RULES

FOR THE CLASSIFICATION OF SHIPS

PART 7 – MACHINERY INSTALLATION
January 2026

CROATIAN REGISTER OF SHIPPING

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By the decision of the General Committee to the Croatian Register of Shipping,

RULES FOR THE CLASSIFICATION OF SHIPS
Part 7 – MACHINERY INSTALLATION
edition January 2026

have been adopted on 22nd December 2025 and shall enter into force on 1 January 2026

REVIEW OF AMENDMENTS IN RELATION TO PREVIOUS EDITION OF THE RULES

RULES FOR THE CLASSIFICATION OF SHIPS
Part 7 – MACHINERY INSTALLATION

All major changes in respect to the Rules for the classification of ships, Part 7 – Machinery installation, edition January 2018, as last amended by Amendments No. 4, edition January 2025 throughout the text are shaded (if any).

Items not being indicated as corrected have not been changed.

The grammar and print errors, have been corrected throughout the Rules and are not subject to above indication of changes.

This Part of the Rules includes the requirements of the following international Organisations:

International Maritime Organization (IMO)

Conventions: International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and all subsequent and applicable amendments adopted up to MSC 108
Protocol of 1988 relating to the International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS PROT 1988)

Circulars: MSC.1/Circ.1203

International Association of Classification Societies (IACS)

Unified Requirements (UR):
K3 (Corr. 2, 1998), M25 (Rev. 5, Dec. 2024), M34 (1980), M40 (1981), M46 (Rev. 4, Aug. 2024), M52 (Rev. 3, Nov. 2024), M62 (2002), M68 (Rev.3, 2021), M83 (Oct 2023), M85 (Nov. 2024)

Unified Interpretations (UI):
SC16 (Rev. 2, 2006), SC17 (Rev. 2, 2005), SC95 (1994), SC184 (Rev. 1, 2005), SC242 (corr. 1, Aug 2011, reinstated)

Recommendations (Rec.):
No. 26 (Rev. 2, 2023), No. 27 (Rev. 2, 2024), No. 28 (Rev. 2, 2024), No. 29 (Rev. 2, 2024), No. 30 (Rev. 2, 2024)

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1 GENERAL REQUIREMENTS

1.1 APPLICATION

1.1.1 This part of the *Rules* states the general conditions for arrangement and control of ship machinery installations, shaftlines, propellers and spare parts.

1.1.2 The requirements of this part of the *Rules* are based upon the requirement that the flash point of fuel oil used for propulsion engines and boilers in ships of navigation area 1 (unrestricted service) shall not be below 60°C, and the flash point of fuel oil for emergency generator engine not below 43°C (see the *Rules for the classification of ships, Part 17-Fire protection*, 3.1.2.24).

The use of fuel oil with a flash point lower than 60°C, but in any case not below 43°C, may be admitted in ships of navigation area from 2 to 8 (restricted service), provided that the ambient temperature of spaces, in which fuel oil is stored or used, is always at least 10°C below the flash point. Proper measures to be taken to fulfil this requirement, in each particular case, shall be separately considered by the *Register*.

1.2 DEFINITIONS AND EXPLANATIONS

1.2.1 Definitions and explanations relating to general terminology of the Rules are referred to in the *Rules for the classification of ships, Part 1 - General requirements, Chapter 1 – General information*. For the purpose of this Part of the Rules, for the *Rules for the classification of ships, Part 8 - Piping* and the *Rules for the classification of ships, Part 9 - Machinery* the following definitions have been adopted:

1.2.2 **Oil Fuel Units** – any equipment, used for the preparation and delivery of oil fuel, heated or not, to boilers (including inert gas generators) and engines (including gas turbines) at a pressure of more than 0,18 MPa. Oil fuel transfer pumps are not considered as oil fuel units (MSC.1/Circ.1203).

1.2.3 **Equipment** – various types of filters, heat exchangers, tanks and other arrangements ensuring normal operation of machinery installations.

1.2.4 **Machinery spaces of category A** – spaces and trunks to such spaces which contain either:

- internal combustion machinery used for main propulsion;
- 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
- any oil-fired boiler or oil fuel unit, or any oil-fired equipment other than boilers, such as inert gas generators, incinerators, etc.

1.2.5 **Machinery Spaces** – all machinery spaces of A Category and all other spaces containing main engines, shaftlines, boilers, oil fuel units, steam engines, internal combustion engines, generators and major electrical equipment, fuel oil filling stations, refrigerating, stabilising, ventilation and air-conditioning machinery, and similar spaces; together with the trunks to such spaces.

1.2.6 **Engine Room** – machinery spaces intended for main engines and, in the case of electrically propelled ships, for the main generators and/or propulsion electric motors.

1.2.7 **Main Engines** – machinery intended for driving propellers or propulsors (propulsion units).

1.2.8 **Auxiliary Engines and Machinery** – machinery necessary for the operation of main engines, supply of the ship with electric power and other kinds of energy, as well as for normal operation of the systems and arrangements subject to supervision of the *Register*.

1.2.9 **Rated Power** – maximum continuous (not time-limited) power used as the basis for calculations. It is stated in the *Rules* and in the documents issued by the *Register*.

1.2.10 **Rated Speed** – rotational speed (number of revolutions per minute) corresponding to rated power.

1.2.11 **Remote Control** – remote-functioning system used for the changing of the speed and direction of rotation, as well as for starting and stopping of the machinery from a distance.

1.2.12 **Control Stations** – those spaces in which the ship's radio or main navigating equipment or the emergency source of power is located or where the fire recording or fire control equipment is centralised. The last mentioned spaces are also considered to be fire control stations (the *Rules for the classification of ships, Part 17 - Fire protection*, 3.1.2.18).

Main navigational equipment includes, in particular, the steering stand and the compass, radar and direction-finding equipment.

Steering gear rooms containing an emergency steering position are not considered to be control stations.

Spaces containing, for instance, the following battery sources should be regarded as control stations regardless of battery capacity:

.1 emergency batteries in separate battery room for power supply from black-out till start of emergency generator,
.2 emergency batteries in separate battery room as reserve source of energy to radiotelegraph installation,
.3 batteries for start of emergency generator, and
.4 in general, all emergency batteries required by the *Rules*.

1.2.13 **Central Control Station** – control station where remote controls are arranged to operate the main and auxiliary engines, controllable pitch propellers, or cycloidal propulsors (Voith-Schneider), as well as measuring instruments and gauges, alarm devices and means of communication.

1.2.14 **Local Control Station** – control station fitted with controls, measuring instruments and gauges and means of communication, located in proximity to, or directly on, the engine.

1.2.15 **Common Control Station** – control station fitted with measuring instruments and gauges, alarm devices, means of communication, and equipment for simultaneous control of two or several main engines.

1.2.16 **Escape Way** – way leading from the lowest level of the machinery space floor plates to the exit of that space.

1.2.17 **Exit** – opening in the bulkhead or deck provided with means for closing and intended for the passage of persons.

1.3 SCOPE OF SUPERVISION

1.3.1 General requirements related to classification, supervision during construction and surveys, as well as the requirements for the technical documentation which shall be sent to the Register for review or approval, are set forth in the *Rules, Part 1 - General Requirements*.

1.3.2 The *Register* shall carry out supervision during manufacture, in compliance with the approved technical documentation, of the following assemblies and items:

.1 shaftline assemblies, including propeller shafts with liners or other corrosion protections, shaft bearings, thrust bearings and stern tube bearings, couplings, glands, etc.;

.2 propellers, bow thrusters, water-jet propulsion units, pitch control gear, lubrication and propeller blades controlling systems;

.3 items referred to in the Table 1.3.2;

.4 corresponding spare parts recommended in accordance with Chapter 9.2.

Table 1.3.2
The parts which shall be supervised by the *Register* during manufacture

Nos.	Component	Material [1]	Chapter of the *Rules, Part 25 - Metallic Materials*
1	**SHAFTING** [4]		
1.1	Thrust, intermediate and propeller shafts[2]	forged steel	3.11
1.2	Propeller shaft liners	copper alloys stainless steel	4.2 approved by the *Register*
1.3	Coupling flanges	forged steel cast steel	3.11 3.12
1.4	Coupling flange bolts	forged steel	3.11
1.5	Stern tubes	cast steel cast iron steel plates	3.12 3.13.2 3.2
1.6	Stern bushes and strut bushes	copper alloys cast iron cast steel	4.2 3.13.2 3.12
1.7	Bearing materials	bearing alloys and non-metal materials	approved by the *Register*
1.8	Thrust bearing casting	cast steel cast iron steel plates	3.12 3.13.2 3.3
2	**PROPELLERS**[1),3)]		
2.1	Solid propellers, blades and hubs of built propellers	cast steel copper alloys	3.12 4.3
2.2	Bolts for fastening blades, cap and glands	copper alloys forged steel	approved by the *Register* 3.11
2.3	Propeller cap	cast steel copper alloys	3.12 4.2 and 4.3

Notes:
1) Material shall be chosen in accordance with 1.14.
2) Thrust shafts, propeller and intermediate shafts as well as propeller blades shall be examined by one of the non-destructive methods approved by the *Register*.
3) Nomenclature, material and test groups of parts of controllable pitch propellers and cycloidal propulsors (Voith-Schneider), in each case, shall be submitted to the Register for special consideration.
4) For use of rolled steel see 1.14.5

1.3.3 The fitting of equipment in machinery space as well as testing of machinery installations listed below, are subject to supervision of the *Register*:

.1 main engines, their reduction gears and couplings;

.2 boilers, heat exchangers and other pressure vessels;

.3 auxiliary machinery;

.4 control, monitoring and signalling systems;

.5 shafting and propellers.

1.3.4 After assembling on board all machinery installations shall be tested under a load according to the approved program.

1.4 POWER OF MAIN ENGINES

1.4.1 For nominal output of main engines in ships with ice class notations see the *Rules, Part 29 – Polar Class Ships and Ice Class Ships*.

1.4.2 For use of propulsion turbines in ships with ice class notations see the *Rules, Part 29 – Polar Class Ships and Ice Class Ships*.

1.4.3 The machinery installation shall provide sufficient astern power to maintain manoeuvring of the ship in all normal service conditions.

The ability of the machinery to reverse the direction of thrust in sufficient time, and so to bring the ship to rest within a reasonable distance from maximum ahead service speed, shall be demonstrated and recorded.

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 or multiple propulsion/steering arrangements to navigate and manoeuvre with one or more of these devices inoperative, shall be available on board for the use of the master or designated personnel.

1.4.4 The minimum astern power required by SOLAS II-1 / 28.1 to secure proper control of the ship in all normal circumstances is to be determined by the ship designer and is not to exceed the maximum permissible astern power (MPAP) for which the propulsion plant is designed. Astern trials are to be conducted in accordance with the provisions of ISO 19019:2005, section 5.4: Astern trials.

1.4.5 Where steam turbines are used for main propulsion, the astern trial is to demonstrate that they are to be capable of operating at their maximum permissible astern power (MPAP) for a period of at least 15 minutes. The astern trial is to be limited to 30 minutes or in accordance with manufacturer's recommendation to avoid overheating of the turbine due to the effects of "windage" and friction.

1.4.6 Main propulsion systems with reversing gears, controllable pitch propellers or electric propeller drive are to be designed for the maximum permissible astern power, which should not lead to the overload of propulsion machinery.

NOTE:
The designed maximum astern power, as referred to in SOLAS II-1 / 3.15, defining the maximum astern speed for the design of the main steering gear and rudder stock as per SOLAS II-1 / 29.3.4 and UR S10.2.1.1, shall not to be taken less than the MPAP.

The astern tests are to be carried out from control positions. A test plan is to be provided by the yard and accepted by the surveyor. If specific operational characteristics have been defined by the manufacturer these shall be included in the test plan..

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

Dead ship condition shall be understood to mean a condition under which the main propulsion plant, boilers and auxiliaries are not in operation. In addition to this in restoring the propulsion, no stored energy for starting and operating the propulsion plant, the main source of electrical power and other essential auxiliaries is assumed to be available.

Where the emergency source of power is an emergency generator 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.

Where there is no emergency generator installed the arrangements for bringing main and auxiliary machinery into operation shall 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 shall 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.

1.4.8 Medium and high-speed engines (over 750 rpm), whose increased noise level makes load control difficult, may be approved for use as main engines, if provision is made for remote control and monitoring so that a constant presence of attending personnel in the engine room will not be necessary.

Control and monitoring facilities are to comply with requirements of the *Rules for the classification of ships, Part 13 - Automation.*

1.4.9 Machinery installations of ships with one internal combustion main engine, in the event of failure of one turbocharger (see the *Rules for the classification of ships, Part 9 - Machines*, 2.5.1), shall generally operate at a speed required for proper steerage of a ship.

1.5 NUMBER OF MAIN BOILERS

1.5.1 In ships of navigation area 1 (unrestricted service), as a rule, not less than two main boilers shall be fitted. The possibility of using a steam powered plant with one main boiler shall be separately considered by the *Register* in each particular case.

1.6 AMBIENT CONDITIONS TO ENSURE PROPER OPERATION OF MACHINERY AND APPLIANCES

1.6.1 Ambient conditions specified in this part of the *Rules* are to be applied to the layout, selection and arrangement of shipboard machinery, equipment and appliances (addressed in this Head of the Rules) to ensure proper operation.

1.6.2 Limit values of inclinations [2)]
- for main and auxiliary machinery and equipment:
  athwartships static inclination..........15°
  fore and aft static inclination[4)].........5°
  athwartships dynamic inclination.....22,5°
  fore and aft dynamic inclination.........7,5°
- for safety equipment (e.g. emergency power installations, emergency fire pumps and their devices, switchgear, electrical and electronic appliances[1)] and remote control systems):

athwartships static inclination[3]........22,5°
fore and aft static inclination............10,0°
athwartships dynamic inclination[3]...22,5°
fore and aft dynamic inclination.......10,0°

NOTES:
1) No undesired switching operations or operational changes are to occur.
2) Athwartships and fore-and-aft inclinations may occur simultaneously.
3) In ships for the carriage of liquefied gases and of chemicals, the emergency power supply is to remain operable with the ship flooded to a final athwartships inclination up to maximum of 30°. (see 1983 IGC Code, clause 2.9.2.2, 2014 IGC Code, clause 2.7.2.2, IBC Code, clause 2.9.3.2).
4) Where the length of the ship exceeds 100 m, the fore-and-aft static angle of inclination may be taken as 500/L degrees where L – length of the ship [m], as de-fined in the *Rules for the classification of ships, Part 2 – Hull*, 1.2.3.1.

The *Register* may consider deviations from these angles of inclination taking in consideration the type, size and service conditions of the ship.

1.6.3 Limit temperature values for installations and components[1] which are intended to operate:

- in enclosed spaces .... 0 to 45°C
- in machinery spaces, boiler room and other spaces subjected to higher and lower temperatures shall be determined according to specific local conditions
- on the open decks .... –25 to 45°C
- at sea water temperature .... to 32°C[2]

NOTES:
1) Electronic appliances shall be suitable for proper operation with an air temperature of 55°C.
2) In case of the ships intended for restricted service in certain geographical areas the *Register* may approve other temperature limits in case.

1.6.4 Conditions which shall be fulfilled regardless of where machinery installations are located:

- resistance to oil vapours and salt mist in air;
- proper operation at 100% humidity with respect to temperature of 45°C;
- resistance to corrosion, for deck machinery and equipment exposed to seawater.

1.6.5 In specially protected spaces, such as central control station, resistance to up to 80% humidity at 45°C is required.

1.6.6 Shipboard accelerations

- Main propulsion and steering machinery and auxiliary machinery that is essential to the propulsion and steering, and the safety of the ship shall be capable of operation under the effects of acceleration and motions.
- The requirements in 1.6.7 and 1.6.9 apply where documented evidence of equipment suitability is specifically required by other relevant Rules requirements for such equipment or requested by the *Register*.

1.6.7 Documentation

For ships subject to the SOLAS Convention, ship builders are to identify and document the ship accelerations and motions periods to which machinery and equipment might be subjected to. The expected accelerations and ship motions periods are to be within machinery and equipment manufacturers requirements. The estimations are to consider vessel type, machinery or equipment location and expected service conditions.

1.6.8 Evaluation of equipment suitability

Machinery and equipment manufacturers are to submit evidence to the *Register* that their machinery or equipment can operate under the required static and dynamic conditions stated in 1.6.2 and at least at the levels of shipboard accelerations as stated in 1.6.7 and/or specified in the relevant part of the Rules. Documentation of satisfactory performance shall take the form of:

- Report of testing under representative conditions; or
- Report of theoretical verification using recognised computational techniques accompanied by detailed and relevant validation data; or
- Historical data which provides relevant demonstration of satisfactory experience in service.

1.6.9 Installation and operation

- Machinery and equipment manufacturers are to submit details of the requirements /recommendations for installation of the machinery and equipment onboard to ensure satisfactory operation in service under the required static and dynamic conditions as described in 1.6.2 and at least at the levels of shipboard accelerations as stated in 1.6.4 and/or specified in the relevant part of the Rules.

  NOTE: Consideration should be given for positioning machinery in order to minimize the dynamic load on bearings due to ship motion.

- Shipbuilders are to submit details demonstrating that the installation of the machinery and equipment onboard is in accordance with manufacturer's requirements /recommendations.

1.7 CONTROL DEVICES OF MAIN ENGINES

1.7.1 The starting and reversing arrangements shall be so designed and placed in such a way that each engine can be started or reversed by a single operator.

1.7.2 Proper working direction of control handles and hand-wheels shall be clearly indicated by arrows and relevant inscriptions.

1.7.3 The setting of manoeuvring handles in the direction from, or to the right of the operator, or turning the hand wheel clockwise, shall correspond to the ahead speed direction of the ship.

The setting of handles in the direction astern shall correspond to the astern speed direction of the ship.

1.7.4 Means of control shall to be so designed as to eliminate self-acting operation.

1.7.5 The control device of the main engine shall have an interlocking system to preclude starting of the main engine while a shaft turning gear is engaged.

1.7.6 It is recommended to provide an interlocking system between the engine telegraph and the reversing arrangements so as to prevent the engine from running in the direction opposite to the prescribed one.

1.7.7 The control devices of the main engine shall have a signalling device indicating that the distance control system is out of operation.

1.8 CONTROL STATIONS

1.8.1 Bridge control stations of the main engines and propellers, as well as central control stations with any remote control system shall be equipped with:

.1 Control device for main engines and propellers. In case of controllable pitch propellers or cycloidal propulsors (Voith-Schneider), only remote control of propellers may be permitted and the requirements referred to under 6. and 10. are not mandatory;

.2 One tachometer and one sense of rotation indicator of the main engines and propellers;

.3 Signalling devices indicating that the main engines and remote control system are ready to start;

.4 Indicator showing which control station is active.

.5 Means of communication (according to 1.9)

.6 Emergency stopping device, independent of normal control system. In case that a clutch is provided for disconnecting the main engine from propeller, the remote disconnecting of the clutch shall be permitted only;

.7 Emergency control device for overriding automatic protection of the main engines (except the engine over-speed protection system). In case of the multi-propulsion system this device is not mandatory;

.8 Signalling devices indicating whether the automatic protection of the main engines is overridden or activated. Signalling devices indicating that the main engines shut-off device have been activated or that the main engine has been declutched;

.9 In case of the controllable pitch propeller, one pitch indicator and signalling device of the minimum pressure in the hydraulic system and that of over-loading of propulsion engines (in case that the recommendation under 3.5.2 is not accepted);

.10 Signalling devices for minimum starting air pressure equal to the pressure which enables three consecutive starts of each reversible main engine from the local control station.

1.8.2 Control station on the navigation bridge wings may not be provided with the devices referred to in 1.8.1.3, 1.8.1.5, 1.8.1.7, 1.8.1.8, 1.8.1.9 and 1.8.1.10.

1.8.3 Emergency stop control devices of the main engines and devices for protection of overriding shell be such as to preclude the possibility of accidental activating.

1.8.4 In case of the multi-propulsion system on a ship operating on one shaft line, the common control station shall be provided.

1.8.5 In addition to the remote control, also local control stations for engines and propellers shall be provided. In case of mechanically operated remote control, the local control stations may be dispensed with in agreement with the *Register*.

1.8.6 Remote control of the main engines and propellers shall not be possible simultaneously from different control stations. Change-over of control shall be possible from the engine room only or from the central control station. Considerable changes in running of the ship shall not occur during the change-over.

Control station on the bridge wings shall be so connected with those on the navigation bridge that the operation from each station is possible without the change-over.

1.8.7 Remote control of the main engine from the navigation bridge, as a rule, shall be effected by a single control element (lever, hand wheel, push button and similar).

In case of controllable pitch propellers two-lever control system may be applied, wherein the possibility of accidental stop of main engine shall be precluded.

1.8.8 Central and local control stations shall be provided with means to indicate the main engine operating orders that are given from the navigation bridge.

1.9 MEANS OF COMMUNICATION

1.9.1 At least two independent means shall be provided for communicating orders from the navigation bridge to the position in the machinery space or in the control room from which speed and direction of thrust of the propellers are normally controlled. One of these shall be an engine-room telegraph which provides visual indication of the orders and responses both in the machinery spaces and on the navigation bridge. Appropriate means of communication shall be provided from the navigation bridge and the engine room to any other position from which the speed or direction of thrust of the propellers may be controlled.

For two control stations located closely together, only one voice communication may be provided.

If the engine telegraph and voice communication devices are of electrical type they are to comply with the requirements of the *Rules for the classification of ships, Part 12 - Electrical Equipment*.

1.9.2 Two-way communication shall be provided between engine room, auxiliary machinery space and boiler room and on tankers, in addition, between the engine room and cargo pump rooms.

1.9.3 When installing telephones, provisions shall be made to ensure clear audibility during machinery operation.

1.10 MEASURING AND INDICATING INSTRUMENTS

1.10.1 All the measuring and indicating instruments, except liquid-filled thermometers, shall be checked by testing institutions approved by the *Register*. Pressure gauges for boilers, heat exchangers, pressure vessels and refrigerating plants shall comply with the *Rules for the classification of ships, Part 10 - Boilers, heat exchangers and pressure vessels* and the *Rules for the classification of ships*, *Part 11- Refrigerating plant*.

1.11 MACHINERY SPACES

1.11.1 Main and auxiliary engines shall be so arranged as to provide passages from the control stations and attendance positions to the exits of machinery spaces. The width of the passages shall be at least 600 mm.

In ships with gross tonnage less than 1000, the width of passages may be reduced to 500 mm.

The width of passages along the switchboard shall comply with the *Rules for the classification of ships, Part 12 - Electrical equipment.*

1.11.2 The width of escape ladders and exit doors shall be at least 600 mm. In ships of less than 1000 gross tons the width of the ladders may be reduced to 500 mm.

1.11.3 Each machinery space of Category A, shaft tunnels and pipeline tunnels shall be provided with at least two escape ways leading to the lifeboat deck. These escape ways shall be as widely separated from each other as possible. Steel ladders shall lead to the exit doors of these spaces.

Fire protection of stairways shall comply with the *Rules, Part 17 - Fire protection.*

One of the escape ways may lead through a steel door operable from both sides into a space which has its own escape way.

The exits from shaft tunnels and pipeline tunnels shall terminate in watertight casings extending to the open deck. One of these escape ways may lead to the machinery space. In tankers one of the escape ways from pipeline tunnels located below cargo tanks may lead to the cargo pump room, but shall not lead to the machinery space.

Doors of shaft line tunnels and pipeline tunnels leading to the machinery space or cargo pump room shall comply with the *Rules for the classification of ships, Part 3 - Hull equipment*.

In ships with gross tonnage less than 1000, with respect to the size of these spaces, the second escape way may be dispensed with in agreement with the *Register*.

Lifts shall not be considered as escape ways.

1.11.4 Machinery spaces, other than those referred to in 1.11.3 may have one escape way only.

Workshops, spaces intended for testing of fuel devices, separators and other enclosed spaces within machinery spaces, may have exits leading into these spaces.

In passenger ships two means of escape shall be provided from the central control station located within a machinery space, at least one of which will provide continuous fire shelter to a safe position outside the machinery space.

In engine rooms of smaller size or where an extra escape way of the central control station is located closely to the escape way of the engine room, an extra escape way of the central control station may be dispensed with in agreement with the *Register*.

1.11.5 If two adjacent machinery spaces communicate through a door and each of them has only one escape way through its casing, these escape ways shall be located at the opposite ship sides.

1.11.6 Escape ways from the pump rooms shall lead straight to the open deck. Exits to other machinery spaces shall not be permitted.

1.11.7 Escape ways from machinery spaces shall lead to the places providing ready access to the lifeboat deck.

1.11.8 All the doors, covers of companion ways and skylights through which it is possible to leave the machinery spaces shall be capable of being operable (opened and closed) both from inside and outside.

The covers of companion ways and skylights shall bear a clear inscription prohibiting to stow any load on them.

The cover of skylights which do not serve as escape ways shall be fitted with closing device arranged for locking them from outside.

The doors and hatch covers of cargo pump rooms shall be capable of opening and closing both from inside and outside, and their design shall preclude the possibility of sparking.

1.11.9 The surfaces of machinery, equipment and pipelines liable to be heated to temperatures equal or exceeding 220°C shall be heat insulated. Provisions shall be made to protect the insulation against mechanical damage and effect of vibrations.

1.11.10 Insulation material shall comply with *the Rules for the classification of ships, Part 17 - Fire protection*, 4.4.3.

1.11.11 All the machinery spaces shall be fitted with ventilation system in compliance with the *Rules for the classification of ships, Part 8 - Piping*, Section 7.

1.12 ARRANGEMENT OF MACHINERY AND EQUIPMENT

1.12.1 Machinery, boilers, equipment, pipes and fittings shall be so arranged as to provide free access to them for maintenance and overhaul; the requirements of 1.11.1 shall also be met.

In emergency firefighting pump spaces of cargo ships, as well as in the spaces of their driving units, enough space shall be provided for maintenance works and inspections.

1.12.2 The distance from the outer surface of the boiler insulation to the walls of the oil fuel and lubrication oil tanks, should be at least 600 mm.

Where the fuel oil tanks are located in the double bottom under the boilers, the distance between the boiler casing and double bottom plating shall be at least 750 mm.

Manholes to fuel oil tanks shall not be arranged close to boiler fronts.

1.12.3 Auxiliary boilers installed in the engine room shall be fitted in way of the furnace with a metal screen or other measures shall be taken to protect the equipment in this space against effects of flame accidentally thrown off the furnace.

1.12.4 The auxiliary oil-fired boilers fitted on the platform or in tween deck spaces which are not watertight shall be protected with oil-tight coamings at least 200 mm in height.

1.12.5 The fuel oil tanks shall generally be structural and shall be located outside machinery spaces of category A. Where these tanks, other than double bottom tanks, are necessarily located adjacent to or within machinery spaces of category A, the area of the tank boundary common with the machinery spaces shall be kept to a minimum and they shall preferably have a common boundary with the double bottom tanks. Where fuel such tanks are situated within the machinery spaces of category A, they shall not contain fuel oil having flash point below 60°C. If the *Register* permits the use of non-structural tanks, the application of oil-trays shall be provided around them. In passenger ships, if non-structural tanks cannot be avoided, then they shall be located outside the machinery spaces of category A.

Fuel oil and lubricating oil tanks shall not be located above machinery and other installations with surface temperature under insulation exceeding 220°C, boilers, internal combustion engines, electrical equipment and shall be as distant from the mentioned engines and installations as possibly practicable.

Passenger ships in length up to 30 m, of restricted navigation areas 5 to 8, may be fitted with non-structural tanks within machinery spaces of category A, in a way that tanks shall be made of steel or any other equivalent material.

1.12.6 Cargo pump driving units and those of ventilators in cargo pump rooms, except steam engines temperature of which does not exceed 220°C and hydraulic motors, shall not be installed in the cargo pump rooms. Such machinery may be installed in the spaces adjacent to the pump room provided with mechanical ventilation or in the gas-tight compartments located inside the pump room but not communicating directly therewith.

Pump driving units and those of ventilators may be installed in spaces partly located above the cargo pump room.

Penetrating bulkhead or deck drive shafts of cargo pumps and ventilators shall be fitted with gas-tight sealing glands, efficiently lubricated, from outside of the pump room.

The structure of the seal glands shall be such as to exclude the possibility of its being overheated. Those parts of the seal glands which, due to the loss of centricity of the drive shaft or damage of the bearings, might contact each other, shall be made of material that will not initiate sparks.

If siphons are incorporated in seal glands, they shall be pressure tested before fitting.

1.12.7 Air compressors shall be fitted in such places where the air, sucked by the compressor, contains the minimum vapours of combustible liquids.

1.12.8 Main parts of the installations intended for preparation of flammable liquids for necessities of boilers, main and auxiliary engines (e.g. centrifugal separators) of working pressure above 1,5 MPa, not belonging into systems of main and auxiliary engines, boilers etc., may be located in separated rooms.

If the main parts of stated installations are not possible to be located into separated spaces, special attention shall be paid to their accommodation, collecting of drained liquid and mechanical protection of the equipment.

1.12.9 Emergency diesel generator shall comply with the *Rules for the classification of ships, Part 12 - Electrical equipment*, section 9.2.

1.12.10 In tankers, the internal combustion engines, boilers and other installations with possible flame sources, shall be located outside dangerous areas, in accordance with the *Rules for the classification of ships, Part 12 - Electrical equipment*.

1.13 INSTALLATION OF MACHINERY AND EQUIPMENT

1.13.1 The machinery and equipment shall be fitted and fastened to strong and rigid foundations. The foundation design shall comply with the *Rules for the classification of ships, Part 2 - Hull*, 7.3.3.

1.13.2 Boilers shall be installed on foundations so that their welded joints do not rest on supports.

1.13.3 To prevent shifting of boilers, these shall be provided with special stops and stays, the thermal expansion of the boiler casing being taken into account.

1.13.4 Where it is necessary to install engines on dampers or resin chocks, design and materials shall be approved by the *Register*.

1.13.5 Main engines, their gears and shaft line bearings shall be secured to the foundations with fitted bolts throughout or in part. Special stoppers may be substituted for bolts.

Where necessary, fitted bolts shall be used to fasten auxiliary machinery to their foundations.

1.13.6 Bolts used for fastening of the main and auxiliary engines and shaft line bearings to their foundations, as well as the bolts connecting the shafting shall be secured against loosening.

1.13.7 Machinery with horizontal shafts shall be installed parallel to the centre line of the ship. If their design is in compliance with requirements of 1.6, any other direction is permitted.

1.13.8 Generator prime movers shall be fitted on the same foundations where their generators are installed.

1.14 MATERIALS AND WELDING

1.14.1 Materials intended for the manufacture of shaftlines and propeller details shall comply with the *Rules for the classification of ships, Part 25 - Metallic materials*.

In the Table 1.3.2, column 4, the relevant chapters of the *Rules for the classification of ships, Part 25 - Metallic materials* are indicated for the particular parts which are subject to supervision of the *Register*.

Materials of parts referred to in the Table 1.3.2 under 1.7 may be chosen according to standards. Materials of parts referred to in the Table 1.3.2 under 1.2 to 1.6 and 1.8, 2.2 and 2.3 may be chosen according to standards as well. The *Register* decides about the application of these materials during the approval of the technical documentation.

Materials of parts referred to under 1.1, 2.1, and 2.2 in the Table 1.3.2 shall be supervised by the *Register* during their manufacture. The *Register* may require supervision of other materials stated in the mentioned table.

1.14.2 The requirements for tensile strength of materials used for the manufacture of shafting are stated in 2.1.4.

1.14.3 Propeller materials

Solid propellers, blades and hubs of fixed pitch propellers with detachable blades and of controllable pitch propellers shall be made of the materials specified in the Table 1.14.3.

Table 1.14.3
Propeller materials, for ships without ice strengthening category

Copper alloys (*Rules for the classification of ships, Part 25 - Metallic materials*, 4.3)	Cast steel[2] (*Rules for the classification of ships, Part 25 - Metallic materials*, 3.12)
Category CU1, CU2, CU3 and CU4	Stainless steel

Notes:
1) Hubs of fixed pitch propellers with detachable blades and of controllable pitch propellers for ships with ice strengthening of categories 1AS and 1A may be manufactured from carbon steels
2) Steels with the minimum value of the absorbed energy of 21 J at the temperature of –10°C.
3) For ships with ice class notations see the *Rules for the classification of ships, Part 29 – Polar Class Ships and Ice Class Ships*.

1.14.4 Where it is intended to make shafts and propellers of alloy steels, corrosion-resistant or high strength steels, data on chemical composition, mechanical and special properties, confirming suitability of the steel for intended application, shall be submitted to the *Register*.

1.14.5 Thrust shafts, intermediate shafts and propeller shafts with limit of diameters of 250 mm, as well as coupling bolts may be manufactured from rolled steels produced according to recognized standards. In that case the use of these materials is subject to approval by the Register, during the inspection of technical documentation.

The extents of non-destructive examinations and acceptance criteria are to be agreed with Register. *IACS Recommendation No.68* is regarded as an example of an acceptable standard.

Testing and certification of mentioned rolled steel shall be in compliance with the requirements referred to in the *Rules for the classification of ships, Part 25 - Metallic materials*, 3.11.6, 3.11.8, 3.11.10, 3.11.11, as applicable.

1.14.6 Bolts for fastening propeller blades and caps, stern tubes, stern bushes and glands shall be manufactured from stainless materials.

1.14.7 Welding and methods of control of welded joints shall comply with the *Rules for the classification of ships, Part 26 - Welding*.

2 SHAFTINGS

2.1 GENERAL REQUIREMENTS

2.1.1 This Chapter applies to propulsion shafts such as intermediate and propeller shafts of traditional straight forged design and which are driven by rotating machines such as diesel engines, turbines or electric motors.

For shafts that are integral to equipment, such as for gear boxes, podded drives, electrical motors and/or generators, thrusters, turbines and which in general incorporate particular design features, additional criteria in relation to acceptable dimensions have to be taken into account. For the shafts in such equipment, the requirements of this Chapter may only be applied for shafts subject mainly to torsion and having traditional design features. Other limitations, such as design for stiffness, high temperature etc. are to subject to the special consideration by the *Register*.

Explicitly the following applications are not covered by this Chapter:

.1 gearing shafts,
.2 electric motor shafts,
.3 generator rotor shafts,
.4 turbine rotor shafts,
.5 diesel engine crankshafts.

Shaft diameters calculated by the formulae referred to in the present chapter apply to the minimum shaft diameters without taking into account additions for weardown. It is assumed that additional stresses from torsional vibrations will not exceed permissible values stipulated in Chapter 4.

2.1.2 Alternative calculation methods may be considered by the *Register*. Any alternative calculation method is to include all relevant loads on the complete dynamic shafting system under all permissible operating conditions. Consideration shall 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.

2.1.3 Shafts complying with this part of the Rules satisfy the following:

.1 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 formulae (2.2.1) and (2.4.1).

.2 High cycle fatigue criterion (typically $>>10^7$), i.e. torsional vibration stresses permitted for continuous operation as well as reverse bending stresses.
The limits for torsional vibration stresses are given in 4.2.
The influence of reverse bending stresses is addressed by the safety margins inherent in the formulae (2.2.1) and (2.4.1).

.3 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 is addressed by the criterion for transient stresses in 4.2.

2.1.4 Material intended for the manufacture of shaftlines shall meet the requirements in 1.14, provided that the tensile strength under normal conditions shall be within 400 to 800 N/mm². Steels with other properties or any other material may be used if approved by the *Register* in each particular case.

Where shafts may experience vibratory stresses close to the permissible stresses for transient operation, the materials are to have specified minimum ultimate tensile strength of 500 N/mm².

2.1.5 For ships with ice class notations shaft diameters shall be increased in accordance with the *Rules, Part 29 – Polar Class Ships and Ice Class Ships*.

2.1.6 For ships navigating in restricted navigation areas 5 to 8 the minimal shaft diameters, calculated in accordance with the formulae stated in this chapter, may be reduced by 5%.

2.2 INTERMEDIATE SHAFTS

2.2.1 The diameter of the intermediate shaft d_m shall not be less than that determined by the formula:

$$d_M = F_M \cdot k_M \sqrt[3]{\frac{P}{n} \cdot \frac{1}{1-(\frac{d_{uM}}{d_{vM}})^4} \cdot \frac{560}{R_{mM}+160}} \quad \text{[mm]} \quad (2.2.1)$$

where:

F_M – factor for the type of propulsion installation:
= 95, for turbine installation, internal combustion engine installation with slip type coupling and for electric propulsion installation.
= 100, for all other internal combustion engine installations.

k_M – factor for different shaft design features chosen from the Table 2.2.1. Transitions of diameters shall be designed with either a smooth taper or a blending radius. For guidance, a blending radius equal to the change of diameter is recommended.

P – rated power of the main engine (losses in gearboxes and bearings shall be disregarded), [kW];

n – rated speed of propeller shaft, [rpm];

d_{uM} – diameter of internal longitudinal shaft bore, [mm];

d_{vM} – outside shaft diameter, [mm];
In cases where $d_u \le 0{,}4 d_v$ the following expression may be used:

$$1-(\frac{d_{uM}}{d_{vM}})^4 = 1{,}0$$

R_{mM} – Tensile strength of the material taken for calculation, [N/mm²].

When the intermediate shaft material is a carbon or carbon-manganese steel having the tensile strength exceeding 760 N/mm², for the calculation purpose will be considered that of R_{mM}=760 N/mm² only.
When the intermediate shaft material is an alloy steel having the tensile strength exceeding 800 N/mm², for the calculation purpose will be considered that of R_{mM}=800 N/mm² only.

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 in 2.2.1 unless the Register verifies that the materials exhibit similar fatigue life as conventional steels (see Annex A).

Table 2.2.1
k_M -factors for intermediate shafts

No.	Intermediate shafts with	k_M
1	integral coupling flanges [1)]	1,0
2	straight sections	1,0
3	shrink fit coupling (keyless) [2)]	1,1
4	keyways (cylindrical or tapered connections) [3) 4)]	1,1
5	radial bores or transverse holes [5)]	1,1
6	longitudinal slots [6)]	1,2

Note: Transitions of diameters are to be designed with either a smooth taper or a blending radius. For guidance, a blending radius equal to the change in diameter is recommended.

Footnotes:
[1)] Fillet radius shall not be less than 0,08d_M.
[2)] Factor k_M refers to the plain shaft sections 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% and a blending radius as described in the Table note stated above.
[3)] At a distance of not less than 0,2d_M from the end of the keyway the shaft diameter may be reduced to the diameter calculated with k_M=1. Fillet radius in the transverse section of the bottom of the keyway shall not be less than 0,0125d_M.
[4)] Keyways are in general not to be used in installations with a barred speed range (see Chapter 4.4).
[5)] Diameter of radial bore shall not exceed 0,3d_M. Intersection between a radial and an eccentric axial bore is a subject of special consideration.
[6)] Length of the slot shall not exceed 0,8d_M. Inner diameter shall not exceed 0,8d_M. Width of the slot shall be higher than 0,1d_M. The end rounding of the slot shall not be less than half its width. An edge rounding should preferably be avoided. The values in the table are valid for 1, 2 and 3 slots, i.e. with slots at 360º respectively, 180º respectively and 120º apart.

2.2.2 The portion of the shaft outside of the keyway, bore or slot area may be gradually reduced to the diameter calculated with k_M=1.

2.2.3 The determination of k_M factors for shaft design features other than those referred in 2.2.1 is left to the discretion of the *Register*.

2.3 THRUST SHAFTS

2.3.1 The diameter of the thrust shaft which is not incorporated in the main engine shall be determined by the formula (2.2.1) with factor k_M =1,1.

2.3.2 The diameter referred to in 2.3.1 applies to the length equal to the diameter of shaft considered from both sides of thrust collar (fillet radius shall not be less than 0,08*d,* where: *d* - shaft diameter), or to the length of axial bearing, if the antifrictional bearing is used as thrust bearing. Outside of these lengths, the diameter may be gradually reduced to the diameter of the intermediate shaft.

2.4 PROPELLER SHAFTS

2.4.1 The diameter of the propeller shaft dP shall not be less than that calculated from the following formula:

$$d_P = F_P \cdot k_P \sqrt[3]{\frac{P}{n} \cdot \frac{1}{1-(\frac{d_{uP}}{d_{vP}})^4} \cdot \frac{560}{R_{mP}+160}} \text{ [mm]} \quad (2.4.1)$$

where:

F_P – factor for the type of propulsion installation.
= 100 for turbine installations, all internal combustion engine installations and electric propulsion installations;

k_P – factor dependent on shaft design features:

.1 Factor k_P applied to the portion of propeller shaft between the forward edge of the aft stern tube bearing and propeller boss, equal to minimum length 2,5d_P.

k_P =1,22 for propeller shafts where the propeller is keyless fitted on the propeller shaft taper or where the propeller is attached to an integral propeller shaft flange and where the propeller shaft bearings are oil lubricated and provided with an approved type of sealing glands or where the shaft is fitted with a continuous liner.

k_P =1,26 for propeller shafts where the propeller is keyed on the propeller shaft taper and where the propeller shaft bearings are oil lubricated and provided with an approved type of sealing glands or where the shaft is fitted with a continuous liner.

For propeller shafts without liners in case of water lubricated bearings, factor k_P shall be increased by 2%. This is not required for propeller shafts made of austenitic stainless steels.

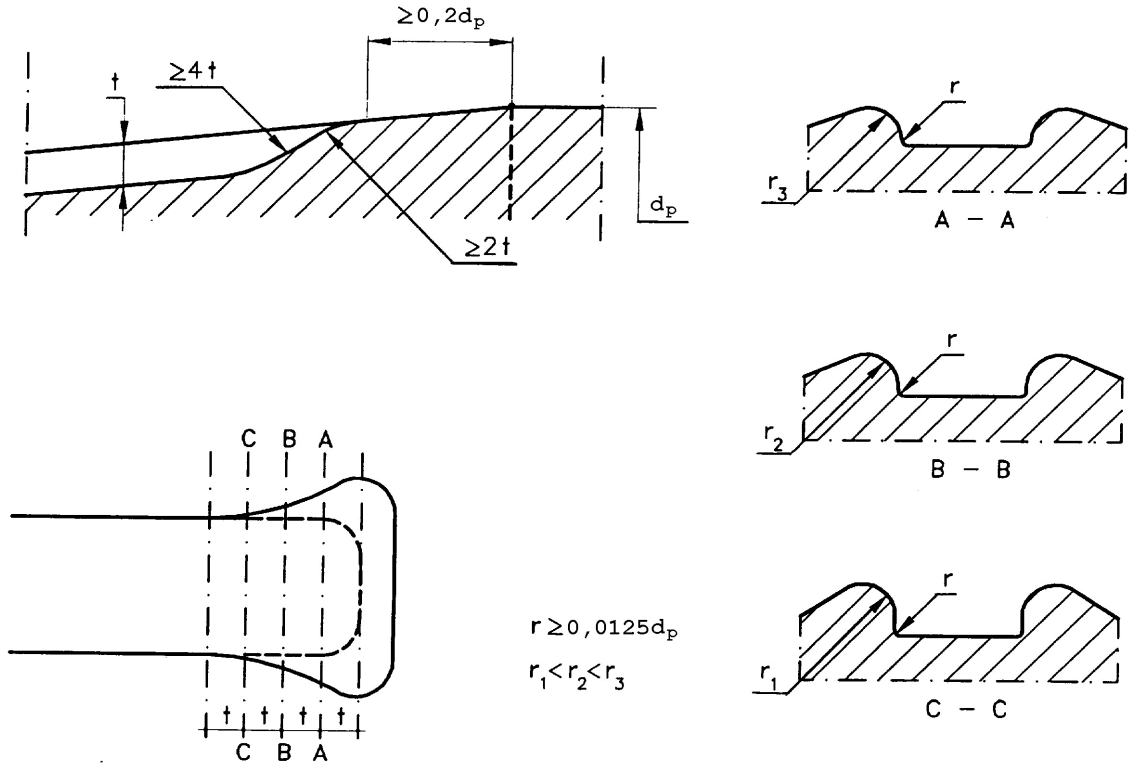

Figure 2.4.2.2
Keyways in tapered end of propeller shaft

.2 Factor k_P applied to the portion of propeller shaft between the forward edge of the forward stern tube seal to the forward edge of the aft stern tube bearing:
k_P =1,15 for all shaft design features.

.3 The determination of k_P factors for shaft design features other than those referred to above is left to the discretion of the *Register*.

.4 The diameter of the propeller shaft located forward of the inboard stern tube seal may be gradually reduced to the corresponding diameter required for the intermediate shaft (calculated by formula 2.2.1), where the minimum specified tensile strength of the propeller shaft material *(R_{mP})* is used as the material specified tensile strength.

P – the same as in 2.2.1, [kW];

n – rated speed of propeller shaft, [rpm];

d_{uP} – diameter of internal longitudinal shaft bore, [mm];

d_{vP} – outside shaft diameter, [mm].
If $d_{uP} \le 0{,}4d_{vP}$, it may be taken that:

$$1-\left(\frac{d_{uP}}{d_{vP}}\right)^4 = 1{,}0$$

R_{mP} – tensile strength of the shaft material taken for calculation, [N/mm²]. When the shaft material is a steel having tensile strength exceeding 600 N/mm² for the calculation purposes it shall be taken R_{mP} =600 N/mm².
For ships under 90 meters in length and with unprotected shaft exposed to sea water, when the propeller shaft material, or the material of other shafts, is an age-hardened martensitic stainless steel, or a higher strength austenitic stainless steel, or another high strength alloy with the particular tensile strength exceeding 930 N/mm² for the calculation purposes it shall be taken R_{mP} =930 N/mm². The materials referred to are e.g. ASTM type XM-19 (UNS number S20910), XM-21 (UNS number S30452), XM-28 UNS number S24100), or equivalent.

2.4.2 Propeller shaft cone with keyways

2.4.2.1 Where the propeller is fitted to the shaft by means of a key, the propeller shaft cone shall be made with a taper not in excess of 1:12.

2.4.2.2 For shafts of 100 mm in diameter and over, the forward ends of the keyway should be spoon-shaped. The edges shall be smoothly rounded off and the keyway corners shall be rounded to a radius equal to 1,25% of the propeller shaft diameter, but not less than 1 mm. The distance between the top of the cone and the forward end of the keyway shall not be less than 20% of the propeller shaft diameter (Figure 2.4.2.2).

2.4.3 Corrosion protection of the propeller shaft

2.4.3.1 Propeller shafts shall be effectively protected against exposure to sea water.

2.4.3.2 Propeller shaft liners shall be made of high quality alloys resistant to sea water.

2.4.3.3 The thickness of shaft bronze liner shall not be less than that given by the formula:

$$s = 0{,}033 \cdot d_P + 7{,}5 \quad \text{[mm]} \qquad (2.4.3.3)$$

where:

d_P – actual diameter of the propeller shaft, [mm].

The thickness of the liner between the working surfaces may be reduced to 0,75*s*.

2.4.3.4 Continuous liners are recommended. The junctions of composite liners shall be made by welding or other method approved by the *Register*.

Welded joints shall be outside the working areas of the liner.

Where non-continuous liners are applied, the portion of the shaft between the liners shall be protected against the effect of the sea water by a method approved by the *Register*.

2.4.3.5 To protect the propeller shaft cone against the sea water penetration a special seal shall be fitted between the shaft cone and propeller boss.

2.4.3.6 Sealing system of stern tube shall be approved by the *Register*. Oil-lubricated stern bearings shall be provided with the seals of type approved by the *Register*.

2.4.3.7 Pins, bolts and similar shall not be used for securing the shaft liner.

Appropriate protection between propeller and sterntube shall be provided (rope guard).

2.5 SHAFT COUPLINGS

2.5.1 As a rule, couplings of intermediate thrust and propeller shafts shall be coupled by means of fitted bolts. The diameter of the fitted coupling bolts shall not be less than that given by the formula:

$$d_S = 0{,}65\sqrt{\frac{d_M{}^3}{i \cdot D} \cdot \frac{(R_{mM} + 160)}{R_{mS}}} \quad \text{[mm]} \qquad (2.5.1)$$

where:

d_M – intermediate shaft diameter determined in accordance with 2.2.1, [mm];

i – number of fitted bolts;

D – diameter of the pitch circle of the bolts, [mm];

R_{mM} – tensile strength of the intermediate shaft material [N/mm²], in accordance with 2.2.1;

R_{mS} – tensile strength of bolts material, [N/mm²], taken as: $R_{mM} \le R_{mS} \le 1{,}7 R_{mM}$.
If $R_{mS} \ge 1000$ N/mm² the value $R_{mS} = 1000$ N/mm² shall be used.

2.5.2 The use of types of bolts other than those in accordance with 2.5.1, shall be a matter of special consideration by the *Register* in each case.

2.5.3 The thickness of the flanges of intermediate and thrust shafts and the propeller shaft forward (inside) flange shall be at least equal to the one of the following values, whichever is greater:

- 0,2 of the diameter of intermediate shaft, in accordance with 2.2.1, or
- diameter of bolts calculated in accordance with 2.5.1 for the material with tensile strength equal to the one of the shaft in question.

Flanges with surface areas which are not parallel shall be a matter of special consideration by the *Register*. In no case flange thickness shall be less than that of the bolt diameter concerned.

The thickness of aft (outside) propeller shaft flange shall be not less than 0,25 of the diameter of the shaft in the flange area.

2.5.4 The fillet radius at the base of the flange shall not be less than 0,08 of the actual shaft diameter. The surface of the rounding shall be smooth and without any recesses in the way of nut and the bolt head. The rounding may be performed with different radii, but the factor of stress concentration shall not exceed the value for the equivalent circular rounding with the radius 0,08 of the actual shaft diameter.

2.5.5 The use of removable coupling flanges will be specially considered by the *Register* in each particular case. Safety factor against friction slip at nominal load shall not be less than 2,8.

In these cases special consideration shall be given to the way of the transmission of propeller forces when running astern.

2.5.6 Flange couplings with non-fitted coupling bolts may be accepted on the basis of the calculation of bolt tightening, bolt stress due to tightening, and assembly instructions.

To this end, the torque based on friction between the mating surfaces of flanges is not to be less than 2,8 times the transmitted torque, assuming a friction coefficient for steel on steel of 0,18. In addition, the bolt stress due to tightening in way of the minimum cross-section is not to exceed 0,8 times the minimum yield strength (R_{eH}), or 0,2 proof stress ($R_{p\,0,2}$), of the bolt material.

The value 2,8 above may be reduced to 2,5 in the following cases:

- ships having two or more main propulsion shafts
- when the transmitted torque is obtained, for the whole functioning rotational speed range, as the sum of the nominal torque and the alternate torque due to the torsional vibrations

Transmitted torque has the following meanings:

.1 For main propulsion systems powered by diesel engines fitted with slip type or high elasticity couplings, by turbines or by electric motors: the mean transmitted torque corresponding to the rated power P and the relevant speed of rotation n.

.2 For main propulsion systems powered by diesel engines fitted with couplings other than those mentioned above the mean torque above increased by 20% or by the torque due to torsional vibrations, whichever is the greater.

2.6 PROPELLER SHAFT BEARINGS

2.6.1 For oil lubricated bearings of white metal the length of white metal lined bearings is to be not less than 2.0 times the rule diameter of the shaft in way of the bearing. The length of the bearing may be less provided the normal bearing pressure is not more than 8 bar as determined by static bearing reaction calculation taking into account shaft and propeller weight which is deemed to be exerted solely on the aft bearing divided by the projected area of the shaft. However, the minimum length is to be not less than 1.5 times the actual diameter.

For oil lubricated bearings of synthetic rubber, reinforced resin or plastic materials which are approved for use as oil lubricated stern bush bearings, the length of the bearing is to be not less than 2.0 times the rule diameter of the shaft in way of the bearing.

The length of bearing may be less provided the nominal bearing pressure is not more than 6 bar as determined by static bearing reaction calculation taking into account shaft and propeller weight which is deemed to be exerted solely on the aft bearing divided by the projected area of the shaft. However, the minimum length is to be not less than 1.5 times the actual diameter.

Where the material has proven satisfactory testing and operating experience, consideration may be given to an increased bearing pressure.

Synthetic materials used for oil lubricated aftmost propeller shaft bearings are to be Type Approved. The type approval requirements in this clause apply to all aftmost propeller shaft bearings made of synthetic materials.

For type approval testing requirements of synthetic material for the aftmost propeller shaft bearing, see requirements as stated in Annex B.

For water lubricated bearing the length of the bearing is to be not less than 4.0 times the rule diameter of the shaft in way of the bearing.

For a bearing of synthetic material, consideration may be given to a bearing length not less than 2.0 times the rule diameter of the shaft in way of the bearing, provided the bearing design and material is substantiated by experiments to the satisfaction of the *Register*.

Synthetic materials used for water lubricated aftmost propeller shaft bearings are to be Type Approved. The type approval requirements in this clause apply to all aftmost propeller shaft bearings made of synthetic materials.

For type approval testing requirements of synthetic material for the aftmost propeller shaft bearing, see requirements as stated in Annex B.

For the grease lubricated bearings, the length of a bearing is to be not less than 4.0 times the rule diameter of the shaft in way of the bearing.

2.6.2 In case of sea-water lubricated bearings, a valve or a cock shall be fitted on the after peak bulkhead or stern tube to check water inflow. A flow indicator shall be provided on the pipe-line. Provision shall be made for a signalling device to indicate minimum permissible flow.

It is recommended to provide a device protecting stern tube from freezing.

2.6.3 The oil lubricated stern bush shall be provided with means of forced cooling, unless water is continuously maintained in the after peak.

A suitable device shall be provided for measuring the oil or bearing temperature in stern tube.

2.6.4 In the gravity system of lubrication, the gravity tanks shall be located at least 3 m above the waterline of the ship's maximum draught. The oil tanks shall be provided with level indicators and level alarms.

2.6.5 It is recommended that the distance between the centres of adjacent bearings of shaftline, where there are no concentrated masses in the span, meets the condition:

$$5{,}5\sqrt{d} \le l \le \lambda\sqrt{d} \qquad (2.6.5)$$

where:

l – distance between the bearings, [m];
d – intermediate shaft diameter, [m];
λ – factor taken:
= 14,0 for $n \le 500$ rpm,
= $\frac{300}{\sqrt{n}}$ for $n > 500$ rpm,
n – the same as in 2.2.1, [rpm].

2.7 HYDRAULIC TESTS

2.7.1 After being mechanically treated, propeller shaft liners and stern tubes shall be subjected to hydraulic tests with test pressure of 0,2 MPa.

Welded and forged-welded stern tubes are not to be subjected to hydraulic tests if the 100% of welded seam is examined by one of the non-destructive methods.

2.7.2 In case of oil lubrication, the sealing glands of the stern tube shall be tested for tightness after assembling with hydraulic pressure equal to the maximum lubricating oil head in the gravity tank. The propeller shaft shall be turning during testing.

2.8 KEYLESS FITTING OF PROPELLERS (WITHOUT ICE STRENGTHENING)

2.8.1 These conditions apply to the solid shafts without a sleeve between the propeller boss and the shaft. Other cases shall be specially considered and approved by the *Register*.

The formulae are suitable for forward running, but also in case of running astern they give reasonable safety.

2.8.2 The taper of the propeller shaft cone shall not be greater than 1:15.

2.8.3 Prior to the final push-up of the boss onto the cone, the contact area shall be checked and shall not be less than 70% of the theoretical fitting area and the contact shall be uniformly distributed. Continuous non-contact bands extending circumferentially around the cone or over the full length of the cone are not acceptable.

2.8.4 After final push-up, the propeller shall be secured by a nut on the tailshaft. The nut shall be secured to the shaft.

2.8.5 The factor of safety against friction slip at 35˚C shall not be less than 2,8 under loading specified in 2.8.9.

2.8.6 For the oil injection method, the coefficient of friction for bosses made of steel or copper alloys shall be assumed to be 0,13. For other methods, the coefficient of friction shall be considered by the *Register* in each particular case.

2.8.7 The maximum equivalent stresses in the boss, calculated in accordance with HMH energy theory, at 0˚C shall not exceed 70% of the yield point (R_e) or 0,2% offset yield point ($R_{p0,2}$).

Table 2.8.8
Material properties

Material	Modulus of elasticity [N/mm²]	Poisson's ratio	Coefficient of linear thermal expansion [mm/mm˚C]
Cast and forged steel	210 000	0,29	$12{,}0\cdot10^{-6}$
Cast iron	100 000	0,26	$12{,}0\cdot10^{-6}$
Copper alloys, category CU1 and CU2[1]	110 000	0,33	$17{,}5\cdot10^{-6}$
Copper alloys, category CU3 and CU4[1]	120 000	0,33	$17{,}5\cdot10^{-6}$
Note: [1] The *Rules, Part 25 - Metallic materials*, Table 4.3.6.1			

2.8.8 Mechanical and thermal material properties shall be determined in accordance with the Table 2.8.8.

2.8.9 Minimum required surface pressure at 35˚C.

$$p_{35} = \frac{S\cdot T}{A\cdot B}\cdot\left[-S\cdot\theta+\sqrt{\mu^2+B\left(\frac{F_v}{T}\right)^2}\right] \text{ [N/mm}^2\text{]} \qquad (2.8.9)$$

where:

S – factor of safety against friction slip at 35°C. (see 2.8.5);

T – continuous thrust developed for free running vessel, [N]. If not known, it shall be determined by the formulas:

$$T = 1760\frac{P}{v_b} \text{ [N]}$$

or

$$T = 57{,}6\cdot10^6\frac{P}{H\cdot n} \text{ [N]}$$

v_b – ship speed at rated power, [knots];

P – rated power, [kW];

H – mean propeller pitch, [mm];

n – rated number of revolutions per minute of the propeller, [rpm];

A – theoretical contact area between boss and shaft (100%), as given from the drawing disregarding oil grooves, [mm²];

B = $\mu^2 - S^2\cdot\theta^2$

μ – coefficient of friction between mating surfaces;

θ – half taper, (e.g. for taper l/15 it follows θ = 1/30);

F_v – circumferential force determined by the formula:

$$F_v = \frac{2{,}0\cdot C\cdot M_t}{D_s} \text{ [N]}$$

M_t – torque moment resulting from the rated power P at the rated number of revolutions n, [Nmm];

C = 1,0 for turbines or geared diesel drives with a hydraulic, electro-magnetic or highly flexible coupling;
= 1,0 for electric propulsion;
= 1,2 for a direct coupled diesel engine;

D_s – mean diameter of propeller cone, [mm] (Figure 2.8.9).

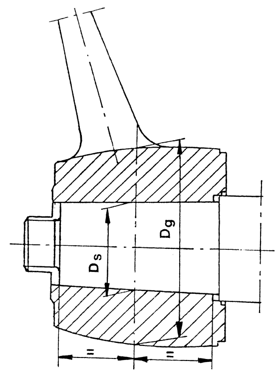

Figure 2.8.9
Keyless fitting of propeller

2.8.10 Corresponding minimum push-up length at temperature of 35˚C:

$$\delta_{35} = p_{35} \cdot \frac{D_s}{2\theta}\left[\frac{1}{E_g}\left(\frac{K^2+1}{K^2-1}+\nu_g\right)+\frac{1}{E_o}\left(1-\nu_o\right)\right] \text{ [mm]} \qquad (2.8.10)$$

where:

E_g – modulus of elasticity of boss material, [N/mm²];

E_o – modulus of elasticity of shaft material, [N/mm²];

K = $\frac{D_g}{D_s}$;

D_g – outer diameter of propeller boss [mm] corresponding to the position of diameter D_s (Figure 2.8.9);

ν_g – Poisson's ratio for boss material;

ν_o – Poisson's ratio for shaft material.

2.8.11 Minimum pull-up length at temperatures $t \leq 35$°C.

$$\delta_t = \delta_{35} + \frac{D_s}{2\theta}\left(\alpha_g - \alpha_o\right)\cdot\left(35 - t\right) \text{ [mm]} \qquad (2.8.11)$$

where:

α_g – coefficient of linear thermal expansion of boss material, [mm/mm°C];

α_o – coefficient of linear thermal expansion of shaft material, [mm/mm°C].

2.8.12 Minimum surface pressure between mating surfaces at $t \leq 35$°C.

$$p_t = p_{35} \cdot \frac{\delta_t}{\delta_{35}} \text{ [N/mm²]} \qquad (2.8.12)$$

2.8.13 Minimum push-up load at $t \leq 35$˚C:

$$F_t = A \cdot p_t(\mu + \theta) \text{ [N]} \qquad (2.8.13)$$

2.8.14 Maximum permissible pressure between mating surfaces at t =0°C:

$$p_{max} = \frac{0{,}7R_e\left(K^2-1\right)}{\sqrt{3K^4+1}} \text{ [N/mm²]} \qquad (2.8.14)$$

where:

R_e – yield point of propeller material, [N/mm²].

2.8.15 Maximum permissible push-up length at t =0°C is determined in accordance with:

$$\delta_{max} = \frac{p_{max}}{p_{35}} \cdot \delta_{35} \text{ [mm]} \qquad (2.8.15)$$

2.8.16 It is necessary to submit, in addition to calculation, the diagram of propeller push-up to the propeller shaft cone with respect to temperature and all other data necessary to check up the joint.

2.8.17 The approved diagram of the propeller push-up to propeller shaft cone with respect to temperature, shift indicator and instructions manual for the fitting and dismantling of propeller shall be available on board ship.

2.8.18 Fixed mark of the longitudinal and circumferential position of propeller to the propeller shaft shall be impressed in the propeller boss, nut and propeller shaft.

2.8.19 Test push-up of the propeller to the propeller shaft shall be carried out in workshop to check up shift, pressure and mating surfaces.

2.9 PROPELLER SHAFT CONDITION MONITORING (PMON) – DESIGN REQUIREMENTS

2.9.1 Oil-lubricated propeller shafts

The class notation PMON is assigned, to ships fitted with oil lubricated systems for propeller shaft bearings complying with the requirements of this Section.

2.9.1.1 Oil sealing gland: Oil-lubricated propeller shafts are to be fitted with an approved oil sealing gland which is capable of being replaced without withdrawal of the propeller shaft or removal of the propeller.

Sealing gland is to be type approved by Register with regard to protection of the sterntube against ingress of seawater.

2.9.1.2 Temperature monitoring and alarm: The vessel is to be provided with a temperature monitoring and alarm system for the propeller shaft stern tube aft bearing. Two temperature sensors or one easily interchangeable sensor shall be fitted on the aft stern tube bearing. The sensor(s) shall be located in the bearing metal near the surface, in way of the area of highest load. When one easily interchangeable sensor is fitted, a spare sensor shall be kept onboard.

Temperature monitoring and alarm system is to be located in the propulsion machinery space. When a centralized control and monitoring station is installed, the alarm is to be activated in such a station.

2.9.1.3 Measurement of bearing weardown: Arrangements and means for the propeller shaft stern tube aft bearing weardown measurement are to be provided. The history of measurements shall be available on board, as well as any change in oil sealing gland arrangement or measuring device.

2.9.1.4 Lubricating oil analysis: The oil sampling points shall be arranged with a test cock and shall be fitted with a signboard. Stern tube lubricating oil analysis shall be carried out at regular intervals not exceeding six months. Testing is to be conducted for the parameters stated in the *Rules for the classification of ships, Part 1, Chapter 5 – Surveys of ships in service,* 10.5.1. Samples shall be taken under similar running conditions and are to be representative of the oil within the sterntube.

2.9.1.5 Records: The following data are to be regularly recorded and available on board showing in particular trend of parameters recorded:

- lubricating oil analysis
- lubricating oil consumption
- bearing temperature

2.9.1.6 Documentation required for approval: The following details are required for scheme approval:

- arrangement plan
- piping diagram of lubrication and sealing oil system
- data of the oil sealing gland

- arrangements for bearing weardown measurements
- arrangements for stern tube bearing temperature measurement and recording
- arrangements for taking oil samples from the stern tube under service conditions.

3 PROPELLERS

3.1 GENERAL REQUIREMENTS

3.1.1 The requirements of the present Chapter apply to the propellers intended for ships without ice strengthening. For the ships with ice class notations see the *Rules for the classification of ships, Part 29 – Polar Class Ships and Ice Class Ships*.

3.1.2 The design and size of cycloidal propulsors (Voith-Schneider) will be specially considered by the *Register* in each particular case.

3.2 BLADE THICKNESS

3.2.1 The thickness of the expanded cylindrical blade section (Figure 3.2.1) of solid propellers, fixed pitch propellers with detachable blades, or controllable pitch propellers) shall not be less than:

$$s = 3{,}67A\sqrt{\frac{k}{z \cdot b} \cdot \frac{P_p}{R'_m \cdot n} + \frac{c \cdot m \cdot 9{,}81}{R'_m}\left(\frac{D \cdot n}{300}\right)^2} \text{ [mm]} \qquad (3.2.1)$$

where:

A – coefficient to be determined from the Table 3.2.1-3 depending on radius r of the section and the corresponding pitch ratio H/D, where the intermediate values, including the values in the Table, may be determined from:

A = $235{,}630127 - 89{,}3916433 r/R - 203{,}659692 \cdot (r/R)^2 + [-167{,}358511 + 157{,}198164 \cdot r/R + 60{,}7248508 \cdot (r/R)^2] \cdot (H/D) + (52{,}732298 - 69{,}0823521 \cdot r/R) \cdot (H/D)^2$

k – coefficient from the Table 3.2.1-1;

z – number of blades;

b – width of the expanded cylindrical section, [m];

P_p – shaft power at rated output of main engine, [kW];

n – revolutions per minute of the propeller, [rpm];

R'_m = $0{,}6R_m + 175$ [N/mm²] but not more than:
570 N/mm² – for steel blades,
608 N/mm² – for blades of non-ferrous metals;

R_m – tensile strength of blades material, [N/mm²];

c – coefficient of centrifugal stresses (determined from the Table 3.2.1-2);

m – rake at blade tip (Figure 3.2.1-1), [mm];

D – propeller diameter (Figure 3.2.1-1), [m].

The blade thickness shall be checked at the blade root and at the radius $0{,}6R$ (Figure 3.2.1-1).

The designed root section shall be:

.1 For solid propellers:
- at the radius of $0{,}2R$, if the hub radius $<0{,}2R$;
- at the radius of $0{,}25R$, if the hub radius $\geq 0{,}2R$;

.2 For fixed pitch propellers with detachable blades:
- at the radius of $0{,}3R$, where the coefficients A and c shall be read off for $r = 0{,}25R$;

.3 For controllable pitch propellers:
- at the radius of $0{,}35R$.

Notes:

.4 The blade thickness so determined does not take into account fillets at blade roots.

.5 The holes for the blade fastening parts of fixed pitch propellers with detachable blades and of controllable pitch propellers shall not reduce the design section.

.6 The thickness of propeller blades in ships of restricted navigation areas 2 to 8 may be reduced by 5%.

Table 3.2.1-1
Coefficient k

	Type of ship and propeller material	Without ice strengthening
1.	Cargo and passenger ships: a) Special brass or bronze b) Cast steel	 7,8 8,6
2.	Fishing vessels: a) Special brass or bronze b) Cast steel	 8,4 9,2
3.	Tugs: a) Special brass or bronze b) Cast steel	 8,4 9,2

Notes:
1 If the number of cylinders of engines is less than four, coefficient k shall be increased by 7%.
2 In propulsion plants with engines with hydraulic or electromagnetic couplings, coefficient k may be reduced by 5%.
3 For side thrusters of ships without ice strengthening, value of k may be reduced by 7%.

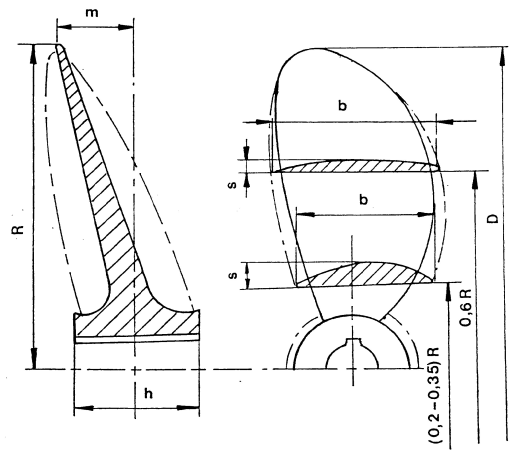

Figure 3.2.1-1
Blade Section

Table 3.2.1-2
Values of coefficient of centrifugal forces stresses *c*

r/R =	0,20	0,25	0,35	0,60
c	0,50	0,45	0,30	0,00

Table 3.2.1-3
Values of coefficient *A*

Coefficient *A*, for		*r/R* =			
		0,20	0,25	0,35	0,60
H/D =	0,5	152,6	147,3	134,1	85,9
	0,6	143,5	138,8	126,7	82,0
	0,7	135,2	130,9	120,0	78,4
	0,8	127,7	123,8	113,7	75,0
	0,9	121,0	117,4	108,1	71,8
	1,0	115,0	111,8	103,0	68,8
	1,1	109,9	106,8	98,6	66,0
	1,2	105,5	102,5	94,6	63,5
	1,3	101,8	98,9	91,3	61,2
	1,4	99,0	96,1	88,5	59,1
	1,5	96,9	93,9	86,3	57,3
	1,6	95,6	92,5	84,7	55,7
Note: For controllable pitch propellers *H/D* shall be based on the designed service operation.					

3.2.2 The thickness of blade tips shall not be less than:

0,0035*D* – for ships without ice strengthening.

3.2.3 The blade thickness calculated in accordance with 3.2.1 and 3.2.2 may be reduced (e.g. for blades of particular shape) provided the relevant documentation with a detailed strength calculation are submitted for consideration to the *Register*. In that case a detailed hydrodynamic load and stress analysis carried out by the propeller designer may be considered by the *Register*, on a case by case basis. The safety factor to be used in this analysis is not to be less than 8 with respect to the ultimate tensile strength of the propeller material R_m.

3.2.4 On ships with ice class notations strength conditions in the case of blade fracture are stated in the *Rules for the classification of ships, Part 29 – Polar Class Ships and Ice Class Ships*.

3.3 HUB AND BLADE FASTENING PARTS

3.3.1 Fillet radii of the transition from blade to hub shall exceed: 0,04*D* on the suction side, and 0,03*D* on the thrust side.

If the blades are without rake, the fillet radii on both sides shall not be less than 0,03*D*.

Gradual transition from blade to hub with variable radii is allowed.

3.3.2 The propeller hub shall be provided with holes through which the empty spaces between the hub and shaft cone are filled with non-corrosive mass. The propeller cap shall be also filled with such a mass.

3.3.3 The internal diameter of the thread (core diameter) of stud bolts (d_v) for fastening the blades to the hub shall not be less than:

$$d_v = K \cdot s \sqrt{\frac{b \cdot R_{mk}}{d_0 \cdot R_{mv}}} \quad \text{[mm]} \qquad (3.3.3)$$

where:

K = 0,33 in case of 3 stud bolts on thrust side;
= 0,30 in case of 4 stud bolts on thrust side;
= 0,28 in case of 5 stud bolts on thrust side;

s – maximum thickness of blade at the design root section. (see 3.2.1), [mm]

b – width of the straightened blade at the design root section, [mm];

R_{mk} – tensile strength of the blade material, [N/mm²];

R_{mv} – tensile strength of the stud bolts material, [N/mm²];

d_0 – diameter of pitch circle of stud bolts holes, [mm].

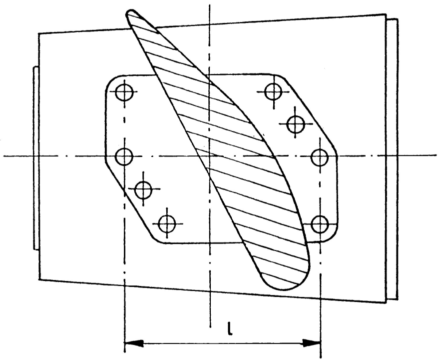

Figure 3.3.3
Propeller hub with holes for blade fastening

For other arrangements of stud bolts:

$d_0 = 0{,}85l$

where:

l – maximum distance between stud bolts, [mm] (Figure 3.3.3).

Stud bolts shall be secured of self-screwing off.

3.4 PROPELLER BALANCING

3.4.1 The completely finished propeller shall be statically balanced. The balancing shall be carried out by means of a test load which, when suspended to any blade in horizontal position shall cause the propeller to rotate.

The mass of test load shall not be greater than the value obtained by the formula:

$$m = k \cdot \frac{m_p}{R} \quad \text{[kg]} \qquad (3.5.1)$$

where:

k = 0,75 with $n \leq 200$;
= 0,50 with $200 < n \leq 500$;
= 0,25 with $n > 500$.

n – rated number of propeller revolutions per minute, [rpm];

m_p – propeller mass, [t];

R – propeller radius, [m].

Where propeller mass exceeds 10 t, the coefficient k shall not be greater than 0,5 irrespective of the propeller rotational speed.

3.4.2 The difference in mass of regular and spare detachable blades of built propellers shall not exceed 1,5%.

3.5 CONTROLLABLE PITCH PROPELLERS

3.5.1 The hydraulic system of the pitch control gear shall be provided with two separate pumps of equal capacity, one of which shall be stand-by pump. One of the pumps may be driven by the main engine in which case the pump shall be capable of operating the propeller blades under all operating conditions of the engine.

Ships having two controllable pitch propellers, may be provided with one independent stand-by pump for both propellers. A stand-by pump may not be provided where the propeller blades can be operated by a hand-driven pump or a hand drive actuated by one person.

The time of putting over the blades shall be in accordance with 3.5.4.

3.5.2 In ships with a controllable pitch propeller in which the main engine may become overloaded due to particular service conditions, it is recommended that automatic protection against overloading be used for the main engine.

3.5.3 The hydraulic control system shall comply with the *Rules for the classification of ships, Part 9 - Machines*, section 7 and the *Rules for the classification of ships, Part 8-Piping*, section 15.

3.5.4 The time of putting over the controllable pitch propeller blades from "full ahead" to "full astern" position when main engine is out of operation shall not exceed:

20 seconds – for propellers with $D \leq 2$ m,
30 seconds – for propellers with $D > 2$ m,

where:

D – propeller diameter, [m].

3.5.5 With gravity systems of lubrication used for controllable pitch propellers, the gravity tanks and lubricating oil system shall comply with the requirements of 2.6.4.

3.6 TIGHTNESS TESTS

3.6.1 After fitting of the propeller to the propeller shaft, the seal shall be tested for tightness by a pressure of 0,2 MPa.

If the seal is exposed to the oil pressure from the stern tube or the propeller hub, it shall be tested by the pressure equal to that used for testing of the stern tube seal or the propeller hub.

3.6.2 The hub of the controllable pitch propeller after being assembled with blades, shall be tested by internal pressure equal to the lubricating oil head in gravity tank or equal to the pressure of the lubricating pump of the lubricating system.

3.6.3 Sealing of cycloidal propulsors (Voith-Schneider) shall be tested by the internal pressure equal to the lubricating oil head in gravity tank.

3.7 TESTING OF THE CONTROL SYSTEM OF CONTROLLABLE PITCH PROPELLERS INTENDED FOR MAIN PROPULSION

3.7.1 Purpose

The purpose of the tests required by this head of the *Rules* is to ascertain that the pitch control system of CP propellers for main propulsion is working correctly.

3.7.2 Application

The requirements in this head of the Rules apply to all new buildings and to all replacements, modifications, repairs, or re-adjustments that may affect the pitch control or response characteristics for main propulsion.

3.7.3 Scope of the tests

3.7.3.1 Pitch response test

- A full range of tests is to be carried out to get the pitch response and verify that it coincides with the combinator curve of the propeller. The tests are to be carried out for at least three positions of the control lever in ahead and astern directions (e.g., dead slow ahead / astern, half ahead / astern, full ahead / astern).
- The tests are to be carried out in normal and emergency operating conditions.
- Tests that are not affected by the control position may be carried out from one control position only.

NOTE: The combinator curve is the relationship between the propeller pitch setting and the propeller speed.

3.7.3.2 Test of the fail-to-safe characteristics

A test of the fail-to-safe characteristics of the propeller pitch control system is to be carried out to demonstrate that failures in the pitch command and control or feedback signals are alarmed and do not cause any change of thrust. Such failures are to be clearly identified and included in the test procedure.

3.7.3.3 Test procedure

Test procedure is to be prepared and proposed by the pitch control system manufacturer or integrator and agreed with *Register.*

3.7.4 Parameters to be recorded

The list of the parameters to be recorded during the pitch response test within this head of the *Rules* is to be established by the pitch control system manufacturer or integrator and agreed with the *Register*. This should include at least the following parameters:

- Position of the control handle,
- Actual pitch indication (local indication, remote indications),
- Rotational speed of the propeller,
- Response time between the pitch change order (modification of the lever position) and the instant when the pitch and propeller speed have reached their final position,
- Propelling thrust variation during the transfer of the control from one location to another one.

3.7.5 Tests results

Tests are to demonstrate:

- that the propelling thrust is not significantly altered when transferring control from one location to another and in case of failures in the pitch command and control or feedback signals,
- that the pitch response times measured during the test do not exceed the maximum value to be defined by the pitch control system manufacturer or integrator.

4 TORSIONAL VIBRATIONS

4.1 GENERAL REQUIREMENTS

4.1.1 The calculation of torsional vibrations shall include the following operations:

.1 running with spare propeller, if its moment of inertia differs from that of the working propeller by 10% or more;
.2 operation at maximum power take-off and idle running, in case of controllable pitch propeller and cycloidal propulsor (Voith-Schneider);
.3 operation with additional power consumers connected to the system, if the inertia moment of the power consumer is significant in comparison with that of the working cylinder;
.4 astern running if a reverse gear is fitted;
.5 with one cylinder not firing;
.6 with individual and simultaneous operation of the main engines for multi engine plants fitted with one reduction gearing.

4.1.2 The calculation of torsional vibrations shall contain all necessary data such as:

.1 detailed data of the component parts of the dynamic system:
- size of moments of mass inertia and torsional stiffness of dynamic system;
- layouts of all possible operating variants of systems referred to in 4.1.1;
- type and the parameters of the vibration damper, flexible couplings, gearing and generators;

.2 natural frequency tables for all modes having significant resonances within the range of 0,2 to 1,2 of the rated number of revolutions;
.3 firing order in cylinders of internal combustion engine and the geometrical sums of the relative vibration amplitudes of the cranks of the working cylinders for all orders and modes under consideration;
.4 stresses at the weakest cylindrical cross sections of the shafting resulted from the existing moment of all resonances in the speed range of 0,2 to 1,2 of the rated number of revolutions;
.5 for flexible couplings:
dynamic moments resulting from the torsional vibrations or the stresses in the coupling elements and the comparison with the permissible values;
.6 for reduction gears:
dynamic moments on the (tooth) gearing and the comparison with the mean torque, dynamic moments in the range of the rated number of revolutions as specified in .4;
.7 for diesel generators:
variable moments on rotor and their comparison with the torque moment;
.8 drawings and calculations of vibration dampers if any;
.9 amplitude of vibrations at the point where the measurement of torsional vibrations corresponds to the calculated values of stresses and dynamic moments required, in compliance with .4 and .5.

4.1.3 The alternating torsional stress amplitude is understood as $(\tau_{max}-\tau_{min})/2$ as can be measured on a shaft in a relevant condition over a repetitive cycle.

4.2 PERMISSIBLE STRESSES

4.2.1 Crankshafts and generator shafts

4.2.1.1 Permissible stresses due to torsional vibrations in crankshafts of main engines when running continuously shall not exceed the values of alternating torsional stresses for which the calculation of the engine crankshaft calculation is approved (the *Rules for the classification of ships, Part 9- Machines*, 2.4.3).

4.2.1.2 Permissible stresses due to torsional vibration for crankshafts of engines driving generators and other auxiliary machinery for essential services shall not exceed the values of alternating torsional stresses for which the calculation of the engine crankshaft calculation is approved (the *Rules for the classification of ships, Part 9 - Machines*, 2.4.3).

4.2.1.3 Permissible stresses in crankshafts of main engines for speed ranges forbidden for continuous operation and allowed only to be rapidly passed through shall not exceed the following values:

$$\tau_{dop1} = \pm 2{,}0\left(45 - 0{,}4\sqrt{d} - 13\frac{n_i}{n}\right)\frac{2R_m - 510}{R_m} \quad \text{[N/mm²]} \tag{4.2.1.3}$$

within the speed range:

0,70n – for ships with ice strengthening of 1AS and 1A categories;
0,80n – for other ships;

where:

τ_{dop1} – permissible stresses, [N/mm²];
d – shaft diameter, [mm];
n_i – speed under consideration, [rpm];
n – rated speed, [rpm];
R_m – tensile strength of the shaft material, [N/mm²].

For ships the main engines of which run continuously with the maximum torque moment at speeds lower than rated values (e.g. tugs, fishing trawlers and similar), $n_i=n$ shall be taken in all cases.

Critical speeds within the manoeuvring speed ranges shall be avoided.

4.2.1.4 Permissible stresses due to torsional vibration, in speed range 0,85n ÷1,05n, for shafts of generators shall not exceed the values determined by:

$$\tau_{dopg} = \pm\left(22{,}5 - 0{,}2\sqrt{d}\right)\frac{2R_m - 510}{R_m} \quad \text{[N/mm²]} \tag{4.2.1.4}$$

d – generator shaft diameter, [mm];

n – nominal rotational speed, [rpm];
R_m – tensile strength of generator shaft material, [N/mm²].

4.2.1.5 Permissible stresses in generator shafts, forbidden for continuous operation and allowed only to be rapidly passed through shall not exceed the following value:

$$5\,\tau_{dop,g} \qquad (4.2.1.5)$$

where:
τ_{dopg} – permissible stresses determined by the formula (4.2.1.4), [N/mm²].

4.2.1.6 Forbidden number of revolutions shall not be allowed in the speed range:
$>0{,}70n$ – for ships with ice strengthening of 1AS and 1A categories;
$>0{,}80n$ – for main engines of other ships;
$\geq 0{,}85n$ – for generators and generator diesel engines.

4.2.2 Intermediate, thrust and propeller shafts

4.2.2.1 Permissible stresses due to torsional vibrations for continuous operation in speed range:

$0{,}7n \div 1{,}05n$ – for ships with ice strengthening of categories 1AS, 1A and 1B;

$0{,}9n \div 1{,}05n$ – for other ships;

shall not exceed the values determined by the formula:

$$\tau_{dop1} = \pm \frac{R_m + 160}{18} C_k \cdot C_d \cdot 1{,}38 \text{ [N/mm²]} \qquad (4.2.2.1\text{-}1)$$

Permissible stresses in speed ranges lower than the above mentioned shall not exceed the values determined by:

$$\tau_{dop2} = \pm \frac{R_m + 160}{18} \cdot C_k \cdot C_d \left[3 - 2\left(\frac{n_i}{n}\right)^2 \right] \text{ [N/mm²]} \qquad (4.2.2.1\text{-}2)$$

where:
τ_{dop1} = permissible stress, [N/mm²];
τ_{dop2} = permissible stress, [N/mm²];
R_m – tensile strength of the shaft material, [N/mm²].
When the intermediate shaft material is a carbon or carbon-manganese steel having the tensile strength exceeding 600 N/mm², for the calculation purpose will be considered that of R_m = 600 N/mm² only.
When the intermediate shaft material is an alloy steel having the tensile strength exceeding 800 N/mm², for the calculation purpose will be considered that of R_m = 800 N/mm² only.
When the propeller shaft material is a carbon, carbon-manganese or alloy steel having the tensile strength exceeding 600 N/mm², for the calculation purpose will be considered that of R_m=600 N/mm² only.

Table 4.2.2.1
C_k -factors for different design features

Factor C_k		
No.	for intermediate shafts with	C_k
1	integral coupling flanges [1]	1,0
2	straight sections	1,0
3	shrink fit coupling (keyless) [2]	1,0
4	keyways, tapered connections [3] [4]	0,60
5	keyways, cylindrical connections [3] [4]	0,45
6	radial holes [5]	0,50
7	longitudinal slot [6]	0,30 [7]
	for thrust shafts external to engines	
8	on both sides of thrust collar [1]	0,85
9	in way of bearing (when a roller bearing is used)	0,85
	for propeller shafts	
10	flange mounted [1] [5]	0,55
11	keyless taper fitted propellers [5]	0,55
12	key fitted propellers [5]	0,55
13	between forward edge of aft most bearing and forward stern tube seal	0,80

Note: Transitions of diameters are to be designed with either a smooth taper or a blending radius. For guidance, a blending radius equal to the change in diameter is recommended.

Footnotes:
[1] Fillet radius shall not be less than $0{,}08d_M$.
[2] C_k refers to the plain shaft sections 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% and a blending radius as described in the Table note stated above.
[3] At a distance of not less than $0{,}2d_M$ from the end of the keyway the shaft diameter may be reduced to the diameter calculated with k=1,0.
[4] In general, keyways are not to be used in installations with a barred speed range. Fillet radius in the transverse section of the bottom of the keyway shall not be less than $0{,}0125d_M$.
[5] Diameter of radial bore shall not exceed $0{,}3d_M$. Intersection between a radial and an eccentric axial bore is a subject of special consideration.
[6] Length of the slot shall not exceed $0{,}8d_M$. Inner diameter shall not exceed $0{,}8d_M$. Width of the slot shall be higher than $0{,}1d_M$. The end rounding of the slot shall not be less than half its width. An edge rounding should preferably be avoided, as this increases the stress concentration slightly. The values in the Table are valid for 1, 2 and 3 slots, i.e. with slots at 360º respectively, 180º respectively and 120º apart.
[7] C_k = 0,3 is an approximation within the limitations given in footnote (6). More accurate estimate of the stress concentration factor (α_t) may be determined from 4.2.2.4 or by direct application of FE calculation, in which case:
$$C_k = 1{,}45/\alpha_t$$
[8] Applicable to the portion of the propeller shaft between the forward edge of the aftermost shaft bearing and the forward face of the propeller hub (or shaft flange), but not less than 2,5 times the required diameter.

C_k – factor for different shaft design features (see Table 4.2.2.1);
C_d – size factor;
$= 0,35 + 0,93/d^{0,2}$
d – shaft diameter, [mm];
n_i – rated speed under consideration, [rpm];
n – rated speed, [rpm].

For ships the main engine of which run continuously with maximum torque at speeds less than calculated n (e.g. tugs, fishing trawlers etc.) the formula (4.2.2.1-1) shall be used throughout the speed range $0,2n$ to $1,05n$.

4.2.2.2 Stress concentration factor α_t (see footnote 7 in the Table 4.2.2.1) is defined as the ratio between the maximum local principal stress and √3 times the nominal torsional stress (determined for the bored shaft without slots).

4.2.2.3 Explanation of low cycle and high cycle fatigue factors

The factors k (for low cycle fatigue) and C_k (for high cycle fatigue) take into account the influence of:

.1 The stress concentration factors α_t relative to the stress concentration for a flange with fillet radius of $0,08d_M$ (geometric stress concentration factor of approximately 1,45).
$k = (\alpha_t/1,45)^x$ (4.2.2.3-1)
$C_k = 1,45/\alpha_t$ (4.2.2.3-2)
where the exponent x considers low cycle notch sensitivity.

.2 The notch sensitivity. The chosen values are mainly representative for soft steels (with their specified tensile strength R_m<600 N/mm²), while the influence of steep stress gradients in combination with high strength steels may be underestimated.

.3 The size factor C_d being a function of diameter only does not purely represent a statistical size influence, but rather a combination of this statistical influence and the notch sensitivity.

The actual values for k and C_k are rounded off.

4.2.2.4 Stress concentration factor of slots

The stress concentration factor α_t at the end of slots can be determined by means of the following empirical formulae:

$$\alpha_t = \alpha_{t(hole)} + 0,8\frac{(l-e)/d}{\sqrt{\left(1-\frac{d_i}{d}\right)\cdot\frac{l}{d}}} \qquad (4.2.2.4\text{-}1)$$

$$\alpha_{t(hole)} = 2,3 - 3\frac{e}{d} + 15\left(\frac{e}{d}\right)^2 + 10\left(\frac{e}{d}\right)^2\left(\frac{d_i}{d}\right)^2 \qquad (4.2.2.4\text{-}2)$$

where:
$\alpha_{t(hole)}$ – the stress concentration of radial holes,
e – hole diameter, mm
l – slot length, mm
d – outside diameter of the shaft, mm
d_i – inner diameter of the shaft, mm

Application of the formulae (4.2.2.4-1) and (4.2.2.4-2) are subject to limitations stated in footnote 6 of the Table 4.2.2.1.

The formula (4.2.2.4-1) applies to:

.1 slots at 120º (three slots apart), or 180º (two slots apart) or 360º (one slot).
.2 slots with semi-circular ends. A multi-radii slot end can reduce the local stresses, but this is not included in this empirical formula.
.3 slots with no edge rounding (except chamfering), as any edge rounding increases the stress concentration factor α_t slightly.

4.2.2.5 Permissible stresses for speed ranges forbidden for continuous running and allowed only to be rapidly passed through (i.e. restricted speed ranges), shall not exceed the values determined by:

$$\pm\frac{1,7\tau_{dop,2}}{\sqrt{C_k}} \text{ [N/mm}^2\text{]} \qquad (4.2.2.5)$$

For notations see 4.2.2.1.

Restricted speed range for continuous running is not allowed with number of revolutions:
$\geq 0,7n$ – for ships with ice strengthening of 1AS and 1A categories,
$\geq 0,8n$ – for other ships.

Restricted speed ranges in one-cylinder misfiring conditions of single propulsion engine ships are to enable safe navigation.

4.2.2.6 If the minimum intermediate shaft, thrust shaft or propeller shaft diameter is greater than minimum permissible value calculated in accordance with 2.2, 2.3 or 2.4.1, permissible stresses due to torsional vibrations may be greater than determined in accordance with 4.2.2.1, subject to consideration of the *Register*.

4.2.2.7 Greater values of the permissible stresses determined by alternative formulae which are not referred to in 4.2.2.1, shall be considered by the *Register* in each particular case.

4.2.3 Diesel generators

Variable torque moments on the generator rotor under conditions of the rated loading of generator within the speed range $0,95n \div 1,10n$, shall not exceed the double rated torque moment of the main engine.

4.3 TORSIOGRAPH RECORDS

4.3.1 Torsional vibration results shall be confirmed by torsiograph measurement during the sea trials. Estimation of non-resonant forced vibration shall be based on the harmonic analysis of the torsiograph record.

4.3.2 The measured frequencies of natural vibrations shall not differ from the calculated ones by more than 5%, otherwise the calculations shall be corrected accordingly.

4.4 BARRED SPEED RANGES

4.4.1 Where the vibration stresses exceed the limiting values for continuous running determined by the items 4.2.1.1, or 4.2.1.2, or by the formula (4.2.2.1-2) barred speed ranges shall be imposed.

4.4.2 The limits of the barred speed range shall be determined as follows:

4.4.2.1 The barred speed range is to cover all speeds where the acceptable limits (τ_{dop}) are exceeded. For controllable pitch propellers with the possibility of individual pitch and speed control, both full and zero pitch conditions have to be considered.

Additionally the tachometer tolerance has to be added. At each end of the barred speed range the engine shall be stable in operation.

4.4.2.2 In general, and subject to 4.4.2.1, the barred speed range shall be determined by the formula:

$$\frac{16n_k}{18-\frac{n_k}{n}} \le n_z \le \frac{\left(18-\frac{n_k}{n}\right)\cdot n_k}{16} \text{ [rpm]} \qquad (4.4.2)$$

where:

n_k – critical speed range, [rpm];
n – rated speed range, [rpm];
n_z – barred speed range, [rpm].

4.4.3 Barred speed range (see 4.4.2) where the stresses due to torsional vibration, or the torque moments in the flexible couplings or reduction gears (see 4.1.2.5 and 4.1.2.6) exceed the permissible values, shall be increased by 0,03n in both directions.

4.4.4 In case of the barred speed range, the accuracy of tachometer shall be within ±2,5%. Barred speed range shall be clearly marked on tachometer scale.

4.4.5 Where the operation referred to in 4.1.1.5 proves, by calculation or measurement, that there are zones where stresses due to torsional vibration or torque moments in flexible couplings or reduction gears, exceed the permissible values, it shall be necessary:

.1 when the main engine is provided with the automatic alarm in case when one of cylinders is out of operation, to provide instructions concerning for bidden area conditions of the engine operation in compliance with 4.4.2 and 4.4.3;

.2 in case the automatic alarm referred to in item .1 is not provided, forbidden speed range shall not be allowed as a rule, or it shall be indicated on the tachometer as specified in 4.4.4 provided that the forbidden speed range does not impede the normal service of the ship.

5 SHAFTING AXIAL VIBRATION

5.1 GENERAL

5.1.1 For all main propulsion shafting systems, it is to be ensured that axial vibration amplitudes are satisfactory throughout the entire speed range. Where natural frequency calculations or measurements indicate significant axial vibration responses, sufficiently wide restricted speed ranges will be imposed.

5.2 PARTICULARS TO BE SUBMITTED

5.2.1 The results of calculations, together with recommendations for any speed restrictions found necessary.

5.2.2 Engine builder's recommendation for axial vibration amplitude limits at the non-driving end of the crankshaft or at the thrust collar.

5.2.3 Estimate of flexibility of the thrust bearing and its supporting structure.

5.2.4 The requirement for calculations to be submitted may be waived upon request provided evidence of satisfactory service experience of similar dynamic installations is submitted.

5.3 CALCULATIONS

5.3.1 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:

.1 Driven directly by a reciprocating internal combustion engine.

.2 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.

5.3.2 Where an axial vibration damper is fitted, the calculations are to consider the effect of a malfunction of the damper.

5.3.3 For those systems as defined in .2 of item 5.3.1 the propeller speed at which the critical frequency occurs may be estimated using the following formula:

$$n_c = \frac{0{,}98}{z}\sqrt{\frac{a \cdot b}{a+b}} \quad \text{[rpm]} \qquad (5.3.3)$$

where:

a = $\dfrac{E}{\rho \cdot \ell^2}\left(66{,}2 + 97{,}5A - 8{,}88A^2\right)^2$ [cyc/min]²

b = $91{,}2\dfrac{k}{m_e}$ [cyc/min]²

k – estimated stiffness at thrust block bearing, [N/m]

l – length of shaft line between propeller and thrust bearing, [mm]

m_s – mass of shaft line considered, [kg]

m_s = $0{,}785(D^2 - d^2)\rho\ell$

A = m_s / m_p

D – outside diameter of shaft, taken as an average over length ℓ, [mm]

d – internal diameter of shaft, [mm]

E – modulus of elasticity of shaft material, [N/mm²]

ρ – density of shaft material, [kg/mm³]

m_p – dry mass of propeller, [kg]

m_e = $m_p \cdot (A+2)$

z – 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.

5.4 MEASUREMENTS

5.4.1 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.

5.5 RESTRICTED SPEED RANGES

5.5.1 The limits of any speed restriction are to be such as to maintain axial amplitudes within recommended levels during continuous operation.

5.5.2 Limits of a speed restriction, where required, may be determined by calculation or on the basis of measurement.

5.5.3 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 procedure for monitoring are to be submitted to the *Register*.

5.6 VIBRATION MONITORING

5.6.1 Where a vibration monitoring system is to be specified, details of proposals are to be submitted to the *Register*.

6 SHAFTING LATERAL VIBRATION

6.1 GENERAL

6.1.1 For all main propulsion shafting systems, it is to be ensured that lateral vibration characteristics are satisfactory throughout the speed range.

6.2 PARTICULARS TO BE SUBMITTED

6.2.1 Calculations of the lateral vibration characteristics of shafting systems having supports outboard of the hull or incorporating cardan shafts are to be submitted.

6.3 CALCULATIONS

6.3.1 The calculations in 6.2.1, 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.

6.3.2 Requirements for calculations may be waived upon request provided evidence of satisfactory service experience of similar dynamic installations is submitted.

6.4 MEASUREMENTS

6.4.1 Where calculations indicate the possibility of significant lateral vibration responses within the range of ±20% of the speed at maximal continuous rated power, measurements using an appropriate recognised technique may be required to be taken from the shafting system for the purpose of determining the need for restricted speed ranges.

6.4.2 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 to the *Register*.

7 SHAFT ALIGNMENT

7.1 GENERAL

7.1.1 Shaft alignment calculations are to be carried out for all installations and to prepare alignment procedures detailing the proposed alignment method and the alignment checks to demonstrate compliance with the requirements of this Section.

7.2 SHAFT ALIGNMENT CALCULATIONS

7.2.1 Shaft alignment calculations are to be submitted to the *Register* for approval for the following shafting systems where the propeller shaft has a diameter of 250 mm or greater in way of the aftermost sterntube bearing:

.1 All geared installations;
.2 Installations with one shaftline bearing, or less, inboard of the sterntube bearing/seal;
.3 Where prime movers or shaftline bearings are installed on resilient mountings.

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

.1 thermal displacements of the bearings between cold static and hot dynamic machinery conditions;
.2 buoyancy effect of the propeller immersion due to the ship's different operating draughts;
.3 effect of predicted hull deformations over the range of the ship's operating draughts, where known;
.4 effect of filling the aft peak ballast tank upon the bearing loads, where known;
.5 gear forces, where appropriate, due to prime-mover engagement on multiple-input single-output installations;
.6 propeller offset thrust effects;
.7 maximum allowed bearing weardown, for water or grease lubricated sterntube bearings, and its effect on the bearing loads.

7.2.3 The shaft alignment calculations are to state the:

.1 expected bearing loads for all operating loading conditions of the ship, for the machinery in cold and hot, static and dynamic conditions;
.2 bearing influence coefficients and the deflection, slope, bending moment and shear force along the shaftline;
.3 details of propeller offset thrust;
.4 details of proposed slope-bore of the aftermost sterntube bearing, where applicable;
.5 manufacturer's specified limits for bending moment and shear force at the shaft couplings of the gearbox/prime movers;
.6 estimated bearing weardown rates for water or grease lubricated sterntube bearings;
.7 expected hull deformation effects and their origin, namely whether finite element calculations or measured results from sister or similar ships have been used;
.8 anticipated thermal rise of prime movers and gearing units between cold static and hot running conditions; and
.9 manufacturer's allowable bearing loads.

7.3 SHAFT ALIGNMENT PROCEDURE

7.3.1 A shaft alignment procedure is to be submitted for review for all main propulsion installations detailing, as a minimum, the:

.1 expected bearing loads for all operating loading conditions of the ship, for the machinery in cold and hot, static and dynamic conditions;
.2 maximum permissible loads for the proposed bearing designs;
.3 design bearing offsets from the straight line;
.4 design gaps and sags on flanges;
.5 location and loads for the temporary shaft supports;
.6 expected relative slope of the shaft and the bearing in the aftermost sterntube bearing;
.7 details of slope-bore of the aftermost sterntube bearing, where applied;
.8 proposed bearing load measurement technique and its estimated accuracy;
.9 jack correction factors for each bearing where the bearing load is measured using a specified jacking technique;
.10 proposed shaft alignment acceptance criteria, including the tolerances (permissible deviations); and
.11 flexible coupling alignment criteria.

7.4 DESIGN AND INSTALLATION CRITERIA

7.4.1 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 7.4.2.

7.4.2 Design and installation of the shafting is to satisfy the following criteria:

.1 The bearings are to be positioned and the bearing seatings constructed to minimize the effects of hull deflections under any of the ship's operating conditions with the aim of optimising the bearing load distribution.
.2 Relative slope between the propeller shaft and the aftermost sterntube bearing is, in

general, not to exceed 0,3 mm/m (i.e. $3 \cdot 10^{-4}$ rad) in the static condition.

.3 Sterntube bearing loads are to satisfy the requirements of 2.6.

.4 Bearings of synthetic material are to be verified as being within tolerance for ovalilty and straightness, circumferentially and longitudinally, after installation.

.5 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.

.6 Intermediate shaft bearings' loads are not to exceed 80% of the bearing manufacturer's allowable maximum load for plain journal bearings, based on the bearing projected area.

.7 Equipment (i.e. prime movers, gearing, etc.) bearing loads are to be within the manufacturer's specified limits.

.8 Resulting shear forces and bending moments are to meet the equipment manufacturer's specified coupling conditions.

.9 The manufacturer's radial, axial and angular alignment limits for the flexible couplings are to be maintained.

7.5 MEASUREMENTS

7.5.1 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.

7.5.2 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.

7.5.3 For vessels of an existing design or similar to an existing design where evidence of satisfactory service experience is submitted to the *Register* 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.

7.5.4 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.

7.6 FLEXIBLE COUPLINGS

7.6.1 Where the shafting system incorporates flexible couplings, the effects of such couplings on the various modes of vibration are to be considered, see Sections 4, 5 and 6.

8 STRENGTHENING FOR NAVIGATION IN ICE

8.1. For the ships with ice class notations see the *Rules for the classification of ships, Part 29 – Polar Class Ships and Ice Class Ships*.

9 SPARE PARTS

9.1 GENERAL REQUIREMENTS

9.1.1 In this Section are stated recommendations for spare parts to be available on ships of navigation area 1 (unrestricted area of navigation).

9.2 SPARE PARTS FOR MAIN INTERNAL COMBUSTION ENGINES

9.2.1 Introduction

As main propulsion machinery, equipment, systems and technologies emerge to address the ever developing and evolving needs of shipping, their complexity and diversity will increase. In such an operating environment, the application of rigid recommendations for spare parts, such as those defined in a traditional list-based approach, may not always be appropriate.

Assessment of the recommended spare parts to be carried onboard ship through risk assessment can provide a flexible and adaptable means to satisfy the core requirement for spare parts and associated maintenance, namely, the avoidance of sudden operational failures to equipment, components and systems which may result in hazardous situations or unsafe events. The ISM Code and IACS Recommendation No. 74 and No. 127 contain guidance upon which a risk assessment may be based.

Main internal combustion engines refers to engines providing propulsion power (irrespective of the configuration of the propulsion system e.g. direct drive, geared, hybrid, etc.) and includes their control systems, both local and remote, their alarm systems and their safety systems.

9.2.2 Risk assessment approach to determining spare parts provision

9.2.2.1 Identification of essential engine components

A risk assessment (e.g. FMEA) should be undertaken for each type of engine to identify components, failure of which, could potentially result in engine damage, unsafe engine operation or a reduction in engine power output.

The risk assessment should consider each fuel on which the engine is designed to operate independently and therefore, for the purposes of determining spare parts, fuel changeover should not be considered a mitigation for component failure.

The risk assessment should be carried out in accordance with recognised national or international standards.

The risk assessment report should be included in the documentation submitted for Type Approval of the engine.

9.2.2.2 Determination of recommended spare parts

Determination of recommended spare parts for each type of engine should take account of the results of the risk assessment together with any evidence of component reliability e.g. relevant service history, MTBF (mean time between failure) data, etc.

The recommended spare parts should be parts (or sets of parts) suitable for exchange onboard by the ship's crew.

The recommended spare parts should be listed and included in the engine user documentation e.g. operating and/or maintenance manual, product guide, project guide etc.

The recommended spare parts list should be included in the documentation submitted for Type Approval of the engine.

9.2.2.3 Recommended number of spare parts to be supplied

For each type of engine, at least one recommended spare part (or set of spare parts) should be supplied for each different type of part determined by 9.2.2 above, unless the risk assessment concludes otherwise.

For spare parts periodically exchanged in normal operation (e.g. exhaust valves), at least two spare parts (or sets of spare parts) should be supplied for each type of part determined by 9.2.2 above, unless the risk assessment concludes otherwise.

Spare parts supplied should be verified and documented by means of Society Certificate (SC), Work Certificate (W) or Test Report (TR), in accordance with IACS UR M72.

9.2.2.4 Spare parts inventory to be carried onboard

For determination of the spare parts inventory to be carried onboard, a ship specific risk assessment should be undertaken (e.g. HAZID) to establish any need to supplement the inventory of engine spare parts supplied with additional spare parts.

The risk assessment should establish the numbers of each type of spare parts (or sets of spare parts) required, the types of spare parts required and the scope of spare parts required taking into account the following considerations:

- ship type and operational profile
- number and types of engines installed, their arrangement and any redundancy
- engine and component service experience and service history
- maintenance policy and maintenance regime
- manufacturers recommendations for maintenance and/or repair
- tools required for fitting spare parts
- spare parts required to be carried by regulations

9.2.3 Traditional approach to determining spare parts provision

In cases where a risk assessment approach has not been taken, Table 9.2.3 provides a generic example of the typical minimum recommended spare parts for conventionally fuelled main internal combustion engines. This example has been developed to deal with cases of such ships complying with the international regulations and should be taken into account when spare parts to be provided onboard the ship and their actual number should be determined. Table 9.2.3 is not intended to replace any guidance set by the engine makers with regard to recommended spares for their equipment.

Table 9.2.3
A generic example of the typical minimum recommended spare parts for conventionally fuelled main internal combustion engines of ships for unrestricted service

Item	Spare parts	Number recommended
1. Main bearings	Main bearings or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1
2. Main thrust block	Pads for one face of Michell type thrust block, or	1 set
	Complete white metal thrust shoe of solid ring type, or	1
	Inner and outer race with rollers, where roller thrust bearings are fitted	1
3. Cylinder liner	Cylinder liner, complete with joint rings and gaskets	1
4. Cylinder cover	Cylinder cover, complete with valves, joint rings and gaskets.	1
	Cylinder cover bolts and nuts, for one cylinder	1/2 set
5. 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 casting, seat springs and other fittings	1
	Cylinder overpressure sentinel valve, complete	1
	Fuel valves of each size and type fitted, complete with all fittings, for one engine	1 set[1]
6. 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
7. Pistons	Crosshead type; piston of each type fitted, complete with piston rod, stuffing box, skirt, rings, studs and nuts	1 set
	Trunk piston type: piston of each type fitted, complete with skirt, rings, studs, nuts, gudgeon pin and connecting rod	
8. Piston rings	Piston rings, for one cylinder	1 set
9. Piston cooling	Telescopic cooling pipes and fittings or their equivalent, for one cylinder unit	1 set
10. Cylinder lubricators	Lubricator, complete, of the largest size, with its chain drive or gear wheels, or equivalent spare part kit	1
11. 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.), or equivalent high pressure fuel pump	1
12. Fuel injection piping	High pressure double wall fuel pipe of each size and shape fitted, complete with couplings	1
13. Scavenge blower (including turbochargers)	Rotors, rotor shafts, bearings, nozzle rings and gear wheels or equivalent working parts if other types	1 set[2]
14. Scavenging system	Suction and delivery valves for one pump of each type fitted	1 set

Item	Spare parts	Number recommended
15. Reduction and/or reverse gear	Complete bearing bush, of each size fitted in the gear case assembly	1 set
16. Control, alarm and safety system	Roller or ball race, of each size fitted in the gear case assembly	1 set

Footnotes:

1. (a) Engines with one or two fuel valves per cylinder: one set of fuel valves, complete.
   (b) Engines with three or more fuel valves per cylinder: two fuel valves complete per cylinder, and a sufficient number of valve parts, excluding the body, to form, with those fitted in the complete valves, a full engine set.
2. The spare parts may be omitted where it has been demonstrated, at the Builder's test bench for one engine of the type concerned, that the engine can be manoeuvred satisfactorily with one blower out of action.
   The requisite blanking and blocking arrangements for running with one blower out of action are to be available on board.

Notes:

1. The availability of other spare parts, such as gears and chains for camshaft drive, should be specially considered and decided upon by the ship operator.
2. It is assumed that the new crew has on board the necessary tools and equipment.
3. When the recommended spares are utilized, it is recommended that new spares are supplied as soon as possible.
4. In case of multi-engine installations, the minimum recommended spares are only necessary for one engine.

9.3 LIST OF MINIMUM RECOMMENDED SPARE PARTS FOR EACH TYPE OF AUXILIARY INTERNAL COMBUSTION ENGINE DRIVING ELECTRIC GENERATORS FOR ESSENTIAL SERVICES

9.3.1 Introduction

Recognising the complexity and diversity of machinery, equipment and systems providing essential services, a recommended list of spare parts may not always be relevant. In such circumstances, a risk-based approach should be taken in order to determine the spare parts to be carried onboard.

Such a risk-based approach is described in Head 9.2 for internal combustion engines, however the approach described is equally relevant to other machinery, equipment and systems.

9.3.2 Traditional approach to determining spare parts provision

In cases where a risk assessment approach is not followed, Table 9.3.2 provides a generic example of the typical minimum recommended spare parts. Table 9.3.2 is not intended to replace any guidance provided by manufacturers or suppliers regarding recommended spare parts.

Table 9.3.2
A generic example of the typical minimum recommended spare parts for auxiliary internal combustion engine driving electric generators for essential services on board ships for unrestricted service

Item	Spare parts	Number recommended
1. Main bearings	Main bearings or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1
2. 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
	Cylinder overpressure sentinel valve, complete	1
	Fuel valves of each size and type fitted, complete with all fittings, for one engine	1/2 set

Item	Spare parts	Number recommended
3. 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
	Trunk piston type: gudgeon pin with bush for one cylinder	1 set
4. Piston rings	Piston rings, for one cylinder	1 set
9. Piston cooling	Telescopic cooling pipes and fittings or their equivalent, for one cylinder	1 set
10. 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.), or equivalent high pressure fuel pump	1
11. Fuel injection piping	High pressure double wall fuel pipe of each size and shape fitted, complete with couplings	1
12. Gaskets and Packings	Special gaskets and packings of each size and type fitted, for cylinder covers and cylinder liners for one cylinder	1 set
13. Control, alarm	Parts essential for safe engine operation	1 set

Notes:
1. The availability of other spare parts should be specially considered and decided upon by the ship operator.
2. It is assumed that the crew has on board the necessary tools and equipment.
3. When the recommended spares are utilized, it is recommended that new spares are supplied as soon as possible.
4. Where the number of generators of adequate capacity fitted for essential services exceeds the required number, spare parts may be omitted.

9.4 LIST OF MINIMUM RECOMMENDED SPARE PARTS FOR AUXILIARY STEAM TURBINES DRIVING ELECTRIC GENERATORS FOR ESSENTIAL SERVICES

9.4.1 Introduction

Recognising the complexity and diversity of machinery, equipment and systems providing essential services, a recommended list of spare parts may not always be relevant. In such circumstances, a risk-based approach should be taken in order to determine the spare parts to be carried onboard.

Such a risk-based approach is described in Head 9.2 for internal combustion engines, however the approach described is equally relevant to other machinery, equipment and systems.

9.4.2 Traditional approach to determining spare parts provision

In cases where a risk assessment approach is not followed, Table 9.4.2 provides a generic example of the typical minimum recommended spare parts. Table 9.4.2 is not intended to replace any guidance provided by manufacturers or suppliers regarding recommended spare parts.

Table 9.4.2
A generic example of the typical minimum recommended spare parts for auxiliary steam turbines driving electric generators for essential services of ships for unrestricted service

Item	Spare parts	Number recommended
1. Turbine shaft	Carbon sealing rings, where fitted, with springs, for each size and sealing rings type of gland, for one turbine	1 set
2. Oil filters	Strainer baskets or inserts, for filters of special design, of each type and size	1 set

Item	Spare parts	Number recommended
3. Control, alarm and safety system	Parts essential for safe turbine operation	1 set
Notes: 1. The availability of other spare parts should be specially considered and decided upon by the ship operator. 2. It is assumed that the crew has on board the necessary tools and equipment. 3. When the recommended spares are utilized, it is recommended that new spares are supplied as soon as possible. 4. Where the number of generators of adequate capacity fitted for essential services exceeds the required number, spare parts may be omitted.		

9.5 LIST OF MINIMUM RECOMMENDED SPARE PARTS FOR MAIN STEAM TURBINES

9.5.1 Introduction

Recognising the complexity and diversity of machinery, equipment and systems providing essential services, a recommended list of spare parts may not always be relevant. In such circumstances, a risk-based approach should be taken in order to determine the spare parts to be carried onboard.

Such a risk-based approach is described in Head 9.2 for internal combustion engines, however the approach described is equally relevant to other machinery, equipment and systems.

9.5.2 Traditional approach to determining spare parts provision

In cases where a risk assessment approach is not followed, Table 9.5.2 provides a generic example of the typical minimum recommended spare parts. Table 9.5.2 is not intended to replace any guidance provided by manufacturers or suppliers regarding recommended spare parts.

Table 9.5.2
A generic example of the typical minimum recommended spare parts for auxiliary steam turbines driving electric generators for essential services of ships for unrestricted service

Item	Spare parts	Number recommended
1. Turbine shaft	Carbon sealing rings, where fitted, with springs, for each size and sealing rings type of gland, for one turbine	1 set
2. Oil filters	Strainer baskets or inserts, for filters of special design, of each type and size	1 set
3. Control, alarm and safety system	Parts essential for safe turbine operation	1 set
Notes: 1. The availability of other spare parts should be specially considered and decided upon by the ship operator. 2. It is assumed that the crew has on board the necessary tools and equipment. 3. When the recommended spares are utilized, it is recommended that new spares are supplied as soon as possible. 4. In the case of multi-turbine installations, the minimum recommended spare parts are only necessary for one turbine.		

9.6 LIST OF MINIMUM RECOMMENDED SPARE PARTS FOR ESSENTIAL AUXILIARY MACHINERY

9.6.1 Introduction

Recognising the complexity and diversity of machinery, equipment and systems providing essential services, a recommended list of spare parts may not always be relevant. In such circumstances, a risk-based approach should be taken in order to determine the spare parts to be carried onboard.

Such a risk-based approach is described in Head 9.2 for internal combustion engines, however the approach described is equally relevant to other machinery, equipment and systems.

9.6.2 Traditional approach to determining spare parts provision

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3. Control, alarm and safety system	Parts essential for safe turbine operation	1 set

Notes:
1. The availability of other spare parts should be specially considered and decided upon by the ship operator.
2. It is assumed that the crew has on board the necessary tools and equipment.
3. When the recommended spares are utilized, it is recommended that new spares are supplied as soon as possible.
4. In the case of multi-turbine installations, the minimum recommended spare parts are only necessary for one turbine.

10 VOID

Section related to qualitative failure analysis for propulsion and steering on passenger ships has been deleted due to cancellation of IACS UR M69.

ANNEX A - SPECIAL APPROVAL OF ALLOY STEEL USED FOR INTERMEDIATE SHAFT MATERIAL

1 APPLICATION

This Annex is applied to the approval of alloy steel which has a minimum specified tensile strength greater than 800 N/mm^2 , but less than 950 N/mm^2 intended for use as intermediate shaft material.

2 TORSIONAL FATIGUE TEST

A torsional fatigue test is to be performed to verify that the material exhibits similar fatigue life as conventional steels. The torsional fatigue strength of said material is to be equal to or greater than the permissible torsional vibration stress τ_{dop} given by the formulae in 4.2.2.

The test is to be carried out with notched and unnotched specimens respectively. For calculation of the stress concentration factor of the notched specimen, fatigue strength reduction factor β should be evaluated in consideration of the severest torsional stress concentration in the design criteria.

2.1 Test conditions

Test conditions are to be in accordance with Table 2.1. Mean surface roughness is to be <0,2 µm Ra with the absence of localised machining marks verified by visual examination at low magnification (x20) as required by Section 8.4 of ISO 1352:2011. Test procedures are to be in accordance with Section 10 of ISO 1352:2011.

Table 2.1
Test condition

Loading type	Torsion
Stress ratio	R= -1
Load waveform	Constant-amplitude sinusoidal
Evaluation	S-N curve
Number of cycles for test termination	1 x 10^7 cycles

2.2 Acceptance criteria

Measured high-cycle torsional fatigue strength τ_{C1} and low-cycle torsional fatigue strength τ_{C2} are to be equal to or greater than the values given by the following formulae:

$$\tau_{C1} \geq \tau_{\mathrm{dop2}} = \frac{\mathrm{R_m} + 160}{6} \cdot \mathrm{C_K} \cdot C_D$$

$$\tau_{C2} \geq 1.7 \cdot \frac{1}{\sqrt{C_K}} \cdot \tau_{C1}$$

C_K = factor for the particular shaft design features, see 4.2.2

α_t = stress concentration factor, see 4.2.2.4 (For unnotched specimen, 1.0.)

C_D = size factor, see 4.2.2.1

R_m = specified minimum tensile strength in N/mm2 of the shaft material

3 CLEANLINESS REQUIREMENTS

The steels are to have a degree of cleanliness as shown in Table 3 when tested according to ISO 4967:2013 method A. Representative samples are to be obtained from each heat of forged or rolled products.

The steels are generally to comply with the minimum requirements of IACS UR W7 Table 2, with particular attention given to minimising the concentrations of sulphur, phosphorus and oxygen in order to achieve the cleanliness requirements. The specific steel composition is required to be approved by the *Register*.

Table 3
Cleanliness requirements

Inclusion group	Series	Limiting chart diagram index *i*
Type A	Fine	1
	Thick	1
Type B	Fine	1,5
	Thick	1
Type C	Fine	1
	Thick	1
Type D	Fine	1
	Thick	1
Type DS	-	1

4 INSPECTION

The ultrasonic testing required by IACS UR W7 is to be carried out prior to acceptance. The acceptance criteria are to be in accordance with IACS Recommendation No. 68 or a recognized national or international standard.

ANNEX B - TYPE APPROVAL TESTING OF SYNTHETIC MATERIALS FOR AFTMOST PROPELLER SHAFT BEARINGS

1 SCOPE

This Annex gives the requirements for the Type Approval testing of synthetic materials for aftmost propeller shaft bearings.

The procedures and requirements of this UR are applicable to Type Approval obtained for the synthetic material required in 2.6.

The qualification for design and application of aftmost propeller shaft bearings shall be provided and guaranteed by the manufacturer.

Testing and inspection shall be carried out in accordance with the specific requirements given in this document.

2 DOCUMENTATION

The manufacturer shall submit request of approval, test programme (see 3.1) and information including the following contents to the *Register*:

1) product name
2) name and address of the manufacturer, including details for all relevant production places.
3) reference of applicable rules and standards which the product shall comply with.
4) product description:
   - material type
   - lubrication type
   - isotropic or anisotropic behavior
   - elastomeric or non-elastomeric type
5) limitations of the product
6) product specification, technical data sheet, and installation manual including:
   (a) maximum nominal surface pressure
   (b) product dimensions:
      - minimum and maximum dimensions
      - other, if relevant
   (c) commonly acceptable mating material (type of shaft material, roughness, hardness, etc.)
   (d) running clearance
   (e) maximum operating temperature
7) safety data sheet.
8) description of production processes.
9) description of quality assurance system or copy of ISO 9001 certificate.
10) in-service experience, if available.
11) list of tests and measuring equipment including calibration certificate.

3 TYPE APPROVAL TESTING

3.1 Test program

Test program shall include following items:

1) description of products to be approved
2) description of the selected test samples
3) content of tests (test items, test standard, test conditions, acceptance criteria, etc.)
4) description of the wear testing stands and the test conditions

The extent of the test program is to test the material properties of 3.3. In particular a reduction or complete suppression of the approval tests may be accepted by the *Register* taking into account:

1) documentation of approval tests performed
2) a proven track record.

3.2 Wear testing procedure

Unless otherwise specified in this Annex, the requirements for the wear test should refer to ASTM G77-17 or other national or international equivalent standards, with the following data:

- material of the shaft used in the test and its properties are to be specified and shall be equivalent to typical mating material e.g. alloyed steel or stainless steel or copper alloy.
- diameter of shaft: the shaft diameter depends on the bearing size. The running clearance should be considered in the wear test.
- motion of shaft: continuous rotation.
- circumferential velocity should be 6 m/s for oil or water lubrication and should be 3 m/s for grease lubrication.
- lubrication: sea water or substitute ocean water (23°C ± 2°C), or mineral oil (80°C ± 2°C), or grease (80°C ± 2°C) according to the applicable lubrication type.
- surface roughness of test shaft: Ra shall not exceed 0.5μm for stainless steel and Ra shall not exceed 0.8μm for copper alloy.
- interface pressure: maximum nominal surface pressure ± 10%
- duration of test: until the coefficient of friction and wear rate remains constant at least 192h. Wear of bushings shall be measured continuously or regularly. If regularly, wear to be measured by disassembling every 48 hours until a constant wear rate has been achieved (minimum of four points of measurements).

Parameters to be recorded:

- dimensions of test specimen
- wear vs. time
- coefficient of friction vs. time
- temperature of test specimen during test cycle
- deviation of load from the maximum nominal surface pressure

3.3 Material properties

The properties of non-elastomeric materials for aftmost propeller shaft bearings are to comply with the requirements of Table 1. The properties of elastomeric materials for aftmost propeller shaft bearings are to comply with the requirements of Table 2.

Table 1
Type testing for non-elastomeric materials for aftmost propeller shaft bearings.

Test items	**Test standard** [1)]	**Number of specimens for each sample, at least** [2)]	**Test conditions**	**Acceptance criteria**
Compressive strength[N/mm^2]	ISO 604: 2002; ASTM D695- 2015	5 [3)]		Min.85 N/mm^2 in the case of isotropic materials. Min.85 N/mm^2 for specimens parallel to sheet plane in the case of anisotropic materials. Min.100 N/mm^2 for specimens normal to sheet plane in the case of anisotropic materials.
Compressive modulus [N/mm^2]	ISO 604: 2002; ASTM D695- 2015	5 [3)]		Min.850 N/mm^2 in the case of isotropic materials. Min.850 N/mm^2 for specimens parallel to sheet plane in the case of anisotropic materials. Min.1000 N/mm^2 for specimens normal to sheet plane in the case of anisotropic materials.
Water swelling [volume, %], only required for water lubrication	ISO 175: 2010	3	Four weeks in substitute ocean water (ASTM D1141-98(2021)) at 20°C ± 2°C and maximum temperature (60°C ± 2°C or advised maximum working temperature by manufacturer, whichever is higher). At least three specimens with dimension:50x50xt mm, t is min. 4 mm or the min. thickness of the bushing product. Testing immediately after extraction (wet condition).	Volumetric Swelling ≤ 3%
Oil swelling (for oil lubricated system) [volume, %], only required for oil lubrication	ISO 175: 2010	3	Four weeks in oil No.3 (ISO 1817:2022) at 20°C ± 2°C. At least three specimens with dimension:50x50xt mm, t is min. 4 mm or the min. thickness of the bushing product. Testing immediately after extraction (wet condition).	Volumetric Swelling ≤ 3%
Compressive strength and modulus change when immersed in water, only required for water lubrication	ISO 604: 2002; ASTM D695- 2015	5 [3)]	Four weeks in substitute ocean water (ASTM D1141) at 20°C±2°C.	Min. 80% retention of minimum specified compressive strength and modulus before water immersion
Temperature resistance	ISO 604: 2002; ASTM D695- 2015	5 [3)]	Compressive strength and compressive modulus at maximum temperature (60°C±2°C or advised maximum working temperature by manufacturer, whichever is higher).	Min. 80% retention of minimum specified compressive strength and modulus at 20°C ± 2°C
Wear test	See 3.2	1	-	-

1) Other testing standards may also be accepted, provided that they are suitable for testing of the synthetic material selected for application in aftmost propeller shaft bearings.
2) The number of specimens is to be prepared for each sample.
3) Test at least five specimens for each sample in the case of isotropic materials. Test at least ten specimens, five normal to and five parallel to sheet plane, for each sample in the case of anisotropic materials.

Table 2
Type testing for elastomeric materials for aftmost propeller shaft bearings.

Test items	**Test standard [1)]**	**Number of specimens, at least [2)]**	**Test conditions**	**Acceptance criteria**
Tensile strength [N/mm^2]	ISO 37:2017; Method A of ASTM D412-16(2021); ASTM D638-22	3		Min.10 N/mm^2 for rubber bearing, and min.30 N/mm^2 for other elastomeric bearing
Elongation (%)	ISO 37:2017; Method A of ASTM D412-16(2021); ASTM D638-22	3		Min.150% for rubber bearing, and min.60% for other elastomeric bearing
Hardness	ISO 48-4:2018; ASTM D2240-15(2021)	3		
Water swelling [volume, %], only required for water lubrication	ISO1817:2022	3	Four weeks in substitute ocean water (ASTM D1141) at 20°C± 2°C and maximum temperature (60°C±2°C or advised maximum working temperature by manufacturer, whichever is higher). At least three specimens with dimension:50x50xt mm, t is min. 4 mm or the min. thickness of the bushing product. Testing immediately after extraction (wet condition).	Volumetric swelling ≤ 3%
Oil swelling (for oil lubricated system) [volume, %], only required for oil lubrication	ISO1817:2022	3	Four weeks in oil No.3(ISO 1817) at 20°C ±2°C. At least three specimens with dimension:50 x 50 x t mm, t is min. 4 mm or the min. thickness of the bushing product. Testing immediately after extraction (wet condition).	Volumetric swelling ≤ 3%
Tensile strength and elongation change when immersed in water, only required for water lubrication	ISO 37:2017; Method A of ASTM D412-16(2021); ASTM D638-22	3	Four weeks in substitute ocean water (ASTM D1141) at 20°C±2°C.	Min. 80% retention of minimum specified tensile strength and elongation before water immersion
Temperature resistance	ISO 37:2017; ISO 7743:2017; Method A of ASTM D412-16(2021); ASTM D638-22	3	Tensile strength and elongation at maximum temperature (60°C±2°C or advised maximum working temperature by manufacturer, whichever is higher).	Min. 80% retention of minimum specified tensile strength and elongation at 20°C±2°C
Adhesion to metals (except those not to be adhered to metals) [N/mm^2]	ISO 813:2019; ISO 1827:2022	3	-	-
Change of properties due to aging [%]	ISO 37:2017; ISO 7743:2017; Method A of ASTM D412-16(2021); ASTM D638-22	3	After oven aging for tension and elongation tests. Test specimens shall be subjected to circulating air at maximum temperature (60°C±2°C or advised maximum working temperature by manufacturer, whichever is higher) for 96 hours. Tension and elongation tests shall be performed not less than 20 hours and not more than 48 hours after removal from the aging environment.	Min. 75% retention of Tensile strength and elongation before aging

Test items	Test standard [1]	Number of specimens, at least [2]	Test conditions	Acceptance criteria
Wear test	See 3.2	1		

1) Other testing standards may also be accepted, provided that they are suitable for testing of the synthetic material selected for application in aftmost propeller shaft bearings.

2) The number of specimens is to be prepared for each sample.

3.4 Test products

At least three representative diameter products of each kind of product shall be selected for type approval testing, except for the wear test where one representative product may be selected.
Each kind of product means:

- same chemical composition range
- same reinforcement, only applicable to composite materials
- same production process

The test products used for type approval testing are to be selected from the manufacturer's production line or stock by a Surveyor of the Society as a:

- finished certified component itself; or
- on samples taken from earlier stages in the production of the component, when applicable.

4 TYPE APPROVAL CERTIFICATE

The *Register* issues a Type Approval Certificate based on the test reports and manufacturer's technical documentation e.g., installation/engineering manuals.

The Type Approval Certificate shall contain the general information as defined by the Rules. As minimum, the following information is specifically applicable to products relevant to this document and shall be included on the relevant Type Approval Certificate:

1) Product description and properties in accordance with paragraph 3.3 above.
2) Maximum nominal surface pressure.
3) Maximum operating temperature.