxy-acetylene welding of pipes.

1.1.4 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.

1.2.2 The procedures are to include the regular systematic supervision of all welding, and the welders are to be subjected by the work’s supervisors to periodic tests for quality of workmanship. Records of these tests are to be kept and are to be available for inspection by the Surveyors.

1.2.3 All welding is to be to the satisfaction of the Surveyors.

■ *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 Materials used in welded construction are to be readily weldable and shall have proven weldability.

2.2.2 Materials are to be supplied by firms that have been approved in accordance with the *Rules for the Manufacture, Testing and Certification of Materials* (hereinafter referred to as the Rules for Materials).

2.2.3 Where the construction details are such that materials are subject to through thickness strains, consideration should be given to using materials with specified through thickness properties as specified in Ch 3,8 of the Rules for Materials).

2.2.4 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.

2.2.5 The identity of materials is to be established by way of markings, etc., so that traceability to the original manufacturer's certificate is maintained.

2.3 Cutting of materials

2.3.1 Materials may be cut to the required dimensions by thermal means, shearing or machining in accordance with the manufacturing drawings or specifications.

2.3.2 Cold shearing should not be used on materials in excess of 25 mm thick and, where used, the cut edges are to be cut back by machining or grinding for a minimum distance of 3 mm.

2.3.3 Material which has been thermally cut is to be machined or ground back to remove all oxides, scale and notches.

2.3.4 Thermal cutting of alloy and high carbon steels may require the application of preheat, and special examination of these cut edges will be required to ensure freedom from cracking. In these cases the cut edges are to be machined or ground back a distance of at least 2,0 mm, unless it has been demonstrated that the cutting process has not damaged the material.

2.3.5 Any material damaged in the process of cutting is to be removed by machining, grinding or chipping back to sound metal; weld repair may only be performed with the agreement of the Surveyors.

2.3.6 All plate edges, after being cut, shall be examined for defects, including laminations, to ensure that these are free from cracks. Visual methods may be augmented by other techniques at the discretion of the Surveyors.

2.3.7 Edges that have been cut by machining or chipping, which will not be subsequently covered by weld metal, are to be ground smooth.

2.4 Forming shell sections and end plates

2.4.1 Shell plates and heads are to be formed to the correct contour up to the extreme edge of the plate.

2.4.2 Plates may be formed to the required shape either hot or cold and by any process that does not impair the quality of the material. Tests to demonstrate the suitability of the forming process may be requested at the discretion of the Surveyors.

2.4.3 Wherever possible, forming is to be performed by the application of steady continuous loading using a machine designed for that purpose. The use of hammering, in either the hot or cold condition should not be employed.

2.4.4 Material may be welded prior to forming or bending, provided that it can be demonstrated that the mechanical properties of the welds are not impaired by the forming operation. All welds subjected to bending are to be inspected on completion to ensure freedom from surface breaking defects.

2.4.5 Vessels manufactured from carbon or carbon manganese steel plates which have been hot formed or locally heated for forming are to be re-heat treated in accordance with the original supplied condition on completion of this operation. Vessels formed from plates supplied in the as-rolled condition shall be heat treated in accordance with the material manufacturer's recommendations.

2.4.6 Where these steels are supplied in the as-rolled, normalized or normalized rolled condition, if hot forming is carried out entirely at a temperature within the normalizing range, subsequent heat treatment will not be required.

2.4.7 For alloy steel vessels, where hot forming is employed the plates are to be heat treated on completion in accordance with the material manufacturer’s recommendations.

2.4.8 Where plates are cold formed, subsequent heat treatment is to be performed where the internal radius is less than 10 times the plate thickness. For carbon and carbon-manganese steels this heat treatment may be a stress relief heat treatment.

2.4.9 In all cases where hot forming is employed, and for cold forming to an internal radius less than 10 times the thickness, the manufacturer is required to demonstrate that the forming process and subsequent heat treatments result in acceptable properties.

2.5 Fitting of shell plates and attachments

2.5.1 Careful consideration is to be given to the assembly sequence to be employed, in order to minimize overall shrinkage and distortion and to reduce the build up of residual stresses.

2.5.2 Excessive force is not to be used in fairing and closing the work. Where excessive root gaps exist between surfaces or edges to be joined, the corrective measures adopted are to be to the satisfaction of the Surveyors.

2.5.3 Provision is to be made for retaining correct alignment during welding operations.

2.5.4 In all cases where tack welds are used to retain plates or parts in position prior to welding they are to be made using approved welding procedures.

2.5.5 Where temporary bridge pieces or strong-backs are used they are to be of similar materials to the base materials and are to be welded in accordance with approved welding procedures.

2.5.6 Where welding to clad materials, any fit-up aids and tack welds are to be attached to the base materials and not to the cladding.

2.5.7 The location of welded joints are to be such as to avoid intersecting butt welds in the vessel shell plates. The attachment of nozzles and openings in the vessels are to be arranged to avoid main shell weld seams.

2.5.8 The surfaces of the plates at the longitudinal or circumferential seams are not to be out of alignment with each other, at any point, by more than 10 per cent of the plate thickness. In no case is the mis-alignment to exceed 3 mm for longitudinal seams, or 4 mm for circumferential seams.

2.5.9 Where a vessel is constructed of plates of different thicknesses (tube plate and wrapper plate), the plates are to be so arranged that their centrelines form a continuous circle.

2.5.10 For longitudinal seams, the thicker plate is to be equally chamfered inside and outside by machining over a circumferential distance not less than twice the difference in thickness, so that the plates are of equal thickness at the longitudinal weld seam. For the circumferential seam, the thickest plate is to be similarly prepared over the same distance longitudinally.

2.5.11 For the circumferential seam, where the difference in the 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 weld joint. 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 to the thicker plate.

2.6 Welding during construction

2.6.1 Welding plant and equipment is to be suitable for the purpose intended and properly maintained, taking due cognisance of relevant safety precautions. Electrical meters are to be properly maintained and have current calibrations.

2.6.2 Welding consumables are to be suitable for the type of joint and grade of material to be welded and satisfactory storage and handling facilities are to be provided close to working areas.

2.6.3 Prior to use, welding consumables should be dried and/or baked in accordance with the consumable manufacturer's recommendations. The condition of welding consumables shall be subject to regular inspections.

2.6.4 All welders and welding operators are to be suitably skilled and qualified for the type of welding work to be undertaken.

2.6.5 Welding procedures are to be established for all welds joining pressure containing parts and for welds made directly onto pressure containing parts.

2.6.6 Welding should be performed wherever possible in covered workshops. Where this is not possible, provision is to be made in the welding area to give adequate protection from wind, rain and cold, etc.

2.6.7 Surfaces of all parts to be welded are to be clean, dry and free from rust, scale and grease. Where prefabrication primers are applied over areas which will be subsequently welded, they are to be approved for that application.

2.6.8 Preheat shall be applied, as specified in the approved welding procedure, for a distance of at least 75 mm from the joint preparation edges. The method of application and temperature control are to be such as to maintain the required level during welding and is to be to the satisfaction of the Surveyors.

2.6.9 When the ambient temperature is 0°C or less, or where moisture resides on the surfaces to be welded, due care should be taken to pre-warm and dry the weld joint.

2.6.10 The welding arc is to be struck on the parent metal which forms part of the weld joint or on previously deposited weld metal.

2.6.11 Tack welds made in the root of the weld joint are to be removed in the process of welding the seam.

2.6.12 Where the welding process used is slag forming (e.g. manual metal arc, submerged arc, etc.) each run of deposit is to be cleaned and free from slag before the next run is applied.

2.6.13 Wherever possible, full penetration welds are to be made from both sides of the joint. Prior to welding the second side, the weld root is to be cleaned, in accordance with the requirements of the approved welding procedure, to ensure freedom from defects. When air-arc gouging is used, care is to be taken to ensure that the ensuing groove is slag and oxide free and has a profile suitable for welding.

2.6.14 After welding has been stopped for any reason, care is to be taken in restarting to ensure that the previously deposited weld metal is thoroughly cleaned of slag and debris, and preheat has been re-established.

2.6.15 Where welding from one side only cannot be avoided, care is to be exercised to ensure the root gap is in accordance with the approved welding procedure and the root is properly fused.

2.6.16 Steel backing strips may be used for the circumferential seams of Class 2/1, Class 2/2 and Class 3 pressure vessels and are to be the same nominal composition as the plates to be welded.

2.6.17 Fillet welds are to be made to ensure proper fusion and penetration at the root of the fillet. At least two layers of weld metal are to be deposited at each weld affixing branch pipes, flanges and seatings.

2.6.18 Where attachment of lugs, brackets, branches, manhole frames, reinforcement plates and other members are to be made to the main pressure shell by welding, these shall be to the same standard as that required for the main vessel shell construction.

2.6.19 The attachment by welding of such fittings to the main pressure shell after post weld heat treatment is not permitted.

2.6.20 Completed welds shall be at least flush with the surface of the plates joined and have the shape and size specified in the approved drawings or specifications. Welds shall have an even contour and blend smoothly with the base materials.

2.6.21 The main weld seams and all welded attachments made to pressure containing parts are to be completed prior to post weld heat treatment. Tubes that have been expanded into headers or drums may be seal welded without further post weld heat treatment.

2.6.22 The finish of welds attaching pressure parts and non-pressure parts to the main pressure shell is to be such as to allow satisfactory examination of the welds. In the case of Class 1 and Class 2/1 pressure vessels, these welds are to be ground smooth, if necessary, to provide a suitable finish for examination.

2.7 Tolerances for cylindrical shells

2.7.1 Measurements are to be made to the surface of the parent plate and not to a weld, fitting or other raised part.

2.7.2 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
≤ 300 > 300 ≤ 460 > 460 ≤ 600 > 600 ≤ 900 > 900 ≤ 1200 > 1220 ≤ 1520 > 1520 ≤ 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 ≤ 2300 > 2300 ≤ 2670 > 2670 ≤ 3950	19 mm	6,4 mm 7,2 mm 8,0 mm
> 3950 ≤ 4650 > 4650	19 mm 0,4 per cent of internal diameter	0,2 per cent of internal diameter

2.7.3 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.

2.7.4 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.

2.7.5 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.

2.7.6 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.

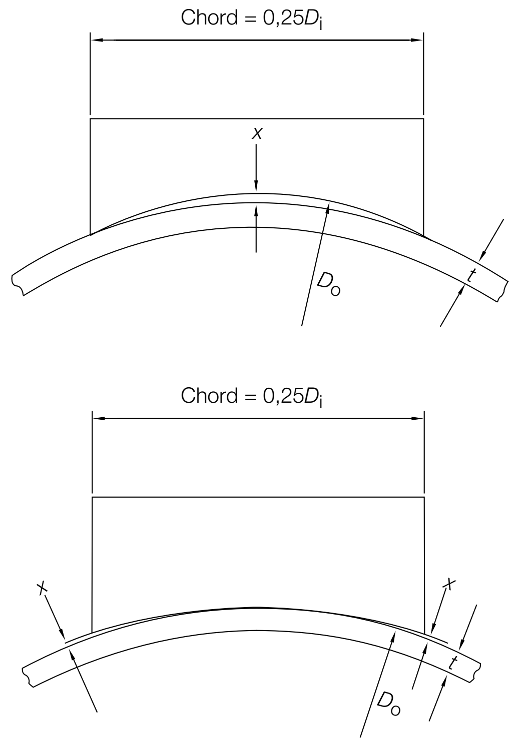


Fig. 17.2.1 Tolerances for cylindrical shells

Table 17.2.2 Circumferential tolerances

Outside diameter (nominal inside diameter plus twice actual plate thicknes), in mm	Circumferential tolerance
300 to 600 inclusive	±5 mm
Greater than 600	±0,25 per cent

■ *Section 3* Routine weld tests for pressure vessels

3.1 General requirements for routine weld tests

3.1.1 Routine or production weld tests are specified as a means of monitoring the quality of the welded joints and are required for pressure vessel Classes 1, 2/1 and 2/2.

3.1.2 Routine test plates are required during the manufacture of vessels and as part of the initial approval test programme for Class 1 vessel manufacturers, refer to MQPS 0-4.

3.1.3 Routine weld tests are not required for Class 3 pressure vessels unless the minimum design temperature is below minus 10°C. However, occasional check tests may be requested at the discretion of the Surveyors.

3.1.4 Routine test plates are not required for circumferential seams of cylindrical pressure vessels. Spherical vessels are to have one test plate prepared having a welded joint which is a simulation of the circumferential seams.

3.1.5 In addition, routine weld tests may be requested by the Surveyor where there is reason to doubt the quality of workmanship.

3.2 Test plate requirements

3.2.1 Two test plates, each of sufficient dimensions to provide one complete set of specimens, are to be prepared for each vessel and are to be welded as a continuation and simulation of the longitudinal weld joint.

3.2.2 For Class 2/2 vessels, where a large number are made concurrently at the same works using the same welding procedure and the plate thicknesses do not vary by more than 5 mm, one test may be performed for each 37 m of longitudinal plus circumferential weld seam with the agreement of the Surveyor. In these cases, the thickness of the test plate is to be equal to the thickest shell plate used in the construction.

3.2.3 Where the vessel size or design results in a small number of longitudinal weld seams, with the agreement of the Surveyors, one test plate may be prepared for testing provided that the welding details are the same for each seam.

3.2.4 Test plate materials shall be of the same grade, thickness and supply condition and from the same cast as that of the vessel shell. The test plate shall be welded at the same time as the vessel weld to which it relates and is to be supported so that distortion during welding is minimized.

3.2.5 Where there is a requirement for several routine tests to be welded, welding is to be performed by different welders, wherever possible.

3.2.6 The test assembly may be detached from the vessel weld only after the Surveyor has performed a visual examination and has added his mark or stamp. Straightening of test weld prior to mechanical testing is not permitted.

3.2.7 Where the pressure vessel is required to be subjected to post weld heat treatment, the test weld shall be heat treated, after welding, in accordance with the same requirements. Subject to agreement with the Surveyor this may be performed separately from the vessel.

3.3 Inspection and testing

3.3.1 The test weld is to be subjected to the type of non-destructive examination and acceptance criteria as specified for the weld seam to which the test relates. Non-destructive examination shall be performed prior to removing specimens for mechanical testing, but after any post weld heat treatment.

3.3.2 The test weld is to be sectioned to remove the number and type of test specimens for mechanical testing as follows.

3.4 Mechanical testing requirements

3.4.1 The test plates are to be machined to provide the following test specimens:

(a) Tensile.
(b) Bend.
(c) Hardness.
(d) Impact, *see* Table 17.3.1.
(e) Macrograph and hardness survey of full weld section.
(f) Chemical analysis of deposited weld metal.

Table 17.3.1 Impact test requirements

Pressure vessel Class	Minimum design temperature	Plate material thickness *t* mm	Impact test temperature
Class 1	–10°C or above	All	5°C below the minimum design temperature or 20°C whichever is the lower
All Classes	Below –10°C	$t \le 20$	5°C below the minimum design temperature
		$20 < t \le 40$	10°C below the minimum design temperature
		$t > 40$	Subject to agreement

3.4.2 One set of specimens for mechanical testing is to be removed, as shown in Fig. 17.3.1 or Fig. 17.3.2 as appropriate for the Class of approval. Impact tests shall be removed and tested where required by Table 17.3.1.

3.4.3 **Longitudinal tensile test for weld metal**. An all weld metal longitudinal tensile test is required and, for thicknesses in excess of 20 mm where more than one welding process or type of consumable has been used to complete the joint, additional longitudinal tests are required from the respective area of the weld. This does not apply to the welding process or consumables used solely to deposit the root weld. Specimens shall be tested in accordance with the following requirements:

(a) The diameter and gauge length of the test specimen shall be in accordance with Fig. 11.2.1 in Chapter 11 of the Rules for Materials.
(b) For carbon steels, the tensile strength of the weld metal is to be not less than the minimum specified for the plate material and not more than 145 N/mm^2 above this value. The percentage elongation, *A*, is to be not less than that given by:

$$A = \frac{(980 - R)}{21,6}$$

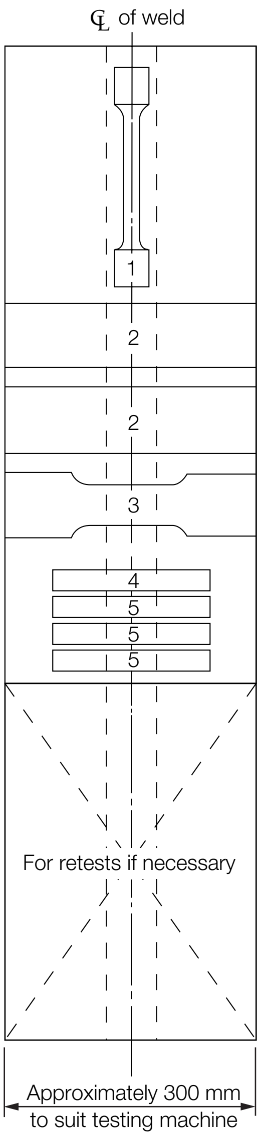


Fig. 17.3.1
Routine test plate – Test specimens for Class 1 and 2/1

1. All weld metal tensile test specimen.
2. Bend test specimens.
3. Tensile test for joints.
4. Macro-test specimen.
5. Charpy V-notch impact test specimens.
   (For all Class 1 pressure vessels and other Classes of pressure vessels where the minimum design temperature is below –10°C).

where *R* is the tensile strength, in N/mm^2, obtained from the all weld metal tensile test. In addition, this elongation is to be not less than 80 per cent of the minmum elongation specified for the plate.

(c) For other materials, the tensile strength and percentage elongation shall not be less than that specified for the base materials welded.

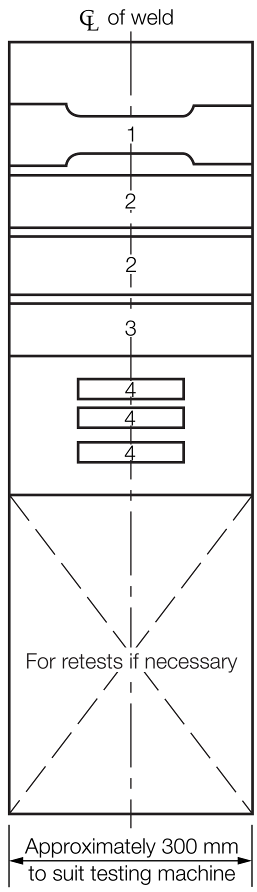


Fig. 17.3.2
Routine test plate – Test specimens for Class 2/2

1. Tensile test for joints.
2. Bend test specimens.
3. Macro-test specimen.
4. Charpy V-notch impact test specimens (if required by Table 17.3.1).

Table 17.3.2 Bend test requirements

Material grade	Former diameter
Up to Grade 460	3*t*
490 and 510	4*t*
13Cr Mo 45	5*t*
11Cr Mo 910	5*t*
Other materials	Subject to agreement

where *t* is the thickness of the bend test specimen.

3.4.4 **Transverse tensile test for joint**. For the transverse tensile test, the weld reinforcement is to be removed, and shall meet the following requirements:

(a) One reduced section tensile test specimen is to be cut transversely to the weld in accordance with the dimensions shown in Fig. 11.2.2 in Chapter 11 of the Rules for Materials.
(b) In general, where the plate thickness exceeds 30 mm, or where the capacity of the tensile test machine prevents full thickness tests, each tensile test may be made up of several reduced section specimens, provided that the whole thickness of the weld is subjected to testing.
(c) The tensile strength obtained is to be not less than the minimum specified tensile strength for the plate material, and the location of the fracture is to be reported.

3.4.5 **Transverse bend test**. The bend test specimens shall meet the following:

(a) Two bend test specimens of rectangular section are to be cut from the test plate transversely to the weld, one bent with the outer surface of the weld in tension (face bend), and the other one with the inner surface in tension (root bend).
(b) The specimens are to be in accordance with Ch 11,2.1.3 of the Rules for Materials.
(c) Each specimen is to be mounted on roller supports with the centre of the weld midway between the supports. The plunger shall have the diameter shown in Table 17.3.2 based on the specimen thickness, *t*.
(d) After bending through an angle of at least 120°, there is to be no crack or defect exceeding 1,5 mm measured across the specimen or 3 mm measured along the specimen. Premature failure at the edges of the specimen should not be cause for rejection, unless this is associated with a weld defect.

3.4.6 **Macro-specimen and hardness survey**. A macro examination specimen is to be removed from the test plate near the end where welding started. The specimen is to include the complete cross-section of the weld and the heat affected zone. The specimen is to be prepared and examined in accordance with the following:

(a) The cross-section of the specimen is to be ground, polished and etched to clearly reveal the weld runs, and the heat affected zones.
(b) The specimen shall show an even weld profile that blends smoothly with the base material and have satisfactory penetration and fusion, and an absence of significant inclusions or other defects.
(c) Should there be any doubt as to the condition of the weld as shown by macro-etching, the area concerned is to be microscopically examined.
(d) For carbon, carbon manganese and low alloy steels, a hardness survey is to be performed on the macro specimen using either a 5 kg or 10 kg load, testing is to include the base material, the weld and the heat affected zone. Hardness scans on the cross-section are to be performed in the cap weld areas within 2 mm of the weld surface. The maximum recorded hardness shall not exceed 350 Hv10.

3.4.7 **Charpy V-notch impact test**. Charpy V-notch impact test specimens are to be prepared for testing when required by Table 17.3.1. Tests are to be performed and satisfy the following requirements:

(a) Each test is to consist of a set of three Charpy V-notch impact specimens and are to be removed with the vee notch perpendicular to the plate surface.
(b) The dimensions and tolerances of the specimens are to be in accordance with Chapter 2 of the Rules for Materials.
(c) Specimens are to be removed for testing from the weld centreline and the heat affected zone (fusion line and fusion line + 2 mm locations). Heat affected zone impact tests may be omitted where the minimum design temperature is above +20°C.
(d) For thicknesses in excess of 20 mm, where more than one welding process or type of consumable has been used to complete the joint, impact tests are required from the respective area of the weld. This does not apply to the welding process or consumables used solely to deposit the root weld.
(e) The average energy of a set of three specimens is not to be less than 27Joules or the minimum specified for the base material, whichever is the higher. The minimum energy for each individual specimen is to meet the requirements of Ch 1,4.5.2 of the Rules for Materials.

3.4.8 **Nick break bend tests**. A nick bend or fracture test specimen is to be a minimum of 100 mm long measured along the weld direction and shall be tested in accordance with and meet the following requirements:

(a) The specimen is to have a slot cut into each side along the centreline of the weld and perpendicular to the plate surface.
(b) The specimen is to be bent along the weld centreline until fracture occurs and the fracture faces have been examined for defects. The weld shall be sound, with no evidence of cracking or lack of fusion or penetration and shall be substantially free from slag inclusions and porosity.

3.5 Failure to meet requirements

3.5.1 If any test specimen fails to meet the requirements, additional specimens may be removed and tested in accordance with Ch 1,1.11 of the Rules for Materials.

3.5.2 Where a routine weld test fails to meet requirements, the welds to which it relates will be considered as not having met the requirements. The reason for the failure is to be established and the manufacturer is to take such steps as necessary to either:

(a) Remove the affected welds and have them re-welded to the Surveyor's satisfaction, or
(b) demonstrate that the affected production welds have acceptable properties.

Section 4
Repairs to welds on fusion welded pressure vessels

4.1 General

4.1.1 Where non-destructive examinations reveal unacceptable defects in the welded seams, they are to be repaired in accordance with the following:

(a) Major repairs shall not be carried out without the prior consent of the Surveyors.
(b) Where cracks have developed as a result of welding, these are to be reported to the Surveyors and the cause established prior to undertaking weld repair.
(c) Defects may be removed by grinding, chipping or thermal gouging. Where thermal gouging is used, the repair groove shall be subsequently ground to remove oxides and debris. In all cases, the groove shall have a profile suitable for welding.
(d) Prior to commencing repair welding, confirmation that the original defect has been removed is required by performing visual examination. This may be augmented by surface crack detection examination at the discretion of the Surveyors.
(e) Repair welding is to be performed using welding procedures agreed with the Surveyors.
(f) Where the pressure vessel requires post weld heat treatment in accordance with Section 5, this shall be performed after completion of the weld repairs.
(g) Weld repairs are to be shown by further non-destructive examinations to have removed the defect to the Surveyor's satisfaction.

4.2 Re-repairs

4.2.1 In general, only two repair attempts are to be made of the same defect. Any subsequent repairs will be at the discretion of the Surveyors and may require the removal of the heat affected zone of the original repair.

Section 5
Post weld heat treatment of pressure vessels

5.1 General

5.1.1 Fusion welded pressure vessels, where indicated in Table 17.5.1 are to be heat treated on completion of the welding of the seams and of all attachments to the shell and ends, and before the hydraulic test is carried out.

5.1.2 Tubes which have been expanded into headers or drums may be seal welded without further post weld heat treatment.

Table 17.5.1 Post weld heat treatment requirements

Type of steel	Plate thickness above which post weld heat treatment (PWHT) is required	
	Steam raising plant	Other pressure vessels
Carbon and carbon/manganese steels without low temperature impact values	20 mm	30 mm
Carbon and carbon/manganese steels with low temperature impact values	20 mm	40 mm
1Cr $^1/_2$Mo	All thicknesses	All thicknesses
2$^1/_4$Cr 1Mo	All thicknesses	All thicknesses
$^1/_2$Cr $^1/_2$Mo $^1/_4$V	All thicknesses	All thicknesses
Other alloy steels	Subject to special consideration	

5.1.3 Where the weld connects parts of different thicknesses, the thickness to be used when applying the requirements for post weld heat treatment is to be either the thinner of the two plates for butt welded connections, or the thickness of the shell for connections to flanges, tubeplates and similar connections.

5.1.4 Parts are to be properly prepared for heat treatment, sufficient temporary supports are to be provided to prevent undue distortion or collapse of the structure and any machined faces are to be adequately protected against scaling.

5.1.5 Care is to be exercised to provide drilled holes in double reinforcing plates and other closed spaces prior to heat treatment.

5.2 Basic requirements for heat treatment of fusion welded pressure vessels

5.2.1 Heat treatment is to be carried out in a properly constructed furnace which is efficiently maintained.

5.2.2 The heat treatment facilities shall be capable of controlling the temperature throughout the heat treatment cycle and adequate means of measuring and recording the vessel temperature are to be provided. To this end, thermo-couples are to be attached such that they are in contact with the vessel.

5.2.3 Unless stated otherwise, post weld heat treatment is to be carried out by means of slow, even heating from 300°C to the soak temperature, holding within the prescribed soaking temperature range for the time specified (usually one hour per 25 mm of weld thickness), followed by slow even cooling to 300°C.

5.2.4 Recommended soaking temperatures and periods are given in Table 17.5.2 for different materials. Where other materials are used for pressure vessel construction, full details of the proposed heat treatment are to be submitted for consideration.

Table 17.5.2 Post weld soak temperatures and times

Material type	Soak temperature, °C (*see* Note)	Soak period
Carbon and carbon/manganese grades:	580–620°	1 hour per 25 mm of thickness, minimum of 1 hour
1Cr $^{1}/_{2}$Mo	620–660°	1 hour per 25 mm of thickness, minimum of 1 hour
2$^{1}/_{4}$Cr 1Mo	650–690°	1 hour per 25mm of thickness, minimum of 1 hour
$^{1}/_{2}$Cr $^{1}/_{2}$Mo $^{1}/_{4}$V	670–720°	1 hour per 25mm of thickness, minimum of 1 hour
NOTE For materials supplied in the tempered condition, the post weld soak temperature shall be lower than the material tempering temperature.		

5.2.5 Where pressure vessels are of such dimensions that the whole length cannot be accommodated in the furnace at one time, the pressure vessels may be heated in sections, provided that sufficient overlap is allowed to ensure the heat treatment of the entire length of the longitudinal seam.

5.2.6 Where it is proposed to adopt special methods of heat treatment, full particulars are to be submitted for consideration. In such cases it may be necessary to carry out tests to show the effect of the proposed heat treatment.

■ *Section 6* **Welded pressure pipes**

6.1 General

6.1.1 Fabrication of pipework is to be carried out in accordance with the requirements of this section unless other more stringent requirements have been specified.

6.1.2 Piping systems are to be constructed in accordance with approved plans and specifications.

6.1.3 Pipe welding may be performed using manual, semi-automatic or fully automatic electric arc welding processes. The use of oxy-acetylene welding will be limited to Class 3 pipework in carbon steel material that is not carrying flammable fluids and limited to butt joints in pipes not exceeding 100 mm diameter or 9,5 mm wall thickness.

6.1.4 Where pressure pipework is assembled and butt welded *in situ*, the piping is to be arranged well clear of adjacent structures to allow sufficient access for preheating, welding, heat treatment and examination of the joints.

6.2 Fit-up and alignment

6.2.1 Acceptable methods of flange attachment are illustrated in Fig. 12.2.2 in Chapter 12. If backing rings are used with flange type (a) then 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. The use of flange types (b) and (c) with alloy steel pipes is limited to pipes up to and including 168,3 mm outside diameter.

6.2.2 Alignment of pipe butt welds shall be in accordance with Table 17.6.1. Where fusible inserts are used the alignment shall be within 0,5 mm in all cases.

Table 17.6.1 Pipe alignment tolerances

Pipe size	Maximum permitted mis-alignment
$D < 150\phi$ mm and $t \le 6$ mm	1,0 mm or 25% of t whichever is the lesser
$D < 300\phi$ mm and $t \le 9,5$ mm	1,5 mm or 25% of t whichever is the lesser
$D \ge 300$ and $t > 9,5$ mm	2,0 mm or 25% of t whichever is the lesser
D = pipe internal diameter t = pipe wall thickness	

6.2.3 Where socket welded fittings are employed, they are to comply with the requirements of Ch 12,2.8. 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.

6.3 Welding workmanship

6.3.1 Welding procedures are to be established for welding of pipework including attachment welds directly to pressure retaining parts and are to be qualified by testing on simulated joints.

6.3.2 Where the work requires a significant number of branch connections, tests may also be required to demonstrate that the type of joint(s) and welding techniques employed are capable of achieving the required quality.

6.3.3 Welding consumables and, where used, fusible root inserts, are to be suitable for the materials being joined.

6.3.4 For welding of carbon and low alloy steels, preheat is to be applied depending on the material grade, thickness and hydrogen grading of the welding consumable in accordance with Table 17.6.2 unless welding procedure testing indicates that higher levels are required.

Table 17.6.2 Minimum preheat requirements

Material grade	Thickness t, in mm (4)	Minimum preheat temperature (1), °C	
		Non-low H_2	Low H_2 (2)
Carbon and carbon/manganese grades: 320 and 360	$t \leq 10$ $t \geq 20$	50 100	10 50
Carbon and carbon/manganese grades: 410, 460 and 490	$t \leq 10$ $t \geq 20$	75 150	20 100
1Cr 1/2Mo	$t < 13$ $t \geq 13$	(3)	100 150
2 1/4Cr 1Mo	$t < 13$ $t \geq 13$	(3)	150 200
1/2Cr 1/2Mo 1/4V	$t < 13$ $t \geq 13$	(3)	150 200

NOTES
1. For thicknesses up to 6 mm, the preheat levels specified may be reduced subject to satisfactory hardness testing during welding procedure qualification.
   In all cases where the ambient temperature is 0°C or below, preheat is required.
2. Low hydrogen process or consumables are those which have been tested and have achieved a grading of H15 or better, *see* Chapter 11 of the Rules for Materials.
3. Low hydrogen process is required for these materials.
4. t = the thickness of the thicker member.

6.3.5 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.

6.3.6 All welding is to be performed in accordance with the approved welding procedures (*see* 6.3.1) by welders who are qualified for the materials, joint types and welding processes employed.

6.3.7 Welding without filler metal is generally not permitted for welding of duplex stainless steel materials.

6.3.8 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.

6.3.9 Check tests of the quality of the welding are to be carried out periodically at the discretion of the Surveyors.

6.4 Heat treatment after bending of pipes

6.4.1 Heat treatment should be carried out in a suitable furnace provided with temperature recording equipment in accordance with 5.2.

6.4.2 Hot forming should generally be carried out within the normalizing temperature range. When carried out within this temperature range, no subsequent heat treatment is required for carbon and carbon/manganese steels. For alloy steels, 1Cr 1/2Mo, 2 1/4Cr 1Mo and 1/2Cr 1/2Mo 1/4V, a subsequent stress relieving heat treatment in accordance with Table 17.5.2 is required irrespective of material thickness.

6.4.3 When hot forming is performed outside the normalizing temperature range, a subsequent heat treatment in accordance with Table 17.6.3 is required.

Table 17.6.3 Heat treatment after forming of pipes

Type of steel	Heat treatment required
Carbon and carbon/manganese: Grades 320, 360, 410, 460 and 490	Normalize at 880 to 940°C
1Cr 1/2Mo	Normalize at 900 to 960°C, followed by Tempering at 640 to 720°C
2 1/4Cr 1Mo	Normalize at 900 to 960°C, followed by Tempering at 650 to 780°C
1/2Cr 1/2Mo 1/4V	Normalize at 930 to 980°C, followed by Tempering at 670 to 720°C
Other alloy steels	Subject to special consideration

6.4.4 After cold forming to a radius measured at the centreline of the pipe of less than four times the outside diameter, heat treatment in accordance with Table 17.6.3 is required.

6.4.5 The heat treatments specified above shall be applied unless the pipe material manufacturer specifies or recommends other requirements.

6.4.6 Bending procedures and subsequent heat treatment for other alloy steels will be subject to special consideration.

6.5 Post weld heat treatment of pipe welds

6.5.1 Post weld heat treatment shall be carried out in accordance with the general requirements specified in 5.2 for pressure vessels.

6.5.2 Post weld heat treatment is to be performed on steel pipes and fabricated branch pieces on completion of welding where the material thickness exceeds that specified in Table 17.6.4.

Table 17.6.4 Thickness limits for post weld heat treatment of pipe welds

Type of steel	Requirements for heat treatment
Carbon and carbon/manganese: Grades 320, 360, 410, 460 and 490	Thicknesses exceeding 30 mm
1Cr $^{1}/_{2}$Mo	Thicknesses exceeding 8 mm
2$^{1}/_{4}$Cr 1Mo	All thicknesses
$^{1}/_{2}$Cr $^{1}/_{2}$Mo $^{1}/_{4}$V	All thicknesses
Other alloy steels	Subject to special consideration

6.5.3 Recommended soaking temperatures and periods for post weld heat treatment are given in Table 17.5.2.

6.5.4 Where oxy-acetylene welding has been used, due consideration should be given to the need for normalizing and tempering after such welding.

■ *Section 7* Non-Destructive Examination

7.1 General

7.1.1 Non-Destructive Examinations (NDE) of pressure vessel welds are to be carried out in accordance with a nationally recognized code or standard.

7.1.2 NDE should not be applied until an interval of at least 48 hours has elapsed since the completion of welding.

7.2 NDE personnel

7.2.1 NDE Personnel are to be qualified to an appropriate level of a nationally recognized certification scheme.

7.2.2 Generally, operators subject to direct supervision are to be qualified to Level I, unsupervised personnel to Level II and more senior personnel to Level III.

7.2.3 Qualification schemes are to include assessments of practical ability for Levels I and II individuals; these examinations to be made on representative test pieces containing relevant defects.

7.3 Extent of NDE

7.3.1 For Class 1 pressure vessels:

(a) All butt welded seams in drums, shells, headers and test plates, together with tubes or nozzles over 170 mm outside diameter are subject to 100 per cent volumetric and surface crack detection inspections.

(b) For circumferential butt welds in extruded connections, tubes, headers and other tubular parts of 170 mm outside diameter or less, at least 10 per cent of the total number of welds is to be subjected to volumetric examination and surface crack detection inspections.

7.3.2 For Class 2/1 pressure vessels, volumetric and surface crack detection inspections are to be applied at selected regions of each main seam. At least 10 per cent of each main seam is to be examined together with the full length of each welded test plate. When an unacceptable indication is detected, at least two additional check points in the seam are to be selected by the surveyor for examination using the same inspection method. If further unacceptable defects are found then either:

(a) the whole length of weld represented is to be cut out and re-welded and re-examined as if it was a new weld with the test plates being similarly treated; or

(b) the whole length of the weld represented is to re-examined using the same inspection methods.

7.3.3 Butt welds in Class 1 pipes of 75mm or more outside diameter are subject to 100 per cent volumetric and surface crack detection inspections. The extent and method of testing applied to butt welds in Class 1 pipes of less than 75 mm outside diameter is at the Surveyor's discretion.

7.3.4 For Class II pipes of 100 mm or more outside diameter, random volumetric examination is to be carried out on at least 10 per cent of butt welds. The extent and method of testing to be applied to fillet welds is at the Surveyor's discretion.

7.3.5 NDE is not required for Class II pipes less than 100 mm outside diameter.

7.3.6 Butt welds in furnaces, combustion chambers and other pressure parts for fired pressure vessels under external pressure are to be subject to spot volumetric examination, the minimum length of each check point being 300 mm.

7.4 Procedures

7.4.1 Non-Destructive Examinations are to be made in accordance with a definitive written procedure prepared in accordance with a nationally recognized standard and endorsed by a Level III individual. As a minimum, the procedure will identify personnel qualification levels, NDE datum and identification system, extent of testing, methods to be applied with technique sheets, acceptance criteria and reporting requirements.

7.5 Method

7.5.1 Volumetric examinations may be made by radiography or, in the case of welds of nominal thickness 15 mm or above, by ultrasonic testing. The preferred method for surface crack detection in ferrous metals is magnetic particle inspection, and that for non-magnetic materials is liquid penetrant inspection.

7.6 Repairs

7.6.1 Unacceptable defects are to be repaired and re-examined using the NDE methods originally applied.

7.7 Evaluation and reports

7.7.1 The manufacturer shall be responsible for the review, interpretation, evaluation and acceptance of the results of NDE. Reports stating compliance or otherwise with the criteria established in the inspection procedure are to be issued. Reports are to include the following information where appropriate:
(a) date of inspection;
(b) names, qualifications and signatures of operator and supervisor;
(c) component identification;
(d) location and extent of testing;
(e) heat treatment status;
(f) weld type, procedure and configuration;
(g) surface condition;
(h) inspection procedure reference;
(j) equipment used;
(k) results showing size, position and nature of any defects repaired; and
(l) statement of final acceptability to established criteria.

■ *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 (centralized) 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.

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 Means, 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.

3.2.12 Arrangements should be made to enable alarm lights on the bridge to be dimmed as required.

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.

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.

■ *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).

1.3 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.

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 the steering gear components and the rudder stock 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^2. 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^2

W = weight of rudder and stock, if applicable, when tending to separate the fit, in N

Q = shear force = $\dfrac{2M}{d_m}$ 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

θ = cone taper half angle in radians (e.g. for cone taper 1:10, θ = 0,05)

μ = coefficient of friction

σ_r = radial interfacial pressure or grip stress, in N/mm^2.

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	(a) For keyed connection, factor of safety against slippage, S = 1,0 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 ≤ 1:10 (b) For keyless connection, factor of safety against slippage, S = 2,0 The maximum equivalent von Mises stress should not exceed the yield stress For conical sections, the cone taper should be ≤ 1:15 (c) Coefficient of friction (maximum) = 0,17 (d) Grip stress not to be less than 20 N/mm^2
(2) Hydraulic fit - tiller to stock, *see also* 1.6.4 and 1.6.5	(a) For keyed connection, factor of safety against slippage, S = 1,0 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 ≤ 1:10 (b) For keyless connection, factor of safety against slippage, S = 2,0 The maximum equivalent von Mises stress should not exceed the yield stress For conical sections, the cone taper should be ≤ 1:15 (c) Coefficient of friction (maximum) = 0,14 (d) Grip stress not to be less than 20 N/mm^2
(3) Ring locking assemblies fit – tiller to stock, *see also* 1.6.3	(a) Factor of safety against slippage, S = 2,0 The maximum equivalent von Mises stress should not exceed the yield stress (b) Coefficient of friction = 0,12 (c) Grip stress not to be less than 20 N/mm^2
(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	Shim to be fitted between two halves before machining to take rudder stock, then removed prior to fitting Minimum thickness of shim, For 4 connecting bolts: $t_s = 0{,}0014\,\delta_t$ mm For 6 connecting bolts: $t_s = 0{,}0012\,\delta_t$ mm Key(s) to be fitted Diameter of bolts, $\delta_{tb} = \dfrac{0{,}60\,\delta_{su}}{\sqrt{n_{tb}}}$ mm 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. Distance from centre of stock to centre of bolts should generally be equal to $\delta_t \left(1{,}0 + \dfrac{0{,}30}{\sqrt{n_{tb}}}\right)$ mm Thickness of flange on each half of the bolted tiller ≥ $\dfrac{0{,}66\,\delta_t}{\sqrt{n_{tb}}}$ mm
(5) Key/keyway, *see* symbols	Effective sectional area of key in shear ≥ $0{,}25\,\delta_t^2$ mm^2 Key thickness ≥ $0{,}17\,\delta_t$ mm 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
(6) Section modulus – tiller arm (at any point within its length about vertical axis), *see* symbols	To be not less than the greater of: (a) $Z_{TA} = \dfrac{0{,}15\,\delta_t^3\,(b_T - b_s)}{1000\,b_T}$ cm^3 (b) $Z_{TA} = \dfrac{0{,}06\,\delta_t^3\,(b_T - 0{,}9\,\delta_t)}{1000\,b_T}$ cm^3 If more than one arm fitted, combined modulus is to be not less than the greater of (a) or (b) For solid tillers, the breadth to depth ratio is not to exceed 2
(7) Boss, *see* symbols	Depth of boss ≥ δ_t Thickness of boss in way of tiller ≥ $0{,}4\,\delta_t$

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^3

δ_t = Rule rudderstock diameter in way of tiller, *see* Pt 3, Ch 13

δ_{tb} = diameter of bolts securing bolted tillers and quadrants, in mm

■ *Section 2* Performance

2.1 General

2.1.1 Unless the main steering gear comprises two or more identical power units, in accordance with 2.1.4 or 8.1.1, every ship is to be provided with a main steering gear and an auxiliary steering gear in accordance with the requirements of the Rules. The main steering gear and the auxiliary steering gear is to be so arranged that the failure of one of them will not render the other one inoperative.

2.1.2 The main steering gear and rudder stock is 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 gear is 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 gear comprises two or more identical power units, an auxiliary steering gear need not be fitted, provided that:
(a) In a passenger ship, the main steering gear is capable of operating the rudder 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 gear is capable of operating the rudder as required by 2.1.2(b) while operating with all power units;
(c) The main steering gear is 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 synchronized 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 minimize local concentrations of stress.

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

σ_B = specified minimum tensile strength of material at ambient temperature

σ_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:

	Wrought steel	*Cast steel*	*Nodular cast iron*
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, utilize 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:

(a) Arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system;

(b) 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:

(a) The setting pressure is not to be less than 1,25 times the maximum working pressure.

(b) 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 recognized 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.

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 recognizable 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 shutdown 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 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.

5.1.3 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.

5.1.4 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.

5.1.5 Two exclusive circuits are to be provided for each electric or electrohydraulic steering gear arrangement consisting of one or more electric motors.

5.1.6 Each of these circuits is to be fed from the main switchboard. One of these circuits may pass through the emergency switchboard.

5.1.7 One of these circuits may be connected to the motor of an associated auxiliary electric or electrohydraulic power unit.

5.1.8 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.

5.1.9 These circuits are to be separated throughout their length as widely as is practicable.

5.1.10 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.

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	—	Indication, *see* 4.1.3
Steering gear power units, power	Failure	—
Steering gear motors	Overload, Single phase	For alarm and running indication locations, *see* 5.1.2 and 5.1.3
Control system power	Failure	—
Steering gear hydraulic oil level	Low	Each reservoir to be monitored. For alarm locations, *see* 5.1.4
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 1
Hydraulic oil filter differential pressure	High	When oil filters are fitted

NOTE
This alarm is to identify the system at fault and to be activated when (for example):
- position of the variable displacement pump control system does not correspond with given order; or
- incorrect position of 3-way full flow valve or similar in constant delivery pump system is detected.

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.

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, an alternative power supply, sufficient at least to supply the steering gear power unit which complies with the requirements of 2.1.3 and also its associated control system and the rudder angle 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.

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, alternative trial conditions may be specially considered. In this case, for the main steering gear trial, the speed of the ship corresponding to the maximum continuous revolutions of the main engine should apply:

(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.

■ *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 recognized standards. Materials for pressure retaining components are to be in accordance with recognized 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^2.

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:

$$\sigma_m \leq f$$
$$\sigma_1 \leq 1{,}5f$$
$$\sigma_b \leq 1{,}5f$$
$$\sigma_1 + \sigma_b \leq 1{,}5f$$
$$\sigma_m + \sigma_b \leq 1{,}5f$$

where

f = the lesser of $\dfrac{\sigma_B}{A}$ or $\dfrac{\sigma_y}{B}$

σ_b = equivalent primary bending stress
σ_m = equivalent primary general membrane stress
σ_y = specified minimum yield stress or 0,2 per cent proof stress of material at ambient temperature
σ_B = specified minimum tensile strength of material at ambient temperature
σ_1 = equivalent primary local membrane stress

A and B are as follows:

	Wrought steel	*Cast steel*	*Nodular cast iron*
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
σ_B = tensile strength as defined in 9.2.4
σ_{Ba} = actual tensile strength.

9.3 Construction details

9.3.1 **General.** The construction should be such as to minimize local concentrations of stress.

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 recognized 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.

9.5.2 When installed on board the ship, the rudder actuator should be subjected to a hydrostatic test 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.

■ *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 In addition to the requirements of Chapter 19, the azimuthing mechanism is to be capable of a maximum rotational speed of not less than 1,5 rev/min.

■ *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 Chapter 9 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.

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, 2.2.1

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 13,2.1.1 (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:

$$Z = 1{,}73\sqrt{(V+3)^4 A_N^2 x_P^2 + \frac{a^2}{4} T_M^2 10^4} \quad \text{cm}^3$$

where

a = dimension, in metres, as shown in Fig. 20.3.1

T_M = maximum thrust of the thruster unit in tonnes.

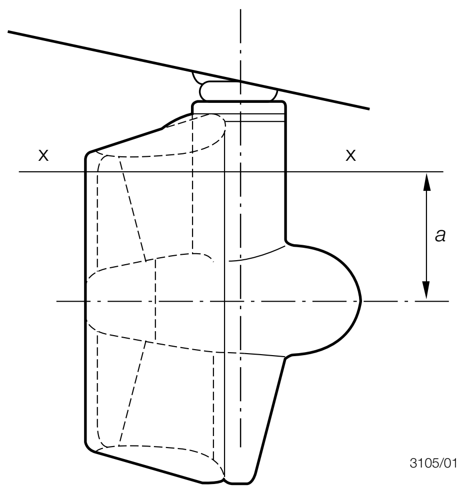


Fig. 20.3.1 Steerable thruster

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 (≤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.

3.4 Components

3.4.1 The hydraulic power operating systems for each azimuth thruster are to be provided with the following:

(a) arrangements to maintain the cleanliness of the hydraulic fluid, taking into consideration the type and design of the hydraulic system;

(b) 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.

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.

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

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 2,15.2.5 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, convertors, 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:

(a) the voltage regulation and current sharing requirements defined in Pt 6, Ch 2,8.4.2 and 8.4.7 are to be maintained over the full range of power factors that may occur in service,

(b) auxiliary equipment and services are to operate with any waveform distortion introduced by convertors 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.

■ *Section 1* General

1.1 Application

1.1.1 This Chapter is applicable to all machinery, and the requirements are to be applied in conjunction with the relevant Chapters of Parts 5 and 6 and the ShipRight procedures.

1.1.2 Details of LR's ShipRight procedures are given in LR's *ShipRight Procedures Overview* and in this Chapter, where related to particular items and notes.

1.1.3 Details of hull ShipRight procedures are to be found in Pt 3, Ch 16.

1.2 Classification notations and descriptive notes

1.2.1 In addition to the machinery class notations defined in Pt 1, Ch 2, ships complying with the requirements of this Chapter will be eligible to be assigned the descriptive notes as defined in Pt 1, Ch 2,2.6 and associated with the ShipRight procedures.

1.3 Information and plans required to be submitted

1.3.1 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 in this Chapter where related to particular items and notes.

■ *Section 2* Machinery Planned Maintenance Scheme

2.1 Descriptive note MPMS

2.1.1 Where an Owner operates an approved Planned Maintenance Scheme as part of the Continuous Survey Machinery (CSM) cycle, the descriptive note **MPMS** will, at the Owner's request, be entered in column 6 of the *Register Book*.

2.1.2 The descriptive note will indicate that procedures and documentation are in place to control and record the inspection and maintenance routines of all machinery and equipment in the ship.

2.1.3 For the requirements and approval procedures, *see* the appropriate procedures in the *ShipRight Procedures Overview*.

■ *Section 3* Machinery Condition Monitoring

3.1 Descriptive note MCM

3.1.1 Where an Owner operates an Approved Planned Maintenance Scheme as part of the Continuous Survey Machinery (CSM) cycle, and monitoring techniques and equipment are used to record the condition against agreed acceptable limits, the descriptive note **MCM** will, at the Owner's request, be entered in column 6 of the *Register Book*.

3.1.2 The descriptive note will indicate that equipment, procedures and documentation are in place to monitor, control and record the physical and operational condition of the equipment on the ship and control the maintenance routines accordingly.

3.1.3 For the requirements and approval procedures, *see* the appropriate procedures in the *ShipRight Procedures Overview*.

■ *Section 4* Turbine Condition Monitoring

4.1 Descriptive note TCM

4.1.1 Where an Owner adopts the requirements for monitoring of the main steam turbine, the descriptive note **TCM** will, at the Owner's request, be entered in column 6 of the *Register Book*.

4.1.2 The descriptive note will indicate that equipment and procedures are in place, in order to determine the physical and operational condition of that equipment.

4.1.3 For the requirements, *see* the appropriate procedure in the *ShipRight Procedures Overview*.

■ *Section 5*
Screwshaft Condition Monitoring

5.1 Descriptive note SCM

5.1.1 Where an Owner adopts the requirements for monitoring of the screwshaft, the descriptive note **SCM** will, at the Owner's request, be entered in column 6 of the *Register Book*.

5.1.2 The descriptive note will indicate that equipment and procedures are in place, in order to determine the physical and operational condition of that equipment.

5.1.3 For the requirements, *see* Pt 1, Ch 3,17.3 and the appropriate procedure in the *ShipRight Procedures Overview*.

■ *Section 6*
Reliability Centred Maintenance

6.1 Descriptive note RCM

6.1.1 Where an Owner operates an Approved Planned Maintenance Scheme based on the use of Reliability Centred Maintenance as part of the Continuous Survey Machinery (CSM) cycle, the descriptive note **RCM** will, at the Owner's request, be entered in column 6 of the *Register Book*.

6.1.2 The descriptive note will indicate that procedures and documentation are in place to control and record the inspection and maintenance routines of all machinery and equipment in the ship, and that they are based on acceptable and applicable methodology.

6.1.3 For the requirements and approval procedures, *see* the appropriate procedures in the *ShipRight Procedures Overview*.

■ *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 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. 100 per cent propulsion power is the approved total power of all the main propulsion units at maximum continuous rating (MCR). 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 of this Chapter will be eligible for the machinery class notation **PMR** (Propulsion Machinery Redundancy), **SMR** (Steering Machinery Redundancy) or **PSMR** (Propulsion and Steering Machinery Redundancy), which will be recorded in the *Register Book*.

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★** (Propulsion Machinery Redundancy in separate machinery spaces), **SMR★** (Steering Machinery Redundancy in separate machinery spaces) or **PSMR★** (Propulsion and Steering Machinery Redundancy in separate machinery spaces) which will be recorded in the *Register Book*.

1.2 Plans and information

1.2.1 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 in equipment, the ship will retain in operation 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.

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 of the installed prime mover capacity and not less than 50 per cent of the installed propulsion systems are available.

(b) Where the steering capability requirements described in 3.2.1 are available.

IMO Resolution A.751(A) *Interim 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 The FMEA is to establish that in the event of a single component failure, for ships assigned:

(a) **PSMR** and **PSMR★** notations, at least 50 per cent of the propulsion power and steering capability remains available;

(b) **PMR** and **PMR★** notations, at least 50 per cent of the propulsion power remains available; and

(c) **SMR** and **SMR★** notations, the steering capability remains available.

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 organized 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 following 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; and
(c) for **SMR** and **SMR★** notations, that the steering capability remains available.

■ *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.

3.2 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, disconnector, 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 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.

3.3.3 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.

3.3.4 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) A fire in any machinery compartment.
(b) 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.

Section

■ *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. 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. 23.1.1. 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.

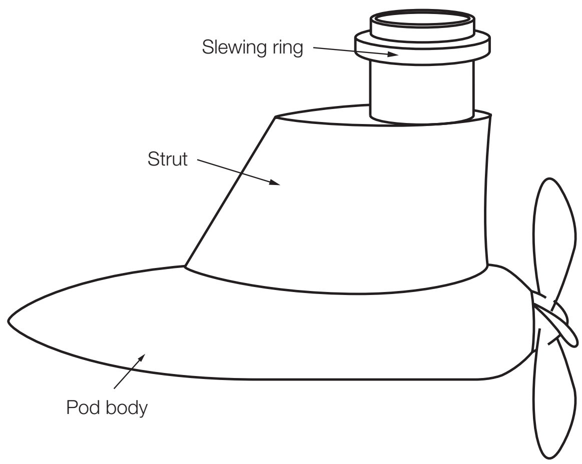


Fig. 23.1.1 Podded propulsion unit

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.

■ *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. 23.2.1.
(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, 6.6.5 and 6.6.6).
(j) Supporting data calculations and direct calculation reports. This is to include 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. *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.
    - 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 ring structure and nozzle support details if applicable to the application.
(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 6.6.6.
(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) 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.

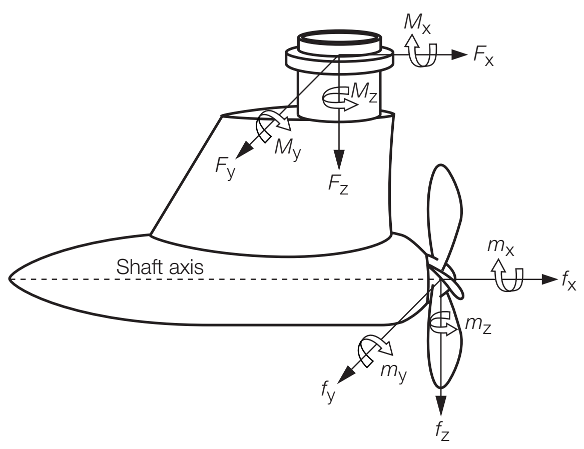


Fig. 23.2.1 Pod co-ordinate system

(v) 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.
(w) Access and closing arrangements for pod unit inspection and maintenance.
(x) Heat balance calculations for pods having an electric propulsion motor but no active cooling system, *see* 6.7.4.
(y) Details of proposed testing and trials required by Section 9.
(z) Details of emergency steering and pod securing arrangements. *See* 6.3.11.

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.

2.3 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. 23.2.1.

2.4.2 Where the maximum loads and moments described in 2.4.1 cannot be readily identified from calculation methods or are based on model testing, the estimated loads and moments are to be stated at pod unit steering angular intervals of 5 degrees over the range from ahead to astern for the relevant combinations of shaft rotational and ship speed. 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.

2.5 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.

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 analyzed 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.

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 analyzed. 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 Chapter 9 and Pt 3, Ch 9 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 In general, the steering mechanism is to be capable of turning the pod between the 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.

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 cleanness 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 to be fully examined in accordance with the manufacturer's recommendations at docking Survey to the Surveyor's satisfaction.

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^2 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 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 23.5.1. Where the scantling requirements in Table 23.5.1 are not 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 operational requirements of the propulsion or steering system components.

Table 23.5.1 Podded propulsion unit structural 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 to 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^3 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^3 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		

5.2 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. 23.5.1. Proposals to use alternative arrangements that provide an equivalent degree of strength and rigidity may be submitted for appraisal.

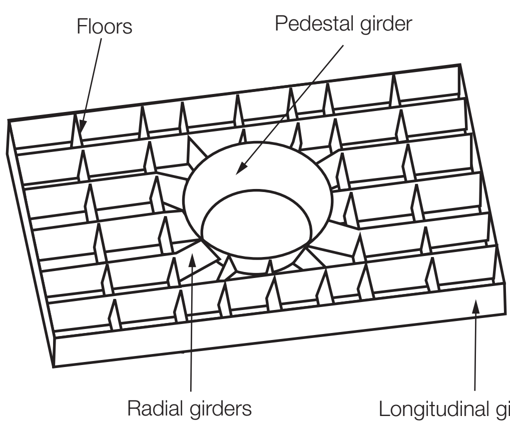


Fig. 23.5.1 Hull support structure

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 23.5.2, *see also* 5.3.5.

Table 23.5.2 Direct calculation maximum permissible stresses

Permissible stress values		
Location	Podded drive structure	Podded drive/hull interface
X-Y shear stress	$0{,}26\sigma_O$	$0{,}35\sigma_O$
Direct stress due to bending	$0{,}33\sigma_O$	$0{,}63\sigma_O$
Von Mises stress	$0{,}40\sigma_O$	$0{,}75\sigma_O$
Localised Von Mises peak stresses	σ_O	σ_O
Symbols		
σ_O = 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.		

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. 23.5.1) 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 23.5.2, *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.

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 23.5.2 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 23.5.2 are not applicable, details of cumulative load history and stress range together with the proposed acceptance criteria are to be submitted for consideration.

■ *Section 6* Machinery design and construction requirements

6.1 General

6.1.1 The requirements detailed in Chapter 1 are applicable.

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 Chapter 6 and Chapter 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 ±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^2 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.

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. 23.2.1.
- 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 On multi podded ships, means are to be provided to hold the propeller on 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 lubricating oil 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 The sampling points required by Ch 14,8.9 are to be located such that the sample taken is representative of the oil present at the bearing.

6.5.4 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.

6.5.5 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.

6.5.6 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.

6.5.7 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 gear in Ch 19,2 is to be achieved by means of two or more identical power units.

6.6.3 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.

6.6.4 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.

6.6.5 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 (≤10^3 load cycles) steering torque. The static duty steering torque should not be less than M_W, 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 recognized 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.

6.6.6 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.

6.6.7 Means of allowing the condition of the slewing gears and bearings to be assessed are to be provided.

6.6.8 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 2,8.6.

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(x) 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 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.

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.

■ *Section 8*
Control engineering arrangements

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, the main machinery control station 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 Means 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 2,15.3.7.

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 1,2.12 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.

8.2 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 23.8.1.

8.2.2 Alarms specified in Table 23.8.1 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 bilge pumping arrangements are to function automatically in the event of a high liquid level being detected in the pod unit.

8.2.5 The number and location of bilge level detectors are to be such that accumulation of liquids will be detected at all design angles of heel and trim.

8.2.6 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 23.8.1 Specific alarms for pod control systems

Item	Alarm	Note
Podded drive azimuth angle	—	Indicator, *see* 8.1.4
Propulsion motors	Overload, power failure	To be indicated on the navigating bridge
Hydraulic oil system pressure	Low	To be indicated on the navigating bridge
Lubricating oil supply pressure	Low	If separate forced lubrication for shaft bearings; to be indicated on the navigating bridge
Lubricating oil temperature	High	
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
Bilge pump operation	Abnormal	Alarm set to indicate a frequency or duration exceeding that which would normally be expected
Bilge level	High	

■ *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. *See* 2.2.1(u).

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.

Published by Lloyd's Register
Registered office
71 Fenchurch Street, London, EC3M 4BS
United Kingdom

Printed by Butler and Tanner,
Frome, Somerset