VERITAS REGISTER OF SHIPPING

RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF SEAGOING SHIPS

Part VII

Machinery Installations

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Veritas Register of Shipping Ltd
Rules for classification and construction of seagoing ships
Part VII Machinery Installations

These Rules developed on the basis of the Rules for classifications and constructions of seagoing ships on Ukrainian Register of Shipping with taking into account the experience of their application, changes in the applicable International conventions, Codes and Resolutions adopted by the International Maritime organization (IMO) with applicable amendments and changes in the applied resolutions of the United Nations Economic Commission for Europe and directives of the European Parliament and Council.

Rules for classification and construction of sea-going ships consist of following parts:
Part I Classification
Part II Hull;
Part III Equipment, Arrangements and Outfit;
Part IV Stability;
Part V Subdivision;
Part VI Fire Protection;
Part VII Machinery Installations;
Part VIII Systems and Piping;
Part IX Machinery;
Part X Boilers, Heat Exchangers and Pressure Vessels;
Part XI Electrical Equipment;
Part XII Refrigerating Plants;
Part XIII Materials;
Part XIV Welding;
Part XV Automation;
Part XVI Structure and Strength of Fiber-Reinforced Plastic Ships;

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PART VII MACHINERY INSTALLATIONS

1. 1 GENERAL

1.1 APPLICATION

1.1.1 The requirements of the present Part of the Rules apply to ship machinery installations, equipment of machinery spaces, shafting lines, propellers, machinery condition monitoring systems, spare parts and active means of the ship's steering, as is specified in **1.2.8**, Part III «Equipment, arrangements and outfit».

In this case, requirements of Sections **1** to **4** and **9**, **10** and recommendations of Appendix 1 of the machinery installations and machinery space equipment on ships of gross tonnage less than 500, as well as the requirements of Part IX "Machinery" may be applied in so much as applicable and sufficient. It also refers to berth-connected ships.

Requirements for the reservation of propulsion installation and steering gear of passenger ships of 120 m or over in length (determination of length in accordance with the International Convention on Load Lines, 1966 (LL 66), as modified by the Protocol of 1988 relating thereto witn futher amendments (LL 66/88) or having three or more main fire vertical zones (refer to **2.2.6.1**, Part VI "Fire protection"), in accordance with the requirements of SOLAS Regulation II-2/21 as amended, as amended by IMO Resolution MSC.216 (82), Annex 3), to the main character of class of which one of the relevant signs is added, which determines the amount of reservation of propulsion installation machinery and systems (refer to **2.2.26**, Part I "Classification" of the Rules for the Classification and Construction of Sea-Going Ships), are set forth in **2.7**.

The requirements for machinery installations of polar class ships (refer to **2.2.3**, Part I "Classification”) are set forth in **2.8**.

The requirements to machinery installations of Baltic ice class ships (refer to **2.2.3**, Part I "Classification”) are set forth in **2.9**.

The requirements for machinery installations of ships equipped to ensure long-term operation at low temperatures (refer to **2.2.30**, Part I "Classification”) are set forth in **2.11**.

1.1.2 The requirements of the present Part are set forth proceeding from the condition that the flash point of fuel oil (refer to 1.2, Part VI "Fire Protection") used in ships of unrestricted service for the engines and boilers is not below 60°C and the flash point of fuel for emergency generator engines, not below 43°C.

In ships certified for restricted service within areas having a climate ensuring that ambient temperature of spaces where such fuel oil is stored will not rise to within 10°C below its flash point may use fuel oil with flash point not less than 43°C. In this case, measures shall be taken to ensure checking and maintenance of the above condition.

- The use of fuel with a flash point not exceeding 60°C, but not below 43°C, is allowed (for example, for emergency fire pumps engines and auxiliary machinery not located in Category A machinery spaces) subject to the following:
- liquid fuel tanks, except in double-bottom compartments, are outside the Category A machinery spaces;
- fuel temperature measurement at the fuel pump inlet has been provided;
- the inlets and outlets of the fuel filter are provided with shut-off valves and / or valves; and
- as far as possible, welded structures or circular cone or sphere type structures are used in piping connections.

Crude oil and slops may be used as boiler fuel in oil tankers. The conditions of such use are stated under **13.17**, Part VIII "Systems and Piping".

1.1.3 Provided that the following requirements have been met, gases or other fuels with low flashpoint may be used as fuel (refer to **2.2.27**, Part I "Classification”).

1.1.3.1 Requirements for the use of gas fuel (take into account, in relation to such fuel, the requirements of the IGF Code) are set forth in **2.10** of this Part; in **7.15.1**, **9.16.2**, **12.14, 13.11** and **13.12,** Part VIII «Systems and Piping»; in **6.8,** Part VI «Fire Protection»; in **8.10** and **9** Part IX «Machinery»; in **3.6**, Part X «Boilers, Heat Exchangers and Pressure Vessels», as well as in **7.23**, Part XI «Electrical Equipment».

If gas other than natural gas or other types of fuel with a low flash point, is used as fuel, in addition to these requirements, the ship shall comply with the requirements of the IGF Code.

1.1.3.2 If the vessel is an LG gas carrier [1] and uses LNG[2] cargo as a fuel it shall comply with the requirements of the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) 1983 with amendments.

If the ship is a gas carrier and when gas other than LNG or other low-flash point fuel is used as fuel, in addition to the requirements of the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels 2015 with amendments (IGF Code) for the use of fuel shall meet the above mentioned requirements for the use of gas fuel and the requirements of IGC Code.

1.1.3.3 In addition to seagoing ships requirements, specified in **1.1.3.1** and **1.1.3.2,** the above conditions of use of gas fuel may be applicable to other offshore facilities under the technical supervision of the Register, mobile offshore drilling units and offshore structures.

In addition to these conditions, such objects shall comply with the relevant national requirements applicable to such objects.

1.2 DEFINITIONS AND EXPLANATIONS

Definitions and explanations relating to general terminology of the Rules are given in General Survey Regulations and Part I "Classification".

The following definitions, as adopted in the present Part, are equally applicable for the purpose of Part VIII "Systems and Piping" and Part IX "Machinery".

Alternative propulsion plant is a combination of machineries, systems and devices that can produce reverse or direct thrust for ship propulsion in emergency situations in case of failure of the main propulsion plant. The following items can be used as alternative propulsion plant: standby emergency engine, electrical motor or shaft generator, which can be used as a propulsion electrical motor.

The total power output of the alternative propulsion plant engines shall be at least 1/8 of the total power output of the main propulsion plant.

Alternative liquid fuel is a liquid fuel that can substitute the appropriate conventional fuels, is produced (mined) from non-conventional sources and kinds of energy materials or is a combination of alternative and conventional fuels and may differ from conventional fuel due to its properties.

Shafting is a structural complex that kinematically connects ship's main machinery or the main gearing (if available) with a propeller including propeller, intermediate and other shafts complete with couplngs and also a sterntube arrangement with bearings, seals, lubrication and cooling systems, other arrangements (e.g. the propeller shaft sag measuring gauges, protective covers, braking arrangement, etc.) and involved in transmitting torque from the engine to propeller.

The upper ice waterline (UIWL) shall be defined by the maximum draughts fore, amidships and aft.

Exit is an opening in bulkhead or deck provided with closing means and intended for the passage of persons.

Means of escape comprise the escape routes leading from the lowest part of the machinery space floor plates to the exit from that space.

Main active means o f the ship's steering is a propulsion and steering unit being part of the propulsion plant.

Main machinery is the machinery being part of the propulsion plant.

Main propulsion plant is a combination of machineries, systems and devices that can produce reverse or direct thrust for ship propulsion and is comprised of propulsion machineries of roughly equal power output, auxiliary machineries and systems supporting their operation, propellers and all necessary monitoring, control and alarm systems.

In case several engines comprise the main propulsion plant, each of the propulsion engines comprising it is be considered as the main engine.

In case each propulsion plant in multi-shaft propulsion plant is completely independent, each such plant is to be considered as the main propulsion plant.

Remote control is the changing of the speed and direction of rotation as well as starting and stopping of the machinery from a remote position.

Technical condition diagnosis is a process of establishing causes for the deviation of diagnostic parameters when performing condition monitoring and/or detecting malfunctions, as a rules, by stripless methods in order to provide maintenance and repair on the actual condition basis.

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[1] *Gas carrier LNG means a* ship intended for the carriage of liquefied gases in bulk, in particular liquefied natural gas, in bulk and other cargoes listed in the table of technical requirements of the IGC Code.

[2] *LNG* means liquefied natural gas.

Auxiliary active means of the ship's steering is a propulsion and steering unit ensuring propulsion and steering of a ship at low speed or steering of a ship at zero speed when the ship is equipped with main means of propulsion and steering, and is used either in combination with the latter or when the main means of propulsion and steering are inoperative.

Auxiliary machinery and systems of propulsion plant are all support systems (including machinery and equipment, fuel, lubrication, cooling, compressed air systems, hydraulics, etc.) that are necessary for operation of propulsion machinery and propeller.

Auxiliary machinery is the machinery necessary for the operation of main engines, supply of the ship with electric power and other kinds of energy, as well as functioning of the systems and arrangements subject to survey by the Register.

Among the essential auxiliary machinery are:

a generating set, which serves as a main source of electrical power;

steam supply source;

condensate pump and arrangements used for maintaining vacuum in condensers;

the mechanical air supply for boilers;

an air compressor and receiver for starting or control purposes;

as well as machinery ensuring operation or functioning of:

boiler feed water systems;

the fuel oil supply systems for boilers or engines;

the sources of water pressure;

the hydraulic, pneumatic or electrical means for control in main propulsion machinery including controllable pitch propellers.

Common control station is a control station intended for simultaneous control of two or several main engines and fitted with indicating instruments, alarm devices and means of communication.

Active means of the ship's steering (AMSS) are special propulsion and steering units and any combinations of them or with the main propulsion devices, capable of producing thrust or traction force both at a fixed angle to the centre plane of the ship and at a variable angle, either under all running conditions (main AMSS) or part thereof including small and zero speed (auxiliary AMSS) (refer to **7.1.1**).

IGF Code is the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels, 2015, adopted by IMO MSC.391(95), as amended, including amended by IMO MSC.458(101).

IGC Code is the The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, 1999, reissued in accordance with IMO MSC.370(93), as amended, adopted by IMO MSC.411(97) and MSC.441(99).

SOLAS-74/78/88[3] – International Convention for the Safety of Life at Sea 1974 and Protocols 1978 and 1988 to it, including the applicable Codes.

Engine room is a machinery space intended for the main engines and, in the case of ships with electric propulsion plants, the main generators.

Machinery spaces are all machinery spaces of category A and all other spaces containing main machinery, shafting, boilers, fuel oil units, steam and internal combustion engines, generators and other major electrical machinery, fuel oil filling stations, ventilation and air-conditioning installations, refrigerating plants, steering engines, stabilizing equipment and similar spaces, and trunks to such spaces.

Machinery spaces of category A are those spaces and trunks to such spaces, which contain:

internal combustion machinery used for main propulsion; or

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.

Local control station is a control station fitted with controls, indicators, means of communication (if necessary), located in proximity to, or directly on, the engine.

Torsional vibration stresses are stresses resulting from the alternating torque, which is superimposed on the mean torque.

Dead ship condition (as well a s black out) is a condition, under which the main propulsion plant, boilers and auxiliaries are not in operation and in restoring the propulsion, no stored energy for starting the propulsion plant, the main source of electrical power and other essential auxiliaries shall be assumed available. It is assumed that means are available to start the emergency generator at all times.

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[3] Hereinafter – SOLAS Convention as amended.

The lower ice waterline (LIWL) shall be defined by the minimum draughts fore, amidships and aft. The lower ice waterline shall be determined with due regard to the ship's ice-going capability in the ballast loading conditions. The propeller shall be fully submerged at the lower ice waterline.

Equipment comprises all types of filters, heat exchangers, tanks and other arrangements ensuring normal operation of a machinery installation.

Single failure of propulsion plant is a failure either of one active element (main engine, generator, their local control system, remote-controlled valve, etc.) or of one passive element (pipeline, power cable, manual-controlled valve, etc.) that does not cause failures of other elements.

Propulsion plant power output is a total power output of all propulsion machinery onboard.

If not otherwise specified, propulsion plant power output does not include power output produced by propulsion machinery but utilized in normal operation conditions for the purposes other than ship propulsion (e. g., shaft generator power output).

RTSM – Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships.

Propulsion plant is the totality of machinery and arrangements intended for generating, converting and transmitting power ensuring propulsion of the ship at all specified rates of speed and comprising propellers, shafting, main gearing and main machinery, including electric propulsion motors.

Cargo control room (CCR) is a room or part thereof where the control, monitoring means and alarm devices, related to performance of cargo handling operations are located; and onboard the tankers, in addition, means for monitoring and alarm of cargo, ballast, atmosphere parameters of cargo and ballast tanks and cargo pump rooms as well as discharge of oil containing and flushing water.

Technical condition prediction is a process of determining causes for the changes in control item for the forthcoming time period, based on the trend of the diagnostic parameter values during the preceding time period.

Propulsion plant is the totality of machinery and arrangements intended for generating, converting and transmitting power ensuring propulsion of the ship at all specified rates of speed and comprising propellers, shafting, main gearing and main machinery, including electric propulsion motors.

Propulsion plant redundancy is a single or multiple duplication of its elements, provided that the propulsion plant is designed so that a single failure of one of its active or passive elements does not cause a loss of ship propulsion and controllability in external conditions specified in the Rules.

Rated power means the maximum continuous (not time-limited) power adopted in calculations under the Rules and stated in documents issued by the Register.

Rated speed means the speed corresponding to the rated power.

Steering system is ship's directional control system, including main steering gear, auxiliary steering gear, steering gear control system and rudder if any (refer to **1.2.9**, Part III "Equipment, Arrangements and Outfit").

Propeller is a mechanism (propeller, steerable propeller, water jet, etc.) that converts the mechanical energy of the propulsion machinery into reverse or direct thrust for ship's propulsion.

Onboard power plant is a combination of machinery, systems and devices that provides a ship with all types of energy and may include the following items: main propulsion plant, alternative propulsion plant, onboard electrical power plant, auxiliary systems and machinery.

Technical condition monitoring system is a complex of inspection facilities and actuators interacting with the control item on demand set forth by the appropriate documentation.

The condition monitoring system provides for the identification of the type of the item technical condition and systematic observation (tracing) of its change on the basis of measurement of the controlled (diagnostic) parameters and comparison of these values with the set standards.

Trend in diagnostic parameter (parameter trend) is a time history of the diagnostic parameter shown graphically or in other form (previous history of the parameter change).

Fuel oil unit is any equipment used for the preparation and delivery of fuel oil (heated or unheated) to boiler, inert gas generator or engine (including gas turbines) and includes any fuel oil pumps, separators, filters and heaters at a pressure of more than 0,18 MPa.

Fuel oil transfer pumps are not considered as fuel oil units.

Main machinery control room is a space containing the remote controls of main and auxiliary machinery, CP-propellers, main and auxiliary AMSS, indicating instruments, alarm devices and means of communication.

1.3 SCOPE OF SURVEYS

1.3.1 General provisions covering the procedure of classification and surveys during construction and in service are stated in the General Survey Regulations and in Part I "Classification".

1.3.2 Survey by the Register, including the approval of technical documentation according to **4.1**, Part I "Classification", shall cover the following parts and components:

.1 shafting as assembled, including propeller shaft with liners and waterproof coatings, shaft bearings, thrust blocks and sterntube bearings, couplings, sterntube seals;

.2 propellers, inclusive vertical-axis propellers and jets, steerable propellers, athwartship thrusters and propulsive systems of active rudders, pitch control units, oil distribution boxes and control systems of propellers;

.3 parts indicated in Table 1.3.2.3, as well as spare parts in **10.2**.

1.3.3 Subject to survey by the Register is the assem-bling of the machinery space equipment and testing of the following components of the machinery installation:

.1 main engines with reduction gears and couplings;

.2 boilers, heat exchangers and pressure vessels;

.3 auxiliary machinery;

.4 control, monitoring and alarm systems of the machinery installation;

.5 shafting and propellers;

.6 active means of the ship's steering.

1.3.4 After assembling of machinery, equipment, systems and piping arrangements on board the ship, the machinery installation shall be tested in operation under load according to the program approved by the Register.

Table 1.3.2.3 **Parts to be surveyed**

Nos.	Item	Material	Chapter of Part XIII "Materials"
1	**2**	**3**	**4**
1	**Shafting**		
1.1	Intermediate, thrust and propeller shafts	Forged steel	3.7
1.2	Propeller shaft liners	Copper alloy Corrosion-resistant steel	4.1 On agreement with the Register
1.3	Half-couplings	Forged steel Cast steel	3.7 3.8
1.4	Coupling bolts	Forged steel	3.7
1.5	Sterntubes	Rolled steel Cast steel Forged steel Cast iron	3.2 3.8 3.7 3.9
1.6	Sterntube and strut bushes	Cast steel Copper alloy Forged steel Cast iron	3.8 4.2 3.7 3.9, 3.10
1.7	Lining of sternbush bearing	Non-metallic materials Metal alloys	On agreement with the Register 3.7
1.8	Thrust block casing	Rolled steel Cast steel Cast iron	3.2 3.8 3.9
2	**Propellers**		
2.1	Solid propellers	Cast steel Copper alloy	3.12 4.2
2.2	Built propellers		
2.2.1	Blades	Cast steel Copper alloy	3.12 4.2
2.2.2	Boss	Cast steel Copper alloy	3.12 4.2
2.2.3	Bolts (studs) for securing of blades, hub cones and seals	Copper alloy Forged steel	4.1 3.7
2.3	Hub cones	Cast steel Copper alloy	3.12 4.1,4.2
2.4	CPP crosshead in **Ice4** - **Ice6** ice class ships and icebreakers	Forged Steel Cast Steel	3.7 3.8

Nos.	Item	Material	Chapter of Part XIII "Materials"
1	2	3	4
2.5	Casings of main AMSS in **Ice4 - Ice6** ice class ships and icebreakers	Forged Steel Cast Steel Rolled Steel	3.7 3.8 3.2

Notes: 1. The materials shall be selected in accordance with **2.4**.
2. All shafts (propeller, thrust, intermediate), propeller blades shall be subjected to non-destructive testing when manufactured. The methods, standards and scope of such tests shall be agreed with the Register.
3. The nomenclature and material of the CPP components: crank pin rings, sliding shoes (other than those given under item **2.4**), push-pull rods; hydraulic cylinders, etc., as well as the AMSS parts (other than those given under item **2.5**) shall be agreed with the Register.

2 GENERAL REQUIREMENTS

.1 POWER OF MAIN MACHINERY

2.1.1 The requirements to power at the propeller shafts P_{min}, in kW, of icebreakers and ice class ships are specified in **2.1.1.1** to **2.1.1.4** depending on their ice class.

2.1.1.1 The power at icebreaker propeller shafts shall be substantiated and correspond to their ice class in compliance with **2.2.3**, Part I "Classification".

2.1.1.2 The minimum required power P_{min}, in kW, delivered to the propeller shaft of ships of ice classes **Ice2** and **Ice3** shall not be less than bigger of the values determined according to **2.1.1.3** and **2.1.1.4**.

The minimum required power P_{min}, in kW, delivered to the propeller shaft of ice ships of arctic category **Ice4** shall not be less than the lesser of values determined according to **2.1.1.3** and **2.1.1.4**.

The minimum required power delivered to the propeller shaft of ships of ice classes **Ice5** ÷ **Ice6** shall be determined according to **2.1.1.3**.

2.1.1.3 Power P_{min}, in kW, shall be determined by the formula

$$P_{min} = f_1 f_2 f_3 (f_4 \Delta + P_0), \qquad (2.1.1.3)$$

where:
f_1 = 1,0 – in kW, shall be determined by the formula;
f_1 = 0,9 – for propulsion plants with controllable pitch propellers or electric drive;
f_2 = φ /200 + 0,675, but not more than 1,1;
φ – slope of stem (refer to **3.10.1.2**, Part II "Hull");
f_2 = 1,1 – for a bulbous stem;
the product $f_1 \cdot f_2$ shall be taken in all cases not less than 0,85;
f_3 =1,2$B/\Delta^{1/3}$, but not less than 1,0;
B – breadth of the ship, m;
Δ – breadth of the ship, m; D = ship's displacement to the summer load waterline (refer to **1.2.1**, Part III "Equipment, Arrangements and Outfit"), t.
When calculating for ships of ice classes **Ice2** and **Ice3** Δ need not be taken more than 80000 t;
f_4 and P_o – from Table 2.1.1.3.

Irrespective of the results obtained in calculating the power as per Formula (2.1.1.3), the minimum power, in kW, shall not be less than:
3500 – for **Ice6** ice class ships**;**
2600 – for **Ice5** ice class ships;
1000 – for **Ice4** ice class ships;
740 – for **Ice3** and **Ice2** ice class ships**.**

Table 2.1.1.3 **Values of f_4 and P_0**

Displacement Δ, t	Value	Ice class ships				
		Ice2	**Ice3**	**Ice4**	**Ice5**	**Ice6**

< 30000	f_4	0,18	0,22	0,26	0,3	0,36
	P_0, in kW	0	370	740	2200	3100
≥ 30000	f_4	0,11	0,13	0,15	0,20	0,22
	P_0, in kW	2100	3070	4040	5200	7300

2.1.1.4 The power P_{min}, in kW, shall be determined as the maximum value calculated for the upper (UIWL) and lower ice waterlines (LIWL)

$$P_{\min} = K_e \frac{\left(R_{CH}/1000\right)^{3/2}}{D_P}, \qquad (2.1.1.4\text{-}1)$$

where:
K_e – coefficient given in Table 2.1.1.4;
R_{CH} – parameter determined as per the formula

$$R_{CH} = 845 \cdot C_\mu \cdot (H_F + H_M)^2 \cdot (B + C_\psi \cdot H_F) + 42 \cdot L_{PAR} \cdot H_F{}^2 + 825 \cdot \left(\frac{L \cdot T}{B^2}\right)^3 \cdot \frac{A_{wf}}{L}, \qquad (2.1.1.4\text{-}2)$$

де:
C_μ = 0,15 cos φ_2 + (sin ψ/sinα), parameter determined as per the formula 0,45;
H_F = 0,26 + ($H_M \cdot B$)0,5;
H_M = 1,0 for **Ice4** ice class ships;
H_M = 0,8 for **Ice3** ice class ships;
H_M = 0,6 for **Ice2** ice class ships;
B – = breadth of the ship, m (refer to Fig. 2.1.1.4);
C_ψ = 0,047 ψ – 2,115;
C_ψ = 0,0 at $\psi < 45^o$;
L_{PAR} – length of the parallel midship body, m;
L – length of the ship between the perpendiculars, m;
T– draught at UIWL or LIWL, m;
A_{wf} – area of the waterline of the bow, m^2;
α – angle of the waterline at B/4, degree;
φ_1 – rake of the stem at the centreline, degree;
$\varphi_1 = 90^o$ – for a ship with a bulbous bow;
φ_2 – rake of the bow at B/4, degree;
χ– buttock area, at B/4;
ψ = arctan (tan φ_2/sinα);
D_p – diameter of the propeller, m;
L_{BOW} – length of the bow, m.
The value $(L \cdot T/B^2)^3$ shall be taken within the range $5 < (L \cdot T/B^2)^3 < 20$.

Formula (2.1.1.4-1) may be used when the conditions given in Table 2.1.1.4-2 are fulfilled.

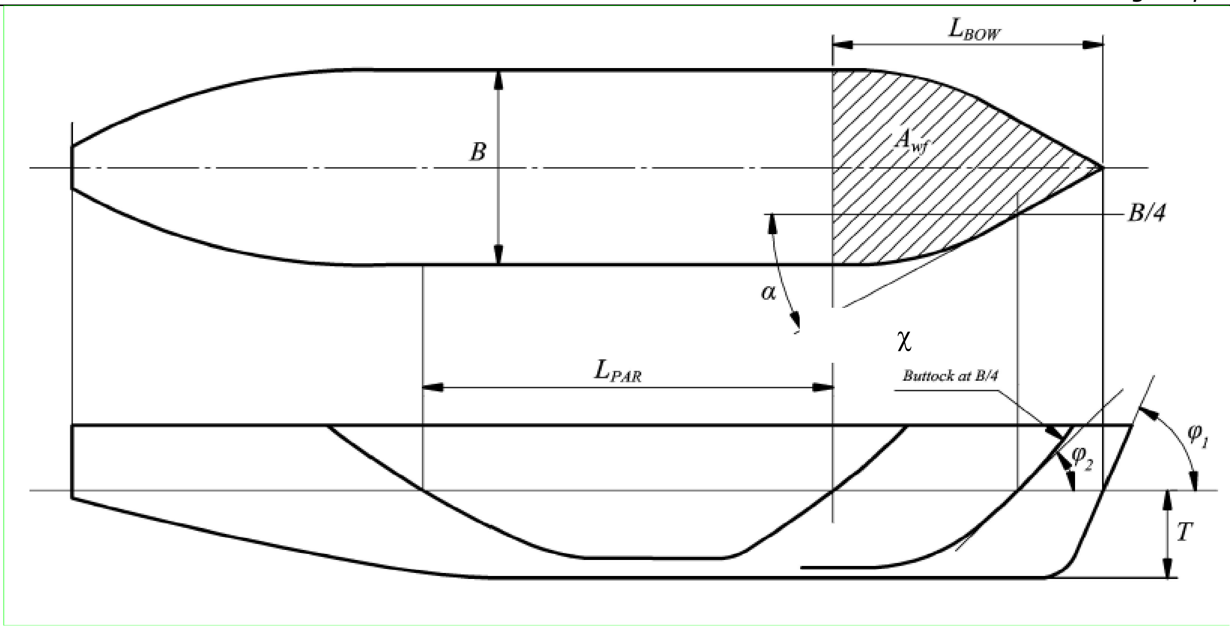

Fig. 2.1.1.4 Geometrical features of the ship for determination of the power delivered to the propeller shaft of ice class ships

Table 2.1.1.4-1 **Values of coefficient K_e**

Number of propellers	Propulsion plant with controllable pitch propeller or electric drive	Propulsion plant with fixed pitch propeller
1	2,03	2,26
2	1,44	1,60
3	1,18	1,31

Table 2.1.1.4-2 **Applicability conditions of Formula 2.1.1.4-1**

Parameter	α, in deg	φ_1, in deg.	φ_2, in deg.	L, in m	B, in m	T, in m	L_{BOW}/L	L_{PAR}/L	D_p/T	$A_{wf}/(L \cdot B)$
Minimum value	15	25	10	65,0	11,0	4,0	0,15	0,25	0,45	0,09
Maximum value	55	90	90	250,0	40,0	15,0	0,40	0,75	0,75	0,27

2.1.1.5 The minimum power values may be reduced subject to the technical substantiation submitted to the Register in each particular case.

2.1.2 In icebreakers and **Ice6** ice class ships, turbines and internal combustion engines with mechanical transmission of power to the propeller may be utilized as main engines, provided use is made of the devices to protect turbines, reduction gears of gas-turbine geared sets and diesel-engine geared sets against the loads exceeding the design torque determined with regard to operation of such ships under ice conditions in compliance with the requirements of **4.2.3.2**, Part IX "Machinery".

2.1.3 Propulsion plant shall provide sufficient astern power to maintain manoeuvring of the ship in all normal service conditions.

2.1.4 Propulsion plant shall be capable of maintaining in free route astern at least 70 per cent of rated ahead speed for a period of at least 30 min. By the rated ahead speed is meant a speed corresponding to the maximum continuous power of the main machinery.

The astern power shall be sufficient to take way off a ship making a full ahead speed on an agreeable length, which must be confirmed during trials.

2.1.5 In propulsion plants with reversing gears or CP-propellers as well as in electric propulsion plants, precautions shall be taken against possible overload of main engines in excess of permissible values.

2.1.6 Means shall be provided to ensure that the machinery may be brought into operation from the dead ship condition without external aid (refer to **16.2.3**, Part VIII "Systems and Piping").

On ships where internal combustion engines are started by compressed air, the set of equipment for starting shall ensure the supply of air in quantity sufficient for the initial start without external aid.

Where the ship is not fitted with an emergency generator, or an emergency generator does not comply with the requirements specified under **2.9.4**, Part IX "Machinery", the means 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, the machinery shall be powered by a hand-starting ICE or a hand-operated compressor.

The emergency generator and other means needed to restore the propulsion shall have a capacity such that the necessary propulsion starting energy is available within 30 min of black out/dead ship condition (refer to **1.2**).

Emergency generator stored starting energy shall not be directly used for starting the propulsion plant, the main source of electrical power and/or other essential auxiliaries (emergency generator excluded).

For steam ships, the 30 min time limit may be interpreted as time from black out/dead ship condition to light-off of the first boiler.

2.1.7 In the event of failure of one or all turbochargers (refer to **2.5.1**, Part IX "Machinery") the machinery installation with one main internal combustion engine shall provide the ship speed at which the steerability of the ship is maintained. The main engine shall provide not less than 10 per cent of the rated power.

2.1.8 The power of main machinery in ships of river-sea navigation shall provide the ahead speed in load condition of at least 10 knots in calm water. Another speed may be set for the ships intended for navigation in geographically restricted areas while providing sufficient speed to maintain the ship's handling capability in load condition.

2.1.9 Supercharged high-speed engines (over 1400 rpm), which increased noise level makes direct local control difficult, may be admitted by the Register for use as main engines in sea-going ships, if provision is made for remote control and monitoring so that constant presence of the attending personnel in the engine room will not be necessary. The control and monitoring facilities shall comply with the requirements of Part XV "Automation".

2.1.10 In the case of ships with twin hulls, the failure of the machinery installation of one hull will not put the machinery installation of the other hull out of action.

2.1.11 Long run of the propulsion plant at all specified rates during its operation under the conditions corresponding to the assigned class shall not lead to the overload. Technically substantiated power supply shall be provided.

2.1.12 Propulsion plants and auxiliary machinery of passenger ships having length, as defined in the International Convention on Load Lines, 1966 (LL 66), as modified by the Protocol of 1988 relating thereto witn futher amendments (LL 66/88), of 120 m or more or having three or more main vertical zones, shall comply with the requirements of **2.2.6.7.1** and **2.2.6.8**, Part VI "Fire Protection".

2.1.13 Passenger ships shall be provided with facilities to maintain or restore normal operation of the main engines in the event of one of the responsible auxiliary machinery failure.

2.1.14 For a ship with a single engine, automatic stopping of this engine shall be excluded, except to prevent override of more than 20% (refer to **3.2.1.7** of this Part and refer to **2.11.2,** Part IX «Machinery» and **2.4.2.1.3, Part** XV «Automation».

2.1.15 Standby ships shall be fitted with at least two propulsion installations.

Propulsion installation shall provide both ahead and astern propulsion**.**

2.1.16 For a ship with gas engines installed in an ESD (emergency shutdown devices)-protected machinery space, the minimum power of the main and auxiliary engines shall be assessed on a case-by-case basis from the operational characteristics of the ship, ensuring that the requirements of para **9.12.2.5**, Part IX "Machinery" are met, taking into account the design and purpose.

2.1.17 For a ship with a single gas engine, the requirements of paras **9.12.2.7 — 9.12.2.8**, Part IX "Machinery" shall be met. The minimum power shall be determined to ensure that this requirement is fulfilled, taking into account the particular design and purpose of the ship.

2.2 NUMBER OF MAIN BOILERS

2.2.1 In general, not less than two main boilers shall be fitted in ships of unrestricted service. Using a steam power plant with one main boiler may be permitted provided the technical substantiation is submitted to the Register.

2.3 ENVIRONMENTAL CONDITIONS

2.3.1 The machinery, equipment and systems installed in the ship shall remain operative under environmental conditions stated in Tables 2.3.1-1 and 2.3.1-2, unless provided otherwise in the other parts of the Rules. Sea water temperature is assumed to be equal to 32°C.

For ships designed for geographically restricted service other temperatures may be adopted if technical substantiation is available.

Table 2.3.1-1 **List, motions and trim[1, 2]**

Machinery and equipment	Steady list either way under static conditions	List either way under dynamic conditions (rolling)	Steady trim by bow or stern	Dynamic inclination by bow or stern (pitching)
Main and auxiliary machinery	15,0	22,5	5,0 [4]	7,5
Emergency machinery and equipment (emergency power installations, emergency fire pumps and their devices)	22,5 [3]	22,5 [3]	10,0	10,0

[1] Steady list and trim shall be taken into account simultaneously. Rolling and pitching are also to be considered simultaneously.

[2] On agreement with the Register, the values of inclinations may be altered depending on the type and dimensions of the ship and its service conditions as well.

[3] In gas carriers and chemical tankers emergency power sources shall remian operative when the ship is listed up to 30 deg.

[4] Where the length of the ship exceeds 100 m, the static trim by bow or stern may be taken as $(500/L)°$ where L is the length of the ship, in m, as defined in **1.1.3**, Part II "Hull".

Table 2.3.1-2 **Air temperature**

Installed location	Temperature range, °C
In enclosed spaces	0 to + 45°C
Machinery or boilers in spaces subject to temperatures exceeding 45°C and below 0°C	According to specific local conditions
On the open deck	– 25 to + 45°C

Note. For ships intended for geographically restricted service other temperatures may be adopted on agreement with the Register.

2.4 MATERIALS AND WELDING

2.4.1 Materials for the manufacture of parts of the shaftings and propellers shall comply with the requirements given in the relevant Chapters of Part XIII "Materials", as indicated in column 4, Table 1.3.2.3.

The materials of shaft components stated in item **1.7** of Table 1.3.2.3 may be chosen in accordance with the relevant standards.

The materials used for the components stated in items **1.2** – **1.6**, **1.8**, **2.2.3** and **2.3** of Table 1.3.2.3 may also be chosen in accordance with the relevant standards. In such a case, the application of materials shall be agreed with the Register when examining the technical documentation.

The materials used for the components (semi-finished products) stated in items **1.1**, **2.1**, **2.2.1** and **2.2.2** of Table 1.3.2.3 subject to supervision by the Register during manufacture; a survey of the materials for the other parts listed in this table may be required at the discretion of the Register.

2.4.2 Intermediate, thrust and propeller shafts shall generally be made of steel with tensile strength R_m between 400 and 800 MPa.

2.4.3 The mechanical properties and chemical composition of materials used for the manufacture of propellers shall be in compliance with **3.12** and **4.2**, Part XIII "Materials". Whereas steel of martensitic grade is permitted for the manufacture of propellers for ships of all types, steel of austenitic grade is permitted for the manufacture of propellers for ships without ice strengtheming.

The possibility to use carbon steel for the manufacture of propellers shall be agreed with the Register considering the requirements of **3.8**, Part XIII "Materials".

Copper alloys of Type CU3 and Type CU4 are admitted for propellers in all ships, except icebreakers; copper alloys of Type CU1 and Type CU2 may be used exclusively for propellers in ships not having ice classes.

2.4.4 Where it is intended to make shafting and propellers of alloy steels, including corrosionresistant and 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.

2.4.5 Intermediate, thrust and propeller shafts as well as coupling bolts (studs) may be made of rolled steel in accordance with **3.7.1**, Part XIII "Materials".

2.4.6 Securing and locking items of propeller blades, hub cones, sterntubes, sternbushes and sealings shall be made of corrosion-resistant materials.

2.4.7 Welding procedure and non-destructive testing of welded joints shall comply with the requirements of Part XIV "Welding".

2.4.8 For all ships, new installation of materials which contain asbestos shall be prohibited in machinery installations, machinery and equipment covered by the requirements of Part VI "Fire Protection", Part VII "Machinery Installations", Part VIII "Systems and Piping", Part IX "Machinery", Part X "Boilers, Heat Exchangers and Pressure Vessels" and Part XII "Refrigerating Plants".

2.5 INDICATING INSTRUMENTS

2.5.1 All the indicating instruments, with the exception of liquid-filled thermometers, shall be checked by competent bodies. Pressure gauges fitted on boilers, heat exchangers, pressure vessels and refrigerating plants shall meet the requirements of **3.3.5** and **6.3.8**, Part X "Boilers, Heat Exchangers and Pressure Vessels" and 7.1, Part XII "Refrigerating Plants", respectively.

2.5.2 The tachometer accuracy shall be within ±2,5 per cent. With restricted speed ranges, the accuracy shall not be below 2 per cent, and the ranges shall be marked with bright colour on the scales of tachometers or in another way.

2.6 APPLICATION OF THE RELIABILITY MEASURES OF THE MACHINERY INSTALLATIONS

2.6.1 The reliability measures are established and specified during design and/or order of the machinery installation components by agreement of the appropriate technical documentation between the customer (shipowner) and the designer or supplier. The specific list of the reliability measures to be determined shall be established for each type of products with regard to the peculiarities of its application, failure effects, maintenance and repair system adopted.

2.7 REQUIREMENTS FOR PROPULSION PLANT REDUNDANCY

2.7.1 General.

2.7.1.1 The requirements of the present Chapter are mandatory for ships with the class notation supplemented with one of the following marks in accordance with the requirements of **2.2.26**, Part I “Classification”:

RP-1, RP-1A, RP-1AS, RP-2 or **RP-2S.**

2.7.2 Marks in ship’s class notation for propulsion plant elements redundancy.

2.7.2.1 If ship’s propulsion plant is provided with redundancy of its elements, the main class notation is supplemented with one of the following marks:

.1 RP - 1 — if ship’s propulsion plant has redundancy for all its elements, except of main engine, reduction gear, shafting and propeller; a single failure of any of the elements of the systems and equipment supporting the abovementioned elements shall not result in loss of speed, electric power supply and steerability;

.2 RP - 1A — if ship’s propulsion plant has redundancy for all its elements, except of reduction gear, shafting and propeller; a single failure of any of the elements of the propulsion plant, its auxiliary machinery and systems or monitoring and control systems shall not result in loss of speed and steerability;

.3 RP - 1AS — if ship’s propulsion plant has redundancy for all its elements as required for **RP-1A** mark, and main engines or alternative propulsion plant engines are located in independent machinery spaces, so that the loss of one of the compartments due to fire or flooding shall not result in loss of speed, electric power supply and steerability;

.4 RP - 2 — if ship’s propulsion plant has redundancy for all its elements and consists of several main propulsion plants; a single failure of any of the elements of the propulsion plant and steering gear shall not result in loss of speed, electric power supply and steerability;

.5 RP - 2S — — if ship’s propulsion plant has redundancy for all its elements as required for **RP-2** mark and is located in independent machinery spaces, so that the loss of one of the compartments due to fire or flooding shall not result in loss of speed, electric power supply and steerability.

2.7.2.2 Additional marks **RP-1**, **RP-1A**, **RP-1AS**, **RP-2** o **RP-2S** can be assigned to the ships under construction or in service.

2.7.3 Technical documentation.

2.7.3.1 For assigning additional marks **RP-1**, **RP-1A**, **RP-1AS**, **RP-2** or **RP-2S** in the ship’s class notation the following technical documentation shall be submitted to the Register for approval in addition to the requirements of **4**, Part I, “Classification” (as applicable):

.1 calculations indicating that in case of a single failure the ship maintains its speed and steerability in accordance with the requirements of **2.7.5.3** (for ships with additional marks **RP-1**, **RP-1A**, **RP-1AS**, **RP-2** or **RP-2S**).

The results of model or full-scale testing are allowed for submission as an alternative;

.2 qualitative failure analysis for propulsion plant and steering gear (in accordance with Section 12) or Failure Mode and Effect Analysis (FMEA) for propulsion plant elements based on a failure tree, or equivalent risk assessment method coordinated with the Register;

.3 calculation of torsional vibrations, in which the possibility of continuous operation of the alternative propulsion system shall be considered separately;

.4 programs for mooring and sea trials.

2.7.4 Requirements for ships with additional mark RP-1 in class notation.

2.7.4.1 All elements of the following auxiliary machinery and systems of the main propulsion plant are to be redundant:

.1 fuel system, including slop tanks, but except of fuel reception, transfer and separation system;

.2 lubrication system of propulsion machinery, reduction gears, shafting bearings, sternbush bearings, etc., except of oil reception, transfer and separation system;

.3 hydraulic systems that support the operation of propulsion plant couplings, controllable pitch propellers, reverse deflectors of water jet propellers, etc.;

.4 fresh water and sea water cooling systems that support the main propulsion plant;

.5 fuel heating systems in service tanks that support the main propulsion plant;

.6 starting systems (pneumatic, electric, hydraulic) that support the main propulsion plant;

.7 electric power sources;

.8 ventilation installations, if required, e. g. for air supply for cooling the primary engines;

.9 monitoring, alarm and control systems.

2.7.4.2 A single failure of auxiliary machinery and elements of the systems specified in **2.7.4.1**, including damages to stationary pipelines, shall not result in halt of the ship or loss of its steerability. In order to fulfil this requirement, necessary by-passes and equipment redundancy (pumps, heaters, etc.) shall be provided in the systems.

A loss of power output of the main engine is allowed as a result of a single failure by at most 50%.

2.7.4.3 The parts of the systems and pipelines where a failure has occurred shall be able to be disconnected from the operable parts.

2.7.4.4 The ship shall be equipped with main and auxiliary steering gears in accordance with **2.9**, Part III, “Equipment, Arrangements and Outfit”.

The main and auxiliary steering gears shall be controlled independently from the navigation bridge and from the steering gear room.

2.7.5 Requirements for ships with additional mark RP-1A in class notation.

2.7.5.1 In addition to the requirements of **2.7.4** the ships with additional mark **RP-1A** shall meet the requirements of **2.7.5**.

2.7.5.2 The main propulsion plant shall consists of at least two propulsion machinery, one reduction gear, one propulsion electric motor, one shafting line and one propeller are sufficient. One of the propulsion machinery may be an alternative propulsion plant. In addition, the independent systems that support the redundant machinery are not subject to the requirements of **2.7.4.2** regarding redundancy of each of the elements of the system.

2.7.5.3 In case of a single failure of the main propulsion plant the operable propulsion machinery or alternative propulsion plant shall ensure the following capabilities in any ship loading condition:

.1 ship propulsion at 6 knots or 50% of specification speed according to **1.1.3**, Part II, “Hull”, the lesser of two, at Beaufort 5;

.2 ship steerability sufficient for taking the safest position in respect to stability and maintaining this position at Beaufort 8;

.3 fulfilment of the requirements of **2.7.5.3.1** and **2.7.5.3.2** for at least 72 hours; for ships with the maximum voyage duration less than 72 hours the time specified above may be limited at the maximum voyage duration.

2.7.5.4 The alternative propulsion plant shall be started at most in 5 min after the main propulsion plant fails.

2.7.5.5 A single failure resulting in the loss of at least one generator may be accepted provided that the FMEA performed shows that after failure the ship has enough electric power output to continue propulsion and maintain steerability according to the requirements of 2.7.5.3 without starting the stand-by generator.

After failure the electric power output shall be sufficient for starting the most high-powered consumer without imbalance of the electric loading. Stand-by electric pumps may not be included in electric loading balance during alternative propulsion plant operation.

2.7.5.6 The main switchboard shall consist of two sections. In case one of the sections fails, the remaining section shall be capable of powering the following consumers:

.1 driving motors of the alternative propulsion plant and steering gears, including attached equipment;

.2 equipment for transmission of propulsion thrust;

.3 propulsion electric motor, if any;

.4 propeller;

.5 auxiliary machinery and systems of the propulsion plant;

.6 monitoring, alarm and control systems.

2.7.5.7 The monitoring, alarm and control systems of the alternative propulsion plant shall be independent from the systems of the main propulsion plant.

2.7.6 Requirements for ships with additional mark RP-1AS in class notation.

2.7.6.1 In addition to the requirements of **2.7.5** the ships with additional mark RP-1AS shall meet the requirements of **2.7.6**.

2.7.6.2 The main propulsion plant shall be equipped with at least two main engines located in at least two independent machinery spaces according to the requirements of **2.7.6.3** and **2.7.6.4**.

Non-redundant elements of the main propulsion plant (reduction gear, propeller, shafting line, propulsion electric motor) that are common for several main engines shall be located in a separate room separated with watertight bulkhead of A-0 fire resistance from machinery spaces with the main engines according to **2.7.1.2.1**, Part II, “Hull”.

2.7.6.3 The bulkhead between the machinery spaces mentioned in **2.7.6.2** shall be watertight according to **2.7.1.2.1**, Part II, “Hull” and have fire resistance of A-60.

If the machinery spaces are separated from each other with cofferdams, tanks or other compartments the bulkheads shall have fire resistance at least A-0 but not less than required for adjacent rooms and compartments in accordance with **2**, Part VI, “Fire Protection”.

2.7.6.4 If closures are provided in the bulkheads specified in **2.7.6.3** and **2.7.6.4** they shall meet the requirements of **7.12**, Part III, “Equipment, Arrangements and Outfit”.

This closures may not be considered as emergency exits from machinery spaces.

2.7.7 Requirements for ships with additional mark RP-2 in class notation.

2.7.7.1 In addition to the requirements of **2.7.4** and applicable requirements of **2.7.5**, the ship shall meet the requirements of **2.7.7**.

2.7.7.2 The ship shall be equipped with at least two independent main propulsion plants. In case of a single failure of one of the propulsion plants the propulsion plant shall maintain at least 50% of its power output, which ensures propulsion and steerability in any loading condition.

2.7.7.3 In case of a single failure of one of the propulsion plants the following requirements shall be fulfilled:

.1 the failure shall not affect the operable propulsion plant if it has been in operation when the failure occurred (in particular, no significant change of driving engine power output and rotational speed shall occur);

.2 the operable propulsion plant that has not been in operation when the failure occurred shall be warm stand-by in order to be ready for starting within 45 s after the failure occurs;

.3 safety measures shall be provided for the failed propulsion plant, in particular, shafting block. **2.7.7.4** The ship shall be equipped with at least two independent steering gears in accordance with **2.9**, Part III, “Equipment, Arrangements and Outfit”. In case of any single failure of one of the steering gears the remaining steering gear shall maintain its operability, including synchronization system failure.

Ship steerability shall be maintained in case of external influences specified in **2.7.5.3**, even in case one of the rudders is blocked at the maximum rudder angle, there shall be a possibility of changing the rudder angle in position parallel to the ship’s centreline and fixing it in this position.

2.7.7.5 If only steerable propellers are provided as the means of propulsion and steering, at least two propulsion plants with independent steering shall be provided.

Ship steerability shall be maintained in case of external influences specified in **2.7.5.3**, even in case one of the steerable propellers is blocked or disconnected, there shall be a possibility of changing the angle of the failed steerable propeller into position parallel to the ship’s centreline and fixing it in this position.

2.7.8 Requirements for ships with additional mark RP-2S in class notation.

2.7.8.1 In addition to the requirements of **2.7.4**, applicable requirements of **2.7.5** and requirements of **2.7.7**, the ship shall meet the requirements of **2.7.8**.

2.7.8.2 The ship shall be equipped with at least two independent propulsion plants (including reduction gear, propeller and shafting line) according to **2.7.7.2** and **2.7.7.3** located in at least two independent machinery spaces.

2.7.8.3 The longitudinal bulkhead between the machinery spaces mentioned in **2.7.8.2** shall be watertight according to **2.7.1.2.1**, Part II, “Hull” and have fire resistance of A-60.

If the machinery spaces are separated from each other with cofferdams, tanks or other compartments the bulkheads shall have fire resistance at least A-0 but not less than required for adjacent rooms and compartments in accordance with **2**, Part VI, “Fire Protection”.

2.7.8.4 If closures are provided in the longitudinal bulkhead specified in **2.7.8.4.2** they shall meet the requirements of **7.12**, Part III, “Equipment, Arrangements and Outfit”. This closures may not be considered as emergency exits from machinery spaces.

2.7.8.5 The ship shall be equipped with at least two independent steering gears in accordance with the requirements of **2.7.7.4** located in at least two independent steering gear rooms.

2.7.8.6 The longitudinal bulkhead between the steering gear rooms shall be watertight according to **2.7.1.2.1**, Part II, “Hull” and have fire resistance of at least A-0.

2.7.8.7 The main electric power sources shall be located in separate compartments in accordance with **2.7.8.3** and **2.7.8.4** so that in case of fire or flooding in one of the compartments electric power supply to the consumers specified in **2.7.5.6** can be maintained.

2.7.8.8 The main switchboard shall consist of two sections in accordance with **2.7.5.6**. Each of the sections shall be located in separate room.

The bulkhead separating the rooms accommodating the main switchboard shall meet the requirements of **2.7.8.3** and **2.7.8.4**.

2.7.8.9 Automation systems, monitoring and control systems of propulsion plants and steering gears shall be located in such a manner that in case of loss of one of the machinery spaces as a result of fire or flooding only one propulsion plant or steering gear is out of service.

Control stations shall be located so that in case of fire or flooding in one of the machinery spaces or steering gear rooms control functions are maintained.

2.8 MACHINERY REQUIREMENTS FOR POLAR CLASS SHIPS

2.8.1 Application.

2.8.1.1 The requirements of this Chapter apply to main propulsion, steering gear, emergency and essential auxiliary systems essential for the survivability of the crew and the safety of the ships, intended for operation (self-navigation) in polar waters (Arctic waters and/or the Antarctic region) covered with ice, taking into account the provisions of the POLAR Code based on polar classes (refer to **2.2.3**, Part I "Classification")[4].

2.8.2 General.

2.8.2.1 Drawings and particulars to be submitted:

. 1 details of the environmental conditions and the required ice class for the machinery, if different from ship's ice class;

.2 detailed drawings of the main propulsion machinery.

Description of the main propulsion, steering, emergency and essential auxiliaries shall include operational limitations.

Information on essential main propulsion load control functions;

.3 description detailing how main, emergency and auxiliary systems are located and protected to prevent problems from freezing, ice and snow and evidence of their capability to operate in intended environmental conditions;

.4 calculations and documentation indicating compliance with the requirements of this Chapter.

2.8.2.2 System design.

.1 Machinery and supporting auxiliary systems shall be designed, constructed and maintained to comply with the requirements of periodically unmanned machinery spaces with respect to fire safety.

Any automation plant (i.e. control, alarm, safety and indication systems) for essential systems installed shall be maintained to the same standard.

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[4] POLAR Code: International Code for Ships Navigating in Polar Waters, 2014, adopted by IMO Resolutions MSC.385 (94) and MERC.264 (68), subject to the provisions of the amendments to the International Convention SOLAS-74, as amended by Resolution MSC.386 (94).

.2 Systems, subject to damage by freezing, shall be drainable.

.3 Single screw vessels classed PC1 to PC5 inclusive shall have means provided to ensure sufficient ship operation in the case of propeller damage including CP-mechanism.

2.8.3 Materials.

2.8.3.1 Materials exposed to sea water.

Materials exposed to sea water, such as propeller blades, propeller hub and blade bolts shall have an elongation not less than 15 % on a test piece the length of which is five times the diameter.

Charpy V-notch impact test (determination of impact energy ***KV*** for sharply-notched specimen) shall be carried out for other than bronze and austenitic steel materials. Test pieces taken from the propeller castings shall be representative of the thickest section of the blade.

An average impact energy ***KV*** value of 20 J taken from three Charpy V-notch tests shall be obtained at -10 ºC.

2.8.3.2 Materials exposed to sea water temperature.

Materials exposed to sea water temperature shall be of steel or other approved ductile material.

An average impact energy ***KV*** value of 20 J taken from three tests shall be obtained at -10ºC.

2.8.3.3 Material exposed to low air temperature.

Materials of essential components exposed to low air temperature shall be of steel or other approved ductile material.

An average impact energy KV value of 20 J taken from three Charpy V-notch tests shall be obtained at 10ºC below the lowest design temperature.

2.8.4 Ice interaction load.

2.8.4.1. Propeller ice interaction.

The present requirements cover open and ducted type propellers situated at the stern of a ship having controllable pitch or fixed pitch blades.

Ice loads on bow propellers and pulling type propellers shall be agreed with the Register.

The given loads are expected, single occurrence, maximum values for the whole ships service life for normal operational conditions.

These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice.

These requirements considering loads due to propeller ice interaction apply also for azimuthing (geared and podded) thrusters.

However, ice loads due to ice impacts on the body of azimuthing thrusters are not covered by this Section.

The loads given in **2.8.4** are total loads (unless otherwise stated) during ice interaction and shall be applied separately (unless otherwise stated) and are intended for component strength calculations only. The different loads given here shall be applied separately.

F_b is a force bending a propeller blade backwards when the propeller mills an ice block while rotating ahead;

F_f is a force bending a propeller blade forwards when a propeller interacts with an ice block while rotating ahead.

2.8.4.2 Ice class factors.

Table 2.8.4.2 below lists the design ice thickness and ice strength index to be used for estimation of the propeller ice loads.

Table 2.8.4.2

Polar class	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
H_{ice}, in m	4,0	3,5	3,0	2,5	2,0	1,75	1,5
S_{ice}	1,2	1,1	1,1	1,1	1,1	1,0	1,0
S_{qice}	1,15	1,15	1,15	1,15	1,15	1,0	1,0
H_{ice} — ice thickness for machinery strength design; S_{ice}— ice strength index for blade ice force; S_{qice}— = ice strength index for blade ice torque.							

2.8.4.3 Design ice loads for open propeller.

2.8.4.3.1 Maximum backward blade force F_b, in kN:

when $D < D_{limit}$:

$$F_b = -27 S_{ice} [nD]^{0,7} [EAR/Z]^{0,3} \ [D]^2; \qquad (2.8.4.3.1\text{-}1)$$

when $D \leq D_{limit}$:

$$F_b = -23S_{ice}[nD]^{0,7}[EAR/Z]^{0,3}(H_{ice})^{1,4}[D], \qquad (2.8.4.3.1\text{-}2)$$

where:
D_{limit} - $0,85(H_{ice})^{1,4}$

n- nominal rotational speed (at MCR free running condition) for CP-propeller and 85 % of the nominal rotational speed (at MCR free running condition) for a FP-propeller (regardless driving engine type).

F_b shall be applied as a uniform pressure distribution to an area on the back (suction) side of the blade for the following load cases:

.1 load case **1**: from 0,6R to the tip and from the blade leading edge to a value of 0,2 chord length;

.2 load case **2**: a load equal to 50 % of the F_b shall be applied on the propeller tip area outside of 0,9R;

.3 load case **5**: for reversible propellers a load equal to 60 % of the F_b shall be applied from 0,6R to the tip and from the blade trailing edge to a value of 0,2 chord length.

Refer to load cases 1, 2 and 5 in Table 1 of the Appendix.

2.8.4.3.2 Maximum forward blade force F_f, in kN:

when $D < D_{limit}$:

$$F_f = 250[EAR/Z][D]^2; \qquad (2.8.4.3.2\text{-}1)$$

when $D \geq D_{limit}$:

$$F_f = 500\frac{1}{(1-\frac{d}{D})}H_{ice}[EAR/Z][D], \qquad (2.8.4.3.2\text{-}2)$$

where:
d - propeller hub diameter, in m;
D - propeller diameter, in m;
EAR- expanded blade area ratio;
Z - number of propeller blades.

F_f shall be applied as a uniform pressure distribution to an area on the face (pressure) side of the blade for the following loads cases:

.1 load case **3**: from 0,6R to the tip and from the blade leading edge to a value of 0,2 chord length;

.2 load case **4**: a load equal to 50 % of the F_f shall be applied on the propeller tip area outside of 0,9R;

.3 load case **5**: for reversible propellers a load equal to 60 % F_f shall be applied from 0,6R to the tip and from the blade trailing edge to a value of 0,2 chord length.

Load cases 3, 4 and 5 - refer to Table 1 of the Appendix.

2.8.4.3.3 Maximum blade spindle torque.

Spindle torque Q_{smax}, in kNm, around the spindle axis of the blade fitting shall be calculated both for the load cases described in **2.8.4.3.1** and **2.8.4.3.2** for F_b and F_f.

If these spindle torque values are less than the default value given below, the default minimum value shall be used. Default value:

$$Q_{smax} = Fc_{0,7}, \qquad (2.8.4.3.3)$$

where:
$c_{0,7}$ - length of the blade chord at 0,7R radius, in m;
F = either F_b or F_f, which ever has the greater absolute value.

2.8.4.3.4 Maximum propeller ice torque applied to the propeller Q_{smax}, in kNm:

when $D < D_{limit}$:

$$Q_{max} = 105(1-d/D)S_{qice}(P_{0,7}/D)^{0,16}(t_{0,7}/D)^{0,6}(nD)^{0,17}D^3; \qquad (2.8.4.3.4\text{-}1)$$

when $D \geq D_{limit}$:

$$Q_{max} = 202(1-d/D)S_{qice}H_{ice}^{1,1}(P_{0,7}/D)^{0,16}(t_{0,7}/D)^{0,6}(nD)^{0,17}D^{1,9}, \qquad (2.8.4.3.4\text{-}2)$$

where:

D_{limit}= 1,81H_{ice};

S_{qice} - ice strength index for blade ice torque

$P_{0,7}$ - propeller pitch at 0,7R, in m;

$t_{0,7}$ - =max thickness at 0,7R, in m;

n - =the rotational propeller speed, in rps, at bollard condition. If not known, n shall be taken according to Table 2.8.4.3.4.

Table 2.8.4.3.4

Propeller type	n
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85n_n
n_n - nominal rotational speed at MCR, free running condition.	

For CP propellers, propeller pitch $P_{0,7}$ shall correspond to MCR in bollard condition.

If not known, $P_{0,7}$ shall be taken as 0,7$P_{0,7n}$, where: $P_{0,7}$ is propeller pitch at MCR free running condition.

2.8.4.3.5 Maximum propeller ice thrust (applied to the shaft at the location of the propeller).

Maximum forward propeller ice thrust:

$$T_f=1,1\ \boldsymbol{F_f}. \qquad (2.8.4.3.5\text{-}1)$$

Maximum backward propeller ice thrust (maximum ice axial force acting on the propeller in the opposite direction of the ship):

$$T_b=1,1\ \boldsymbol{F_b}. \qquad (2.8.4.3.5\text{-}2)$$

2.8.4.4 Design ice loads for ducted propeller.

2.8.4.4.1 Maximum backward blade force $\boldsymbol{F_b}$, in kN:

when $D < D_{limit}$:

$$F_b=-9,5S_{ice}(EAR/Z)^{0,3}(nD)^{0,7}D^2; \quad (2.8.4.4.1\text{-}1)$$

when $D \geq D_{limit}$:

$$F_b=-66S_{ice}(EAR/Z)^{0,3}(nD)^{0,7}(H_{ice})^{1,4}D^{0,6}; \quad (2.8.4.4.1\text{-}2)$$

where:

D_{limit} = 4 H_{ice};

N shall be taken as in **2.8.4.3.1**

$\boldsymbol{F_b}$ shall be applied as a uniform pressure distribution to an area on the back side for the following load cases (refer to Table 2 of the Appendix):

.1 load case **1**: on the back of the blade from 0,6R to the tip and from the blade leading edge to a value of 0,2 chord length;

.2 load case **5**: for reversible rotation propellers a load equal to 60 % of $\boldsymbol{F_b}$ is applied on the blade face from 0,6R to the tip and from the blade trailing edge to a value of 0,2 chord length.

2.8.4.4.2 Maximum forward blade force $\boldsymbol{F_f}$, in kN:

when $D \leq D_{limit}$:

$$\boldsymbol{F_f} ,= 250(EAR/Z)\ D^2; \qquad (2.8.4.4.2\text{-}1)$$

when $D \geq D_{limit}$:

$$F_f = 500 \frac{1}{(1-\frac{d}{D})} H_{ice}[EAR/Z][D]^2, \qquad (2.8.4.4.2\text{-}2)$$

where: $$D_{limit} = \frac{2}{(1-\frac{d}{D})} H_{ice},\ \text{м}. \qquad (2.8.4.4.2\text{-}2)$$

$\boldsymbol{F_f}$ shall be applied as a uniform pressure distribution to an area on the face (pressure) side for the following load case (refer to Table 2 of the Appendix):

.1 load case **3**: on the blade face from 0,6R to the tip and from the blade leading edge to a value of 0,5 chord length;

.2 load case **5**: load equal to 60 % F_f shall be applied from 0,6R to the tip and from the blade leading edge to a value of 0,2 chord length.

2.8.4.4.3 Maximum propeller ice torque applied to the propeller Q_{max}, in kNm, is the maximum torque on a propeller due to ice-propeller interaction:

when $D \le D_{limit}$:

$$Q_{\max} = 74(1-d/D)S_{qice}(P_{0,7}/D)^{0,16}(t_{0,7}/D)^{0,6}(nD)^{0,17}D^3; \qquad (2.8.4.4.2\text{-}1)$$

when $D > D_{limit}$:

$$Q_{\max} = 74(1-d/D)S_{qice}(P_{0,7}/D)^{0,16}(t_{0,7}/D)^{0,6}(nD)^{0,17}D^3; \qquad (2.8.4.4.2\text{-}2)$$

where:

D_{limit}= 1,81 H_{ice};

N - rotational propeller speed, in rps, at bollard condition. If not known, n shall be taken according to Table 2.8.4.4.3.

For CP propellers, propeller pitch $P_{0,7}$ shall correspond to MCR in bollard condition.

If not known, $P_{0,7}$ shall be taken as 0,7$P_{0,7n}$, where: $P_{0,7}$ is propeller pitch at MCR free running condition.

Table 2.8.4.4.3

Propeller type	n
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85n_n
n_n - nominal rotational speed at MCR, free running condition	

2.8.4.4.4 Maximum blade spindle torque for CP-mechanism design $Q_{s\max}$, in kNm.

Spindle torque $Q_{s\max}$, in kNm, around the spindle axis of the blade fitting shall be calculated for the load case described in **2.8.4.1.**

If these spindle torque values are less than the default value given below, the default value shall be used:

$$Q_{s\max}=\boldsymbol{F}\boldsymbol{c}_{0,7}, \qquad (2.8.4.4.4)$$

where:

$c_{0,7}$ - length of the blade section at 0,7R radius;

F = either F_b or F_f, whichever has the greater absolute value.

2.8.4.4.5 Maximum propeller ice thrust (applied to the shaft at the location of the propeller).

Maximum forward propeller ice thrust:

$$T_f=1{,}1\ F_f. \qquad (2.8.4.4.5\text{-}1)$$

Maximum backward propeller ice thrust (maximum ice axial force acting on the propeller in the opposite direction of the ship):

$$T_b=1{,}1\ F_b. \qquad (2.8.4.4.5\text{-}2)$$

2.8.4.5 Design loads on propulsion line.

2.8.4.5.1 Torque..

The propeller ice torque excitation for shaft line dynamic analysis shall be described by a sequence of blade impacts which are of half sine shape and occur at the blade.

The torque due to a single blade ice impact as a function of the propeller rotation angle is then:

$$Q(\varphi) = C_q Q_{\max}\sin(\varphi(180/\alpha_i)) \text{ when } \varphi = 0...\alpha_i;$$
$$Q(\varphi) = 0 \text{ when } \varphi = \alpha_i...360. \qquad (2.8.4.5.1)$$

C_q and α_i parameters are given in Table2.8.4.5.1.

The total ice torque is obtained by summing the torque of single blades taking into account the phase shift 360 deg/Z.

The number of propeller revolutions during a milling sequence shall be determined by the formula

$$N_Q=2H_{ice}, \qquad (2.8.4.5.1\text{-}2)$$

The number of impacts is ZN_Q (refer to Fig. 1 in the Appendix)

Milling torque sequence duration is not valid for pulling bow propellers, which shall be agreed with the Register in each particular case.

The response torque at any shaft component shall be analysed considering excitation torque $\boldsymbol{Q}$ (φ) at the propeller, actual engine torque $\boldsymbol{Q_e}$ and mass elastic system.

$\boldsymbol{Q_e}$ actual maximum engine torque at considered speed.

Design torque along propeller shaft line.

The design torqueт $\boldsymbol{Q_r}$ of the shaft component shall be determined by means of torsional vibration analysis of the propulsion line.

Calculations shall be carried out for all excitation cases given above and the response shall be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed.

Table 2.8.4.5.1

The process of torque change	Interaction of the propeller and ice	C_q	α_i
Case 1	A single piece of ice	0,5	45
Case 2	A single piece of ice	0,75	90
Case 3	A single piece of ice	1,0	135
Case 4	Two pieces of ice with a phase of rotation angle equal to 45°	0,5	45

2.8.4.5.2 Maximum response thrust (maximum thrust along the propeller shaft line). Maximum thrust along the propeller shaft line shall be calculated with the formulae below. The factors 2,2 and 1,5 take into account the dynamic magnification due to axial vibration. Alternatively the propeller thrust magnification factor may be calculated by dynamic analysis. Maximum shaft thrust forwards, in kN:

$$T_r = T_n + 2,2\ T_f. \qquad (2.8.4.5.2\text{-}1)$$

Maximum shaft thrust backwards, in kN:

$$T_r = 1,5\ T_b, \qquad (2.8.4.5.2\text{-}2)$$

where

T_n - propeller bollard thrust, in kN;

T_f - maximum forward propeller ice thrust, in kN;

T_b - maximum backward propeller ice thrust, in kN.

If hydrodynamic bollard thrust T_n is not known, T_n shall be taken according to Table 2.8.4.5.2.

Table 2.8.4.5.2

Propeller type	T_n
CP propellers (open)	1,25T
CP propellers (ducted)	1,1T
FP propellers driven by turbine or electric motor	T
FP propellers driven by diesel engine (open)	0,85T
FP propellers driven by diesel engine (ducted)	0,75T
T - nominal propeller thrust at MCR at free running open water conditions.	

2.8.4.5.3 Blade failure load for both open and nozzle propeller. The force is acting at 0,8R in the weakest direction of the blade and at a spindle arm of 2/3 of the distance of axis of blade rotation of leading and trailing edge which ever is the greatest.

The blade failure load F_{ex}, in kN, is determined by formula

$$F_{ex} = \frac{0,3ct^2\sigma_{ref}}{0,8D-2r}\cdot 10^3, \qquad (2.8.4.5.3)$$

where:

$\sigma_{ref} = 0,6\sigma_{0,2} + 0,4\sigma_u$;

$\sigma_{0,2}$ and σ_u - representative values for the blade material;

c, t and *r* - respectively the actual chord length, thickness and radius of the cylindrical root section of the blade at the weakest section outside root fillet, and typically will be at the termination of the fillet into the blade profile;

D - propeller diameter, in m.

2.8.5 Design.

2.8.5.1 Design principle.

The strength of the propulsion line shall be designed: for maximum loads in **2.8.4**;

such that the plastic bending of a propeller blade shall not cause damages in other propulsion line components;

with sufficient fatigue strength.

2.8.5.2 Azimuthing main propulsors. In addition to the above requirements special consideration shall be given to the loading cases which are extraordinary for propulsion units when compared with conventional propellers.

Estimation of the loading cases shall reflect the operational realities of the ship and the thrusters. In this respect, for example, the loads caused by impacts of ice blocks on the propeller hub of a pulling propeller shall be considered.

Also loads due to thrusters operating in an oblique angle to the flow shall be considered.

The steering mechanism, the fitting of the unit and the body of the thruster shall be designed to withstand the loss of a blade without damage.

The plastic bending of a blade shall be considered in the propeller blade position, which causes the maximum load on the studied component.

Azimuth thrusters shall also be designed for estimated loads due to thruster body/ice interaction. The assessment of the relevant ice loads is performed in accordance with the requirements for the protruding parts, where all protruding parts must be designed to perceive the forces corresponding to the place of their attachment to the hull structure or position within the hull area.

2.8.5.3 Blade design.

2.8.5.3.1 Maximum blade stresses.

Blade stresses shall be calculated using the backward and forward loads given in section **2.8.4.3** and **2.8.4.4**.

The stresses shall be calculated with recognised and well-documented FE-analysis or other acceptable alternative method.

The stresses on the blade shall not exceed the allowable stresses σ all for the blade material given below.

Calculated blade stress for maximum ice load shall comply with the following:

$$\sigma_{calc} <= \sigma_{all} = \sigma_{ref}/S, \qquad (2.8.5.3.1\text{-}1)$$

where:

S=1,5

σ_{ref} = reference stress, defined as

$$\sigma_{ref} = 0,7\,\sigma_u \quad \text{or} \qquad (2.8.5.3.1\text{-}2)$$

$$\sigma_{ref} = 0,6\sigma_{0,2} + 0,4\sigma_u \ \text{ whichever is less} \qquad (2.8.5.3.1\text{-}3)$$

$\sigma_{0,2}$ and σ_u —representative values for the blade materia.

2.8.5.3.2 Blade edge thickness.

The blade edge thicknessest_{edge} and t_{tip} thickness tip shall be greater than t_{edge}**,** determined by formula

$$t_{edge} \geqslant xSS_{ice}\sqrt{3p_{ice}/\sigma_{ref}}, \qquad (2.8.5.3.2)$$

where:

x - distance from the blade edge measured along the cylindrical sections from the edge and shall be 2,5 % of chord length, however not to be taken greater than 45 mm.

In the tip area (above 0,975*R*) *x* shall be taken as 2,5 % of 0,975*R* section length and shall be measured perpendicularly to the edge, however not to be taken greater than 45 mm;

S - safety factor;

S = 2,5 for trailing edges;

S = 3,5 for leading edges;
S = 5 for tip;
S_{ice} - according to **2.8.4.2**;
P_{ice} – ice pressure;
P_{ice} = 1 6 MPa for leading edge and tip thickness;
p_{ice} - according to **2.8.5.3.1**.

The requirement for edge thickness shall be applied for leading edge and in case of reversible rotation open propellers also for trailing edge.

Tip thickness refers to the maximum measured thickness in the tip area above 0,975R.

The edge thickness in the area between position of maximum tip thickness and edge thickness at 0,975R shall be interpolated between edge and tip thickness value and smoothly distributed.

2.8.5.4 Prime movers.

2.8.5.4.1 The main engine shall be capable of being started and running the propeller with the CP in full pitch.

2.8.5.4.2 Provisions shall be made for heating arrangements to ensure ready starting of the cold emergency power units at an ambient temperature applicable to the polar class of the ship.

2.8.5.4.3 Emergency power units shall be equipped with starting devices with a stored energy capability of at least three consecutive starts at the design temperature in **2.8.5.4.2**.

The source of stored energy shall be protected to preclude critical depletion by the automatic starting system, unless a second independent means of starting is provided.

A second source of energy shall be provided for an additional three starts within 30 min, unless manual starting can be demonstrated to be effective.

2.8.6 Machinery fastening loading accelerations.

2.8.6.1 Essential equipment and main propulsion machinery supports shall be suitable for the accelerations as indicated in as follows. Accelerations shall be considered acting independently.

2.8.6.2 Longitudinal impact accelerations a_l.

Maximum longitudinal impact acceleration at any point along the hull girder, in m/s^2, is determined by the formula

$$a_l = (F_{IB}/\Delta)\{[1,1\tan(\gamma+\varphi)\ ]+[7H/L]\}, \qquad (2.8.6.2)$$

where:
φ - maximum friction angle between steel and ice, normally taken as 10 deg.;
y - = bow stem angle at waterline, in deg.;
Δ - displacement;
L - length between perpendiculars, in m;
H - distance from the waterline to the point being considered, in m;
F_{IB} - vertical impact force, defined in **3.11.2.13.2.1**, Part II «Hull».

2.8.6.3 Vertical acceleration a_v.

Combined vertical impact acceleration at any point along the hull girder, in m/s^2, is determined by the formula

$$a_v = 2,5\ (F_{IB}/\Delta)F_x, \qquad (2.8.6.3)$$

where:
F_x - 1,3 at FP;
F_x - 0,2 2 at midships;
F_x - 0,4 at AP;
F_x - 1,3 at AP for ships conducting ice breaking astern.

Intermediate values to be interpolated linearly.

2.8.6.4 Transverse impact acceleration a_t.

$$a_t = 3\ F_x F_t/\Delta, \qquad (2.8.6.4)$$

where:
F_x - 1,5 at FP;
F_x - 0,25 at midships;
F_x - 0,5 at AP;
F_x - 1, 5 at AP for ships conducting ice breaking astern.
F_t - total impact force, defined in **3.11.2.13.2.1**, Part II «Hull»

Intermediate values to be interpolated linearly.

2.8.7 Auxiliary systems.

2.8.7.1 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, means shall be provided to purge the system of accumulated ice or snow.

2.8.7.2 Means shall be provided to prevent damage due to freezing, to tanks containing liquids.

2.8.7.3 Vent pipes, intake and discharge pipes and associated systems shall be designed to prevent blockage due to freezing or ice and snow accumulation.

2.8.8 Sea inlets and cooling water systems.

2.8.8.1 Cooling water systems for machinery that are essential for the propulsion and safety of the vessel, including sea chests inlets, shall be designed in accordance with **4.3.3** Part VIII «Systems and Piping».

2.8.9 Ballast tanks.

2.8.9.1 Efficient means shall be provided to prevent freezing in fore and after peak tanks and wing tanks located above the water line and where otherwise found necessary.

2.8.10 Ventilation system.

2.8.10.1 The air intakes for machinery and accommodation ventilation shall be located on both sides of the ship.

2.8.10.2 Accommodation and ventilation air intakes shall be provided with means of heating.

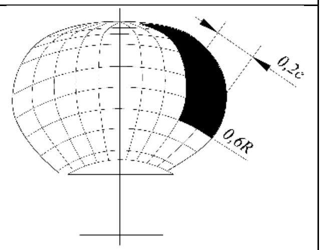
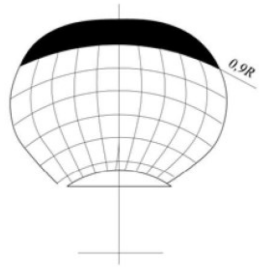
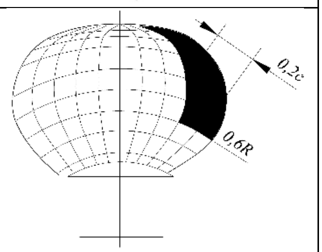
2.8.10.3 The temperature of inlet air provided to machinery from the air intakes shall be suitable for the safe operation of the machinery.

2.8.11 Alternative design[5].

2.8.11.1 As an alternative - a comprehensive design study may be submitted to the Register and may be requested to be validated by an agreed test programme.

APPENDIX

***Table 1.* Load cases for open propeller**

Load	Force	Loaded area	Right handed propeller blade seen from back
Load case **1**	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0,6*R* to the tip and from the leading edge to 0,2 times the chord length	
Load case **2**	50% of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside of 0,9*R*	
Load case **3**	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0,6*R* to the tip and fromthe leading edge to 0,2 times the chord length	

[5] Refer to IMO MSC.386(94) of 21.10.2014.

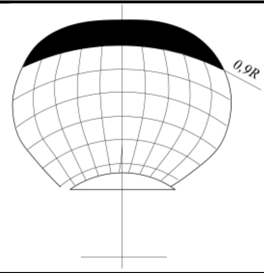
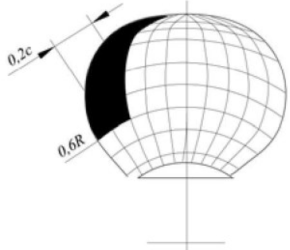
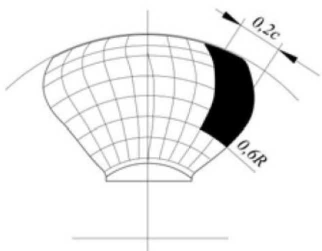
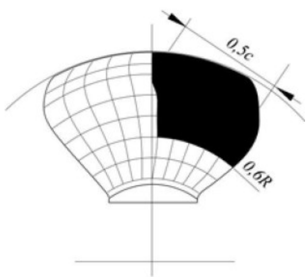
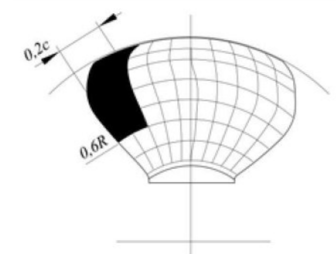
Load case **4**	50% of F_f	Uniform pressure applied on propeller face (pressure side) on the propeller tip area outside of 0,9R	
Load case **5**	60% of F_b or F_f, which one is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0,6R to the tip and from the trailing edge to 0,2 times the chord length	

Table 2. **Load cases for ducted propeller**

Load	Force	Loaded area	Right handed propeller blade seen from back
Load case **1**	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0,6R to the tip and from the leading edge to 0,2 times the chord length	
Load case **3**	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0,6R to the tip and from the leading edge to 0,5 times the chord length	

Load case **5**	60% of F_b or F_f, which one is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0,6*R* to the tip and from the trailing edge to 0,2 times the chord length	

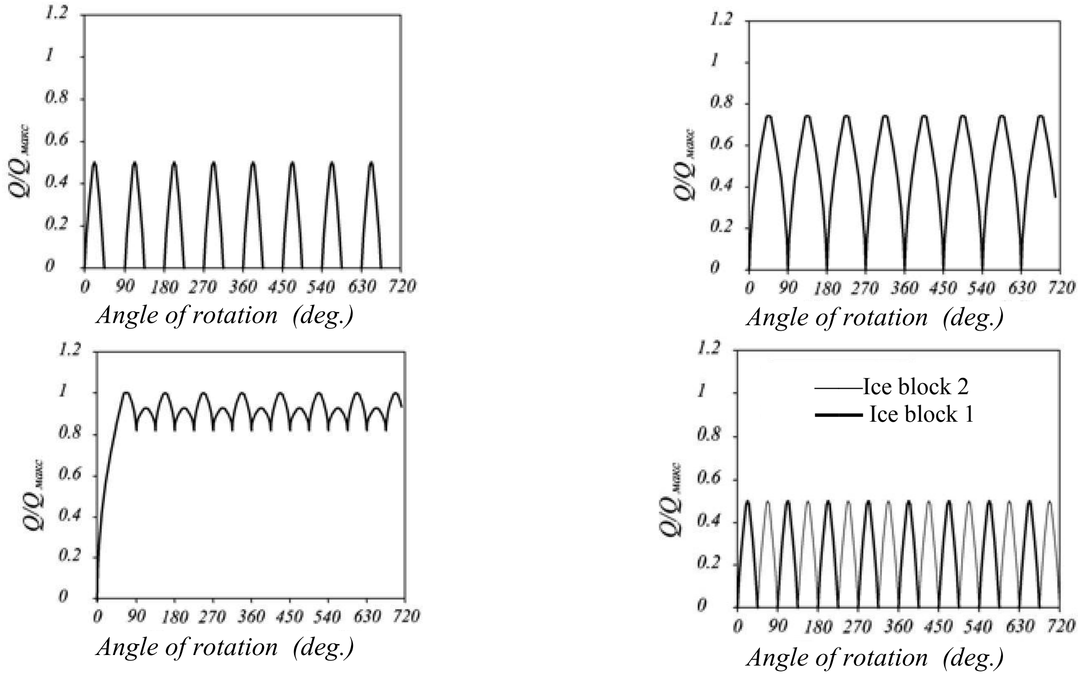


Fig.1. The shape of the propeller ice torque excitation for 45, 90, 135 degrees single blade impact sequences and 45 degrees double blade impact sequence (two ice pieces) on a four bladed propeller

2.9 REQUIREMENTS TO BALTIC CLASS SHIPS MACHINERY INSTALLATIONS

2.9.1 The engine output

2.9.1.1 Definitions and explanations.

.1 *The engine output* P is the maximum output the propulsion machinery can continuously deliver to the propeller(s).

.2 *The dimensions of the ship and some other parameters are defined below* (refer to Fig. 2.1.1.4):

L- length of the ship between the perpendiculars, in m;

L_{BOW} - length of the bow, in m;

L_{PAR} - length of the parallel midship body, in m;

B - maximum breadth of the ship, in m;

T- actual ice class draughts of the ship, in m;

A_{wf} - area of the waterline of the bow, in m^2;

A - the angle of the waterline at B/4, in deg.;

φ_1 - the rake of the stem at the centreline, in deg. With bulbous bow $\varphi_1 = 90°$;

φ_2 - the rake of the bow at B/4, in deg.;

ψ - $\psi = \arctan(\tan\varphi/\sin\alpha)$, in deg., using the appropriate to the position angles α and φ. For the purpose of **2.9.1.3** the angle is calculated using equality $\varphi = \varphi_2$;

D_p - diameter of the propeller, in m;

HM - thickness of the brash ice in mid channel;

HF - thickness of the brash ice layer displaced by the bow, in m.

.3 Upper and lower ice waterlines.

The upper ice waterline (UIWL) shall be the envelope of the highest points of the waterlines at which the ship is intended to operate in ice. The line may be a broken line.

The lower ice waterline (LIWL) shall be the envelope of the lowest points of the waterlines at which the ship is intended to operate in ice. The line may be a broken line.

2.9.1.2 The engine output shall not be less than, determined in **2.9.1.3**.

The engine output shall not be less than that determined by the formula (2.9.1.3-1), and in no case less than 1000 kW for ice class **IA**, **IB** and **IC**, and not less than 2800 kW for **IA Super**.

2.9.1.3 The engine output requirement shall be calculated for two draughts.

The engine output shall not be less than the greater of these two outputs.

In the calculations the ship's parameters, specified in **2.9.1.1**, which depend on the draught are to be determined at the appropriate draught, but L and B are to be determined only at the LWL.

$$P = K_e\,(R_{CH}\ /1000)^{3/2}/D_P, \text{ кВт} \qquad (2.9.1.3\text{-}1)$$

where:

K_e - shall be taken from Table 2.9.1.3;

R_{CH} - is the resistance, in N, of the ship in a channel with brash ice and a consolidated layer.

$$R_{CH} = C_1 + C_2 + C_3 C_\mu (H_F + H_M)^2 (B + C_\psi H_F) + C_4 L_{PAR} H_F + C_5 (LT/B^2)^3 (A_{wf}/L), \qquad (2.9.1.3\text{-}2)$$

Table 2.9.1.3 **Factor *K_e* with conventional propulsion plants**

Propeller type or machinery	CP or electric or hydraulic propulsion machinery	FP propeller
1	2,03	2,26
2	1,44	1,60
3	1,18	1,31

where:

C_μ = 0,15cos φ_2 + sinψsinα is to be taken equal or larger than 0,45;

C_ψ = 0,047ψ -2,115 i C_ψ = 0, if ψ< 45°;

H_F =0,26 + $(H_M B)^{0,5}$;

H_M = 1,0 m for ice classes **IA** and **IA Super**;

H_M = 0,8 m for ice class **IB**;

H_M = 0,6 m for ice class **IC**;

C_1 = 0 for ice classes **IA**, **IB** and **IC**;

for ice class **IA Super**;

f_1 = 23 N/m^2;

f_2 = 45,8 N/m;

f_3 = 14,7 N/m;

f_4 = 29 N/m^2;

C_2 = 0 for ice classes **IA**, **IB** and **IC**;

for ice class **IA Super**;

g_1 = 1530N;

g_2 = 170 N/m;

g_3 = (400 N/m)^{1,5}.

$$C_1 = f_1 \frac{BL_{PAR}}{2(T/B)+1} + (1 + 0{,}021\varphi_1)(f_2 B + f_3 L_{BOW} + f_4 L_{BOW})$$

$$C_2 = (1 + 0{,}063\varphi_1)(g_1 + g_2 B) + g_3\left(1 + 1{,}2\frac{T}{B}\right)\frac{B^2}{\sqrt{L}}$$

C_3 = 845;

C_4 = 42;

C_5 = 825.

The value $(L{\cdot}T/B^2)^3$ in Formula (2.9.1.3-2) shall be taken not less than 5 and not greater than 20.

If the value $(L{\cdot}T/B^2)^3$ is less than 5, then the value equal to 5 shall be used; if the value is greater than 20, the value of 20 shall be used.

2.9.1.4 Formula (2.9.1.3-2) can be used under the conditions specified in Table 2.9.1.4.

Table 2.9.1.4 **Conditions of application of the formula 2.9.1.3-2**

Parameter	α, in deg.	φ_1, in deg.	φ_2, in deg.	L, in m	B, in m	T, in m	L_{BOW}/L	L_{PAR}/L	D_p/T	$A_{wf}/(L\cdot B)$
Minimum value	15	25	10	65,0	11,0	4,0	0,15	0,25	0,45	0,09
Maximum value	55	90	90	250,0	40,0	15,0	0,40	0,75	0,75	0,27

The use of K_e or R_{CH} values based on more exact calculations or values based on model tests may be approved. Such an approval will be given on the understanding that it can be revoked if experience of the ship's performance in practice motivates this.

The design requirement for ice classes is a minimum speed of 5 knots in the following brash ice channels:

H_M = 0,6 m for ice class **IC**;

H_M = 0,8 m for ice class **IB**;

H_M = 1,0 m for ice class **IA**;

H_M = 1,0м m and a 0.1 m thick consolidated layer of ice for ice class **IA Super**.

2.9.2 Propulsion machinery.

2.9.2.1 Application.

These regulations apply to propulsion machinery covering open- and ducted-type propellers with a controllable pitch or fixed pitch design for ice classes **IA Super**, **IA**, **IB** and **IC**.

The given propeller loads are the expected ice loads for the entire ship's service life under normal operational conditions, including loads resulting from the changing rotational direction of FP propellers. However, these loads do not cover offdesign operational conditions, for example when a stopped propeller is dragged through ice.

The regulations also apply to azimuthing and fixed thrusters for main propulsion. However, the load models of the regulations do not include propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially).

The loads arising at interaction of ice with the AMSS casing shall be defined separately.

2.9.2.2 Definitions and explanations.

D - propeller diameter, in m.

R - propeller radius, in m.

c - chord length of blade section, in m.

$c_{0,7}$ - chord length of blade section at 0.7R propeller radius, in m.

d - external diameter of propeller hub (at propeller plane), in m.

D_{limit} - limit value for propeller diameter, in m.

F_b - maximum backward blade force for the ship's service life, in kN.

F_{ex} - ultimate blade load resulting from blade loss through plastic bending, in kN.

F_f - maximum forward blade force during the ship's service life, in kN.

F_{ice} - ice load, kN.

$(F_{ice})_{max}$ - maximum ice load during the ship's service life, in kN.

h_0 - depth of the propeller centreline from the lower ice waterline, in m.

H_{ice} - thickness of the maximum design ice block entering the propeller, in m.

I_e - equivalent mass moment of inertia of all parts on the engine side of the component under consideration, kgm^2.

I_t - equivalent mass moment of inertia of the whole propulsion system, kgm^2.

k - shape parameter for Weibull distribution.

m - slope for SN curve in log/log scale.

M_{BL} - blade bending moment, kNm.

N - propeller rotational speed, rev/s.

n_n - nominal propeller rotational speed at MCR in free running condition, rev/s.

N_{class} - reference number of impacts per nominal propeller rotational speed per ice class.

N_{ice} - total number of ice loads on the propeller blade for the ship's service life.

N_R - reference number of load for the equivalent fatigue stress (10^8 cycles).

N_Q - number of propeller revolutions during a milling sequence.

$P_{0,7}$ - propeller pitch at 0.7R radius, in m.

$P_{0,7n}$ - propeller pitch at 0.7R radius at MCR in free running condition, in m.

$P_{0,7b}$ - propeller pitch at 0.7R radius at MCR in bollard condition, in m.

Q - torque, kNm.

Q_{emax} - maximum engine torque, kNm.

Q_{max} - maximum torque on the propeller resulting from propeller/ice interaction, kNm.

Q_{motor} - electric motor peak torque, kNm.

Q_n - nominal torque at MCR in free running condition, kNm.
Q_r - response torque along the propeller shaft line, kNm.
Q_{smax} - maximum spindle torque of the blade for the ship's service life, kNm.
Q_{sex} - maximum spindle torque due to blade failure caused by plastic bending, kNm.
Q_{vib} - vibratory torque at considered component, taken from frequency domain open water torque vibration calculation (TVC), kNm.
r - blade section radius, in m.
T - propeller thrust, kN.
T_b - maximum backward propeller ice thrust during the ship's service life, kN.
T_f - maximum forward propeller ice thrust during the ship's service life, kN.
T_n - propeller thrust at MCR in free running condition, kN.
T_r - maximum response thrust along the shaft line, kN.
t - maximum blade section thickness, in m.
Z - number of propeller blades.
a_i - duration of propeller blade/ice interaction expressed in rotation angle, in deg.
α_1 - phase angle of propeller ice torque for blade order excitation component, in deg.
α_2 - phase angle of propeller ice torque for twice the blade order excitation component, in deg.
γ_v - the reduction factor for fatigue; variable amplitude loading effect.
γ_m - the reduction factor for fatigue; mean stress effect.
ρ - a reduction factor for fatigue correlating the maximum stress amplitude.
$\sigma_{0,2}$ - proof yield strength (at 0.2% offset) of blade material, in MPa.
σ_{exp} - mean fatigue strength of blade material at 10^8 cycles to failure in sea water.
σ_{fat} - equivalent fatigue ice load stress amplitude for 10^8 stress cycles, in MPa.
σ_{fl} - characteristic fatigue strength for blade material, in MPa.
σ_u - ultimate tensile strength of blade material, in MPa.
σ_{ref} - $\sigma_{ref} = 0{,}6\sigma_{0,2} + 0{,}4\sigma_u$, in MPa.
σ_{ref2} - $\sigma_{ref2} = 0{,}7\sigma_u$ or
σ_{ref2} - $\sigma_{ref2} = 0{,}6\sigma_{0,2} + 0{,}4\sigma_u$, whichever is less, in MPa.
σ_{st} - maximum stress resulting from F_b or F_f, in MPa.
$(\sigma_{ice})_{bmax}$ - principal stress caused by the maximum backward propeller ice load, in MPa.
$(\sigma_{ice})_{fmax}$ - principal stress caused by the maximum forward propeller ice load, in MPa.
$(\sigma_{ice})_{max}$ - maximum ice load stress amplitudę, in MPa.

Table 2.9.2.2

	Definition	Use of the load in design process
1	2	3
F_b	The maximum lifetime backward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to the 0.7*R* chord line. Refer to Figure. 2.9.2.2.	Design force for strength calculation of the propeller blade.
F_f	The maximum lifetime forward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to the 0.7R chord line.	Design force for calculation of strength of the propeller blade.
Q_{smax}	The maximum lifetime spindle torque on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade.	When designing the propeller strength, the spindle torque is automatically taken into account because the propeller load is acting on the blade in the form of distributed pressure on the leading edge or tip area.
T_b	The maximum lifetime thrust on a propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction and the force is opposite to the hydrodynamic thrust	Is used for estimating the response thrust T_r. T_b can be used as an estimate of excitation in axial vibration calculations.
T_f	The maximum lifetime thrust on a propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the	Is used for estimating the response thrust T_r.

	propeller shaft direction acting in the direction of hydrodynamic thrust.	T_f can be used as an estimate of excitation in axial vibration calculations.
Q_{max}	The maximum ice-induced torque resulting from propeller/ice interaction on one propeller blade, including hydrodynamic loads on that blade.	Is used for estimating the response torque (Q_r) along the propulsion shaft line and as excitation for torsional vibration calculations.
F_{ex}	Ultimate blade load resulting from blade loss through plastic bending. The force that is needed to cause total failure of the blade so that a plastic hinge appears in the root area. The force is acting on 0.8R. The spindle arm is 2/3 of the distance between the axis of blade rotation and the leading/trailing edge (whichever is the greater) at the 0.8R radius.	Blade failure load is used to dimension the blade bolts, pitch control mechanism, propellershaft, propeller shaft bearing and trust bearing. The objective is to guarantee that total propeller blade failure does not lead to damage to other components
Q_r	Maximum response torque along the propeller shaft line, taking account of the dynamic behaviour of the shaft line for ice excitation (torsional vibration) and the hydrodynamic mean torque on the propeller.	Design torque for propeller shaft line components.
T_r	Maximum response thrust along the shaft line, taking account of the dynamic behaviour of the shaft line for ice excitation (axial vibration) and the hydrodynamic mean thrust on the propeller.	Design thrust for propeller shaft line components.
F_{ti}	Maximum response force caused by ice block impacts on the thruster body or the propeller hub.	Design load for thruster body and slewing bearings.
F_{tr}	Maximum response force on the thruster body caused by ice ridge/thruster body interaction.	Design load for thruster body and slewing bearings.

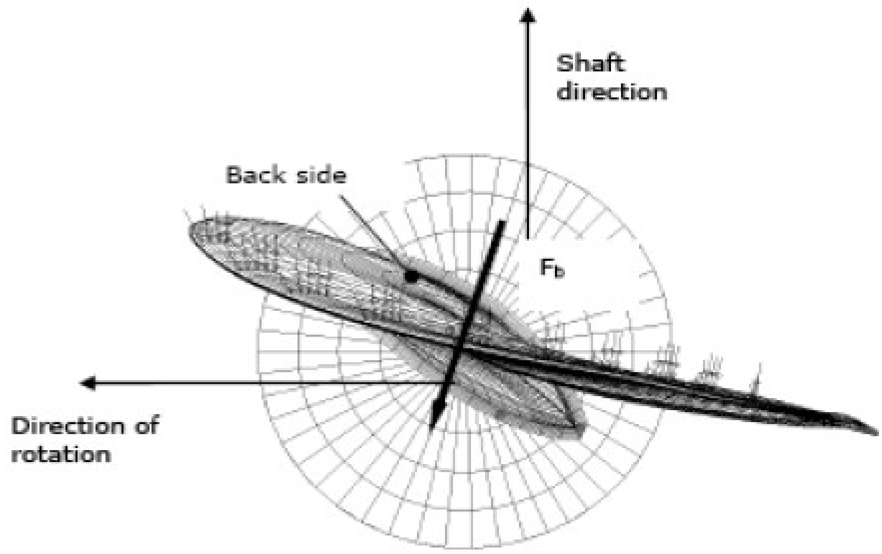


Fig. 2.9.2.2 Direction of the resultant backward blade force taken perpendicular to the chord line at radius 0.7R. The ice contact pressure at the leading edge is indicated with small arrows

2.9.2.3 Design ice conditions.

In estimating the ice loads of the propeller for various ice classes, account was taken of different types of operation as shown in Table 2.9.2.3-1. For the estimation of design ice loads, a maxi- mum ice block size must be determined. The maximum design ice block entering the propeller is a rectangular ice block with the dimensions $H_{ice} \times 2H_{ice} \times 3H_{ice}$

The thickness of the ice block H_{ice} is given in Table 2.9.2.3-2.

Table 2.9.2.3-1 **Types of operation for different ice classes**

Ice class	Operation of the ship
IA Super	Operation in ice channels and in level ice The ship may proceed by ramming

IA, **IB** and **IC**	Operation in ice channels

Table 2.9.2.3-2 **Thickness of design ice block**

Ice class	**IA Super**	**IA**	**IB**	**IC**
Thickness of the design maximum ice block entering the propeller H_{ice}	1,75 m	1,5 m	1,2 m	1,0 m

2.9.2.4 Materials.

2.9.2.4.1 Materials exposed to sea water.

The materials of components exposed to sea water, such as propeller blades, propeller hubs, and thruster body, shall have an elongation of no less than 15% in a test specimen, the gauge length of which is five times the diameter.

A Charpy V impact test shall be carried out for materials other than bronze and austenitic steel.

An average impact energy value of 20 J based on three tests must be obtained at minus 10ºC.

For nodular cast iron, average impact energy of 10 J at minus 10ºC is required accordingly.

2.9.2.4.2 Materials exposed to sea water temperature.

Materials exposed to sea water temperature shall be made of steel or another ductile material. An average impact energy value of 20 J, based on three tests, must be obtained at minus 10 ºC.

The nodular cast iron of a ferrite structure type may be used for relevant parts other than bolts.

The average impact energy for nodular cast iron shall be a minimum of 10 J at minus 10 ºC.

This requirement applies to the propeller shaft, blade bolts, CP mechanisms, shaft bolts, strut-pod connecting bolts etc. It does not apply to surface-hardened components, such as bearings and gear teeth.

2.9.2.5 Design loads.

The given loads are intended for component strength calculations only and are total loads, including iceinduced loads and hydrodynamic loads, during propeller/ice interaction.

The values of the parameters in the formulae given in this section are provided in the units shown in the symbol list in **2.9.2.2**.

If the highest point of the propeller of **IB** and **IC** class ships is not below the water surface when the ship is in ballast condition, the propulsion system shall be designed according to ice class **IA**.

2.9.2.5.1 Design loads on propeller blades.

F_b is the maximum force experienced during the lifetime of a ship that bends a propeller blade backwards when the propeller mills an ice block while rotating ahead.,

F_f is the maximum force experienced during the lifetime of a ship that bends a propeller blade forwards when the propeller mills an ice block while rotating ahead.

F_b and F_f originate from different propeller/ice interaction phenomena, and do not occur simultaneously. Hence, they are to be applied to one blade separately.

2.9.2.5.1.1 Maximum backward blade force F_b for open propellers.

$$F_b = 27(nD)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D^2$$ in kN when $D \le D_{limit}$; (2.9.2.5.1.1 -1)

$$F_b = 23(nD)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D H_{ice}^{1.4}$$ in kN when $D > D_{limit}$, (2.9.2.5.1.1-2)

where:

$D_{limit} = 0{,}85 H_{ice}^{1,4}$

n - is the nominal rotational speed:

$n = n_n$ – for CP propeller;

$n = 0{,}85 n_n$ - for FP propeller.

2.9.2.5.1.2 Maximum forward blade force F_f for open propellers

$$F_f = 250\left(\frac{EAR}{Z}\right)D^2$$ in kN when $D \le D_{limit}$; (2.9.2.5.1.2 -1)

$$F_f = 500\left(\frac{EAR}{Z}\right)D\frac{1}{1-d/D}H_{ice}$$ in kN when $D > D_{limit}$, (2.9.2.5.1.2 -2)

where:

$$D_{limit} = \frac{2}{1 - d / D} H_{ice}$$

2.9.2.5.1.3 Loaded area on the blade for open propellers.
Load cases 1-4 must be covered, as given in Table 2.9.2.5.1.3 below, for CP and FP propellers.
To obtain blade ice loads for a reversing propeller, load case 5 must also be covered for FP propellers.
2.9.2.5.1.4 Maximum backward blade ice force F_b for ducted propellers.

$$F_b = 9,5 (nD)^{0,7} \left(\frac{EAR}{Z} \right)^{0,3} D^2$$ in kN when $D \le D_{limit}$; (2.9.2.5.1.4 -1)

$$F_b = 66 (nD)^{0,7} \left(\frac{EAR}{Z} \right)^{0,3} D^{0,6} H_{ice}^{1,4}$$ in kN when $D > D_{limit}$, (2.9.2.5.1.4 -2)

where:
D_{limit} =4 H_{ice}, in m
n - is the nominal rotational speed:
$n = n_n$ – for CP propeller;
$n = 0,85 n_n$ - for FP propeller.
2.9.2.5.1.5 Maximum forward blade ice force F_f for ducted propellers.

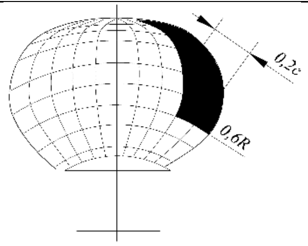
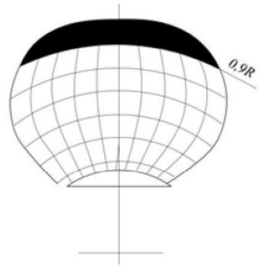
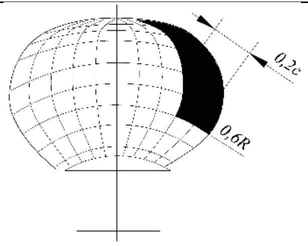
$$F_f = 250 \left(\frac{EAR}{Z} \right) D^2$$ in kN when $D \le D_{limit}$; (2.9.2.5.1.5 -1)

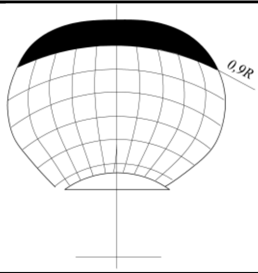
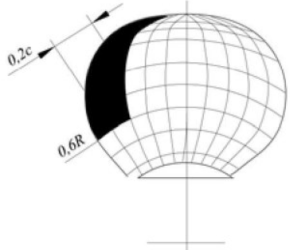
$$F_f = 500 \left(\frac{EAR}{Z} \right) D \frac{1}{1 - d / D} H_{ice}$$ in kN when $D > D_{limit}$, (2.9.2.5.1.5 -2)

where:

$$D_{limit} = \frac{2}{1 - d / D} H_{ice}$$

Table 2.9.2.5.1.3 **Load cases for open propellers**

Load case	Force	Loaded area	Right-handed propeller blade seen from behind
Load case 1	F_b	Uniform pressure applied on the blade back (suction side) to an area from 0.6*R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case **2**	50% of F_b	Uniform pressure applied on the blade back (suction side) on the blade tip area outside 0.9R radius.	
Load case **3**	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord lengt	

Load case **4**	50% of F_f	Uniform pressure applied on the blade face (pressure side) of the blade tip area outside 0.9R radius	
Load case **5**	60% of F_b or F_f, whichever is greater	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length	

2.9.2.5.1.6 Loaded area on the blade for ducted propellers.

Load cases 1 and 3 have to be covered as given in Table 2.9.2.5.1.6 for all propellers, and an additional load case (load case 5) for an FP propeller, to cover ice loads when the propeller is reversed.

2.9.2.5.1.7 Maximum blade spindle torque Q_{smax} for open and ducted propellers.

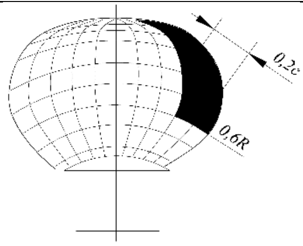
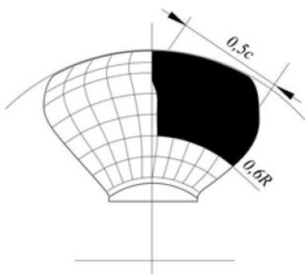
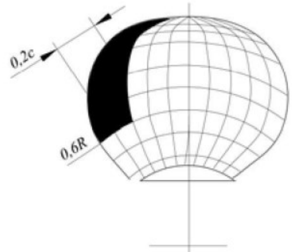
The spindle torque Qsmax around the axis of the blade fitting shall be determined both for the maximum backward blade force F_b and forward blade force Ff, which are applied as in Tables 2.9.2.5.1.3 and 2.9.2.5.1.6.

If the above method gives a value which is less than the default value given by the formula below, the default value shall be used

$$Q_{s\max} = 0{,}25 F c_{0,7}, \qquad (2.9.2.5.1.7)$$

where: F is either F_b or F_f whichever has the greater absolute value.

Table 2.9.2.5.1.6 **Load cases for ducted propellers**

Load case	Force	Loaded area	Right handed propeller blade seen from behind
Load case **1**	F_b	Uniform pressure applied on the blade back (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length	
Load case **3**	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.5 times the chord length	
Load case **5**	60% of F_b or F_f, whichever is greater	Uniform pressure applied on the face (pressure side) to an area from 0.6R to the tip and from blade the trailing edge to 0.2 times the chord length	

2.9.2.5.1.8 Load distributions for blade loads.

The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$), is used for the fatigue design of the blade.

$$P\left(\frac{F_{ice}}{(F_{ice})_{max}} \geq \frac{F}{(F_{ice})_{max}}\right) = \exp\left(-\left(\frac{F_{ice}}{(F_{ice})_{max}}\right)^k \ln N_{ice}\right), \quad (2.9.2.5.1.8)$$

where:
k = 0,75 shall be used for the ice force distribution of an open propeller and the shape parameter;
k = l, 0 for that of a ducted propeller blade;
F_{ice} is the random variable for ice loads on the blade; $0 < F_{ice} < (F_{ice})_{max}$.

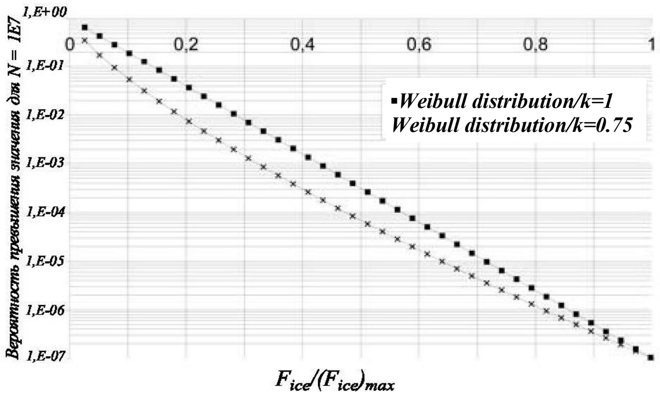


Fig. 2.9.2.5.1.8 The Weibull-type distribution

2.9.2.5.1.9 Number of ice loads.

The number of load cycles per propeller blade in the load spectrum shall be determined according to the formula:

$$N_{ice} = k_1 k_2 k_3 k_4 N_{class} n, \quad (2.9.2.5.1.9)$$

where:

Ice class	**IA Super**	**IA**	**IB**	**IC**
impacts in life/n_n	$9 \cdot 10^6$	$6 \cdot 10^6$	$3,4 \cdot 10^6$	$2,1 \cdot 10^6$

	Centre propeller Bow first operation	Wing propeller Bow first operation	Pulling propeller (wing and centre) Bow propeller or Stern first operation
k_1	1	2	3

Ducted propeller	no	no
k_2	1	1,1

Type	Fixed	Turning
k_3	1	1,1

The submersion factor k_4 is determined from the equation:
$k4 = 0,8 — f$ when $f < 0$;
$k4 = 0,8 — 0,4f$ when $0 \leq f \leq 1$;
$k4 = 0,6 — 0,2f$ when $1 < f \leq 2,5$;
$k4 = 0,1$ when $f > 2,5$,

where the immersion function f is $f = \frac{h_0 - H_{ice}}{D/2} - 1$.

For components that are subject to loads resulting from propeller/ice interaction with all the propeller blades, the number of load cycles (N_{ice}) must be multiplied by the number of propeller blades (Z).

2.9.2.5.2 Axial design loads for open and ducted propellers.

2.9.2.5.2.1 Maximum ice thrust on propeller T_f and T_b for open and ducted propellers:

$$T_f = 1,1\ F_f, \text{ in kN}; \quad (2.9.2.5.2.1\text{-}1)$$
$$T_b = 1,1\ F_b, \text{ in kN}. \quad (2.9.2.5.2.1\text{-}2)$$

2.9.2.5.2.2 Design thrust along the propulsion shaft line for open and ducted propellers.

The design thrust along the propeller shaft line must be calculated using the formulae below. The greater value of the forward and backward direction loads shall be taken as the design load for both directions.

Factors 2.2 and 1.5 take account of the dynamic magnification resulting from axial vibration. In a forward direction.

T_r =T+ 2,2 T_f, in kN; (2.9.2.5.2.2-1)

T_r =1,5 T_b, in kN. (2.9.2.5.2.2-2)

If the hydrodynamic bollard thrust, T, is not known, it must be taken as given in Table *2.9.2.5.2.2-2*:

Table 2.9.2.5.2.2-2

Propeller type	T
CP propellers(open)	1,25 T_n
CP propellers(ducted)	1,1 T_n
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	0,85 T_n
FP propellers driven by diesel engine (ducted)	0,75 T_n
T_n is the nominal propeller thrust at MCR in the free running open water condition.	

2.9.2.5.3 Torsional design loads.

2.9.2.5.3.1 Design ice torque on propeller Q_{max} for open propellers.

$$Q_{max} = 10.9\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}(nD)^{0.17}D^3$$ in kNm when $D \le D_{limit}$; (2.9.2.5.3.1-1)

$$Q_{max} = 20.7\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}(nD)^{0.17}D^{1.9}H_{ice}^{1.1}$$ in kNm when $D > D_{limit}$, (2.9.2.5.3.1-2)

where:

D_{limit} = 1,8H_{ice}, in m;

n is the rotational propeller speed at MCR in bollard condition. If unknown, n must be attributed a value in accordance with Table 2.9.2.5.3.1:

Table 2.9.2.5.3.1

Propeller type	n
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85n_n
n_n is the nominal rotational speed at MCR in the free running open water condition	

For CP propellers, the propeller pitch, $P_{0,7}$ ond to MCR in bollard condition.

If known, $P_{0,7}$ shall have a value equal to 0,7$P_{0,7n}$, where: $P_{0,7}$ is the propeller pitch at MCR in free running condition.

2.9.2.5.3.2 Design ice torque on propeller Q_{max} for ducted propellers.

$$Q_{max} = 7.7\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}(nD)^{0.17}.$$ in kNm when $D \le D_{limit}$; (2.9.2.5.3.2-1)

$$Q_{max} = 14.6\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}(nD)^{0.17}D^{1.9}H_{ice}^{1.1}$$ in kNm when $D > D_{limit}$, (2.9.2.5.3.2-1)

where:

D_{limit} =1,8H_{ice}, in m;

n and $P_{0,7}$ — refer to 2.9.2.5.3.1.

2.9.5.3.3 Design torque for non-resonant shaft lines.

If there is no relevant first blade order torsional resonance in the operational speed range or in the range 20% above and 20% below the maximum operating speed (bollard condition), the following estimation of the maximum torque can be used.

Directly coupled two stroke diesel engines without flexible coupling

Q_{peak}= Q_{emax} +Q_{vib} + Q_{max} I_e /I_t, in kNm; (2.9.2.5.3.3-1)

and other plants

Q_{peak}= Q_{emax} + Q_{max} I_e /I_t, in kNm. (2.9.2.5.3.3-1)

All the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque, Q_{emax}, is unknown, it shall be accorded the value given in Table 2.9.2.5.3.3.

Table 2.9.2.5.3.3

Propellertype	Q_{emax}
Propellers driven by electric motor	$*Q_{motor}$
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	0,75 Q_n
$*Q_{motor}$ is the electric motor peak torque	

2.9.2.5.3.4 Design torque for shaft lines having resonance.

If there is first blade order torsional resonance in the operational speed range or in the range 20% above and 20% below the maximum operating speed (bollard condition), the design torque (Q_{peak}) of the shaft component shall be determined by means of torsional vibration analysis of the propulsion line.

There are two alternative ways of performing the dynamic analysis.

Time domain calculation for estimated milling sequence excitation.

Frequency domain calculation for blade orders sinusoidal excitation.

The frequency domain analysis is generally considered conservative compared to the time domain simulation, provided that there is a first blade order resonance in the considered speed range.

2.9.2.5.3.4.1 Time domain calculation of torsional response.

Time domain calculations shall be calculated for the MCR condition, MCR bollard conditions and for blade order resonant rotational speeds so that the resonant vibration responses can be obtained.

The load sequence given in this chapter, for a case where a propeller is milling an ice block, shall be used for the strength evaluation of the propulsion line. The given load sequence is not intended for propulsion system stalling analyses.

The following load cases are intended to reflect the operational loads on the propulsion system, when the propeller interacts with ice, and the respective reaction of the complete system. The ice impact and system response causes loads in the individual shaft line components.

The ice torque Q_{max} may be taken as a constant value in the complete speed range. When considerations at specific shaft speeds are performed, a relevant Q_{max} may be calculated using the relevant speed according to section **2.9.2.5.3**.

Diesel engine plants without an elastic coupling shall be calculated at the least favourable phase angle for ice versus engine excitation, when calculated in the time domain. The engine firing pulses shall be included in the calculations and their standard steady state harmonics can be used.

If there is a blade order resonance just above the MCR speed, calculations shall cover rotation- al speeds up to 105% of the MCR speed.

The propeller ice torque excitation for shaft line transient dynamic analysis in the time domain is defined as a sequence of blade impacts which are of half sine shape.

The excitation frequency shall follow the propeller rotational speed during the ice interaction sequence.

The torque due to a single blade ice impact as a function of the propeller rotation angle is then defined using the formula:

$Q(\varphi) = C_q Q_{\max} \sin(\varphi (180/ \alpha_i))$ when φ rotates from 0 to α_i plus integer revolutions;

$Q(\varphi) = 0$ when φ rotates from α_i to 360 plus integer revolutions.

φ is the rotation angle from when the first impact occurs and parameters C_q and α_i are given in Table 2.9.2.5.3.4.1.

α_i is the duration of propeller blade/ice interaction expressed in terms of the propeller rotation angle. See Figure 2.9.2.5.3.4.1-1.

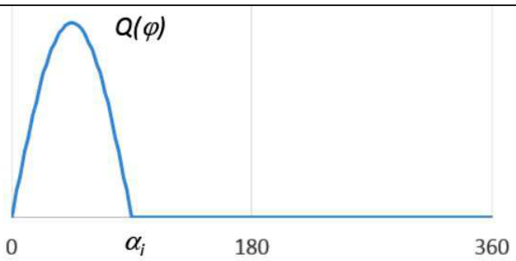


Fig. 2.9.2.5.3.4.1-1 Schematic ice torque due to a single blade ice impact as a function of the propeller rotation angle

The total ice torque is obtained by summing the torque of single blades, while taking account of the phase shift 360 deg./Z, see Figure 2.9.2.5.3.4.1-2.

At the beginning and end of the milling sequence (within the calculated duration) linear ramp functions shall be used to increase C_q to its maximum value within one propeller revolution and vice versa to decrease it to zero (see the examples of different Z numbers in Figure 2.9.2.5.3.4.1-2 and 2.9.2.5.3.4.1-3.

Table 2.9.2.5.3.4.1

Torque excitation	Propeller/ ice interaction	C_q	α_i, in deg. Z=3	Z=4	Z=5	Z=6
Excitation case 1	Single ice block	0,75	90	90	72	60
Excitation case 2	Single ice block	1,0	135	135	135	135
Excitation case 3	Two ice blocks (phase shift 360/(2·Z) deg.)	0,5	45	45	45	30
Excitation case 4	Single ice block	0,5	45	45	45	30

The number of propeller revolutions during a milling sequence shall be obtained from the formula:

$$N_Q = 2H_{ice}. \qquad (2.9.2.5.3.4.1\text{-}1)$$

The number of impacts is $Z \cdot N_Q$ for blade order excitation.

A dynamic simulation must be performed for all excitation cases at the operational rotational speed range.

Number of blades Z= 3 Number of blades Z= 4

Excitation case **1**

Excitation case **2**

Excitation case **3**

Excitation case **4**

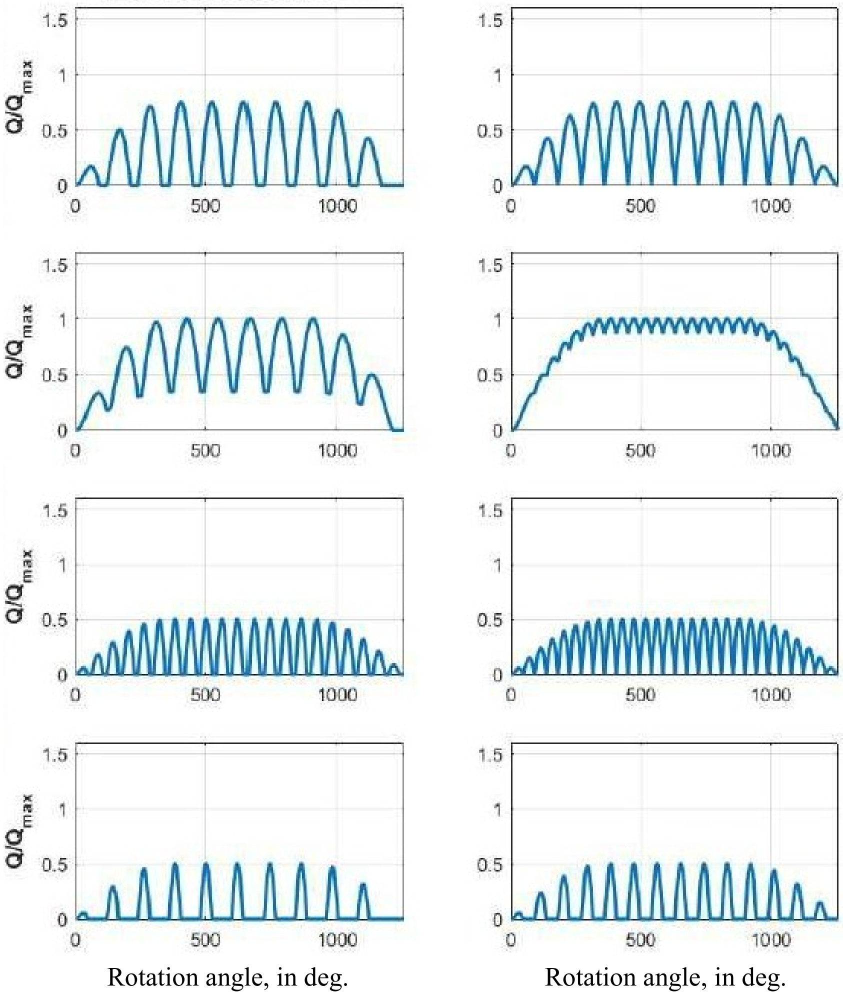


Fig. 2.9.2.5.3.4.1-2 The shape of the propeller ice torque excitation sequences for propellers with 3 and 4 blades

For a fixed pitch propeller propulsion plant, a dynamic simulation must also cover the bollard pull condition with a corresponding rotational speed assuming the maximum possible output of the engine.

If a speed drop occurs until the main engine is at a standstill, this indicates that the engine may not be sufficiently powered for the intended service task.

For the consideration of loads, the maximum occurring torque during the speed drop process must be used.

For the time domain calculation, the simulated response torque typically includes the engine mean torque and the propeller mean torque. If this is not the case, the response torques must be obtained using the formula:

$$Q_{peak} = Q_{emax} + Q_{rtd}, \text{ in kNm.} \qquad (2.9.2.5.3.4.1\text{-}2)$$

where: Q_{rtd} — is the maximum simulated torque obtained from the time domain analysis.

Excitation case	Number of blades Z= 5	Number of blades Z= 6
Excitation case 1		

Excitation case 2

Excitation case 3

Excitation case 4

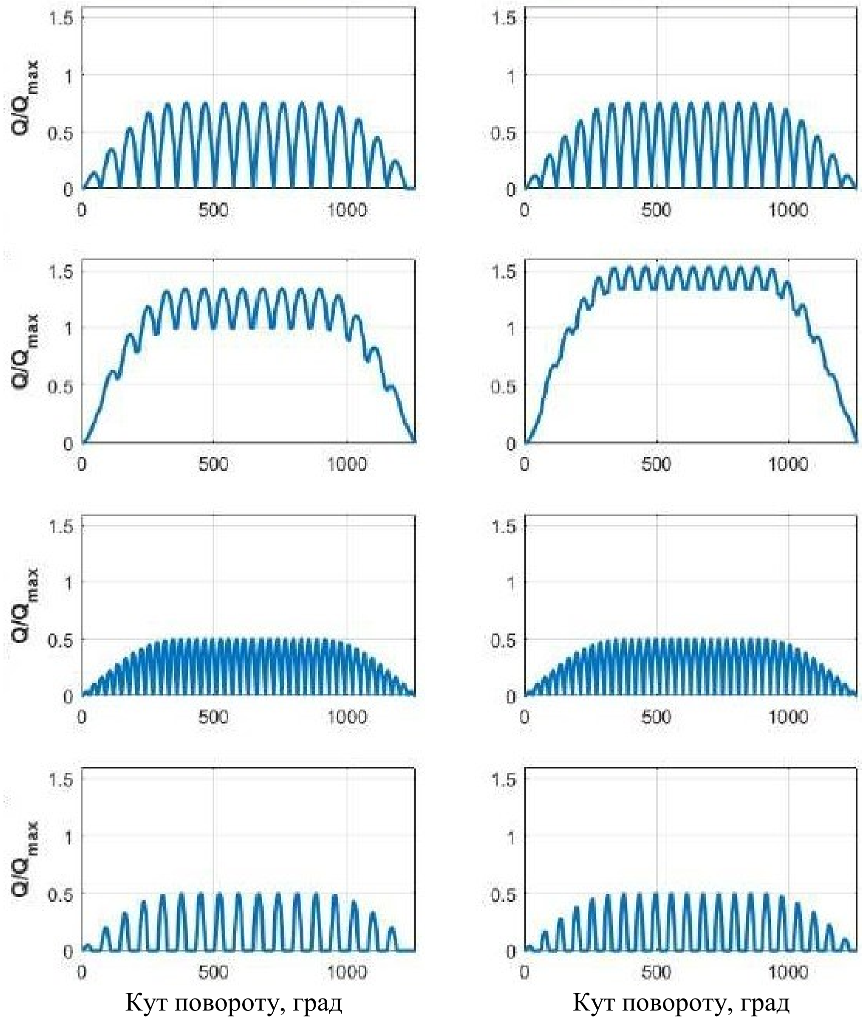


Fig. 2.9.2.5.3.4.1-3 The shape of the propeller ice torque excitation sequences for propellers with 5 or 6 blades

2.9.2.5.3.4.2 Frequency domain calculation of torsional response.

For frequency domain calculations, blade order and twice-the-blade-order excitation may be used.

The amplitudes for the blade order and twice-the-blade-order sinusoidal excitation have been derived based on the assumption that the time domain half sine impact sequences were continuous, and the Fourier series components for blade order and twice-the-blade-order components have been derived.

The propeller ice torque is then:

$$Q_F(\varphi) = Q_{\max}(C_{q0} + C_{q1}\sin(ZE_0\ \varphi + \alpha_1) + C_{q2}\sin(ZE_0\ \varphi + \alpha_2)),\quad \text{in kNm}\quad (2.9.2.5.3.4.2\text{-}1)$$

Where E_0 is the number of ice blocks in contact.

The values of the parameters are given in Table2.9.2.5.3.4.2.

Table 2.9.2.5.3.4.2

Torque excitation (Z=3)	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case **1**	0,375	0,36	-90	0	0	1
Excitation case **2**	0,7	0,33	-90	0,05	-45	1
Excitation case **3**	0,25	0,25	-90	0	0	2
Excitation case **4**	0,2	0,25	0	0,05	-90	1
Torque excitation (Z=4)						
Excitation case **1**	0,45	0,36	-90	0,06	-90	1
Excitation case **2**	0,9375	0	-90	0,0625	-90	1
Excitation case **3**	0,25	0,25	-90	0	0	2
Excitation case **4**	0,2	0,25	0	0,05	-90	1
Torque excitation (Z=5)						

Excitation case **1**	0,45	0,36	-90	0,06	-90	1
Excitation case **2**	1,19	0,17	-90	0,02	-90	1
Excitation case **3**	0,3	0,25	-90	0,048	-90	2
Excitation case **4**	0,2	0,25	0	0,05	-90	1
Torque excitation (Z=6)						
Excitation case **1**	0,45	0,36	-90	0,05	-90	1
Excitation case **2**	1,435	0,1	-90	0	0	1
Excitation case **3**	0,3	0,25	-90	0,048	-90	2
Excitation case **4**	0,2	0,25	0	0,05	-90	1

The design torque for the frequency domain excitation case must be obtained using the formula

$Q_{peak}=Q_{emax}+ Q_{vib}+(Q^{n}_{max}\, C_{q0})I_e/I_t+ Q_{rf1}+ Q_{rf2}$, in kNm (2.9.2.5.3.4.2-2)

where:

$Q_{\max}$ – is the maximum propeller ice torque at the operation speed in consideration;

C_{q0} – is the mean static torque coefficient from Table 2.9.2.3.4.2;

Q_{rf1} – is the blade order torsional response from the frequency domain analysis;

Q_{rf2} – is the second order blade torsional response from the frequency domain analysis.

If the prime mover maximum torque, Q_{emax} is not known, it shall be taken as given in 2.9.2.5.3.3.

2.9.2.5.3.4.3 Guidance for torsional vibration calculation.

The aim of time domain torsional vibration simulations is to estimate the extreme torsional load for the ship's lifespan. The simulation model can be taken from the normal lumped mass elastic torsional vibration model, including damping. For a time domain analysis, the model should include the ice excitation at the propeller, other relevant excitations and the mean torques provided by the prime mover and hydrodynamic mean torque in the propeller.

The calculations should cover variation of phase between the ice excitation and prime mover excitation. This is extremely relevant to propulsion lines with directly driven combustion engines.

Time domain calculations shall be calculated for the MCR condition, MCR bollard conditions and for resonant speed, so that the resonant vibration responses can be obtained.

For frequency domain calculations, the load should be estimated as a Fourier component analysis of the continuous sequence of half sine load sequences. First and second order blade components should be used for excitation.

The calculation should cover the entire relevant rpm range and the simulation of responses at torsional vibration resonances.

2.9.2.5.4 Blade failure load.

10.7.5.4.1 Bending force, F_{ex}.

The ultimate load resulting from blade failure as a result of plastic bending around the blade root shall be calculated using formula (2.9.2.5.4.1), or alternatively by means of an appropriate stress analysis, reflecting the nonlinear plastic material behaviour of the actual blade. In such a case, the blade failure area may be outside the root section.

The ultimate load is assumed to be acting on the blade at the 0.8R radius in the weakest direction of the blade.

$$F_{ex} = 300ct^2\sigma_{ref}/(0,8D-2r),\ \text{in kN}, \qquad (2.9.2.5.4.1)$$

where: c, t and r are, respectively, the actual chord length, maximum thickness and radius of the cylindrical root section of the blade, which is the weakest section out-side the root fillet typically located at the point where the fillet terminates at the blade profile.

2.9.2.5.4.2 Spindle torque, Q_{sex}.

The maximum spindle torque due to a blade failure load acting at 0.8R shall be determined. The force that causes blade failure typically reduces when moving from the propeller centre towards the leading and trailing edges.

At a certain distance from the blade centre of rotation, the maximum spindle torque will occur. This maximum spindle torque shall be defined by an appropriate stress analysis or using the equation given below:

$$Q_{sex}=\max(C_{LE0,8};\ 0,8C_{TE0,8})C_{spex}F_{ex},\ \text{in kNm};$$

$$C_{spex}= 0,7(1-(4EAR/Z)^3),$$

where:

EAR – expanded blade area ratio.

If C_{spex} is below 0,3, a value of 0.3 shall to be used for C_{spex}.

$C_{LE0,8}$ is the leading edge portion of the chord length at 0.8*R*;

$C_{TE0,8}$ – is the trailing edge portion of the chord length at0.8*R*.

Figure 2.9.2.5.4.2 illustrates the spindle torque values due to blade failure loads across the entire chord length.

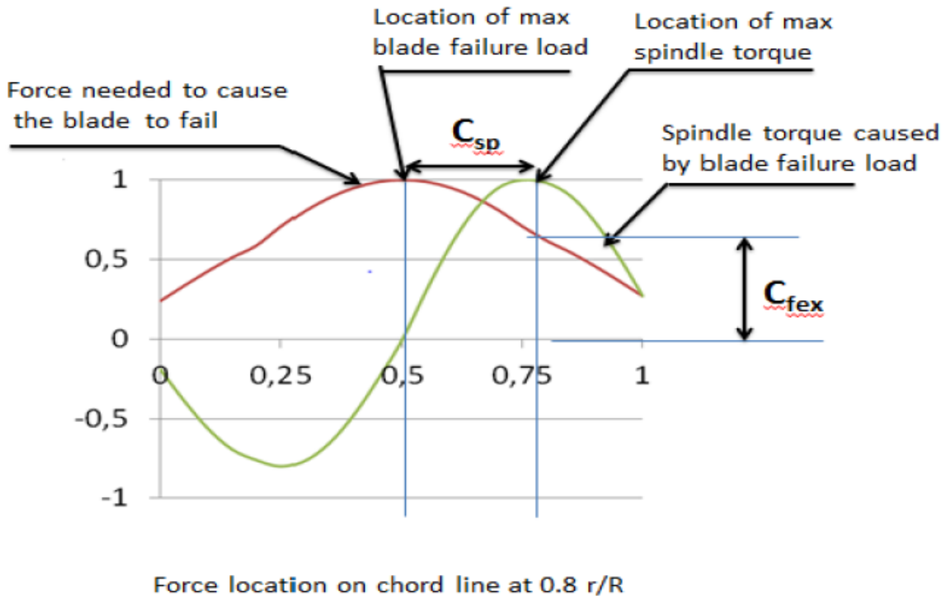


Fig. 2.9.2.5.4.2 Schematic figure showing a blade failure load and the related spindle torque when the force acts at a different location on the chord line at radius0,8*R*

2.9.2.6 Design.

2.9.2.6.1 Design principle.

The strength of the propulsion line shall be designed according to the pyramid strength principle. This means that the loss of the propeller blade shall not cause any significant damage to other propeller shaft line components.

2.9.2.6.2 Propeller blade.

2.9.2.6.2.1 Calculation of blade stresses.

The blade stresses shall be calculated for the design loads given in **2.9.2.5.1**.

Finite element analysis shall be used for stress analysis for the final approval of all propellers. The following simplified formulae can be used for estimating the blade stresses for all propellers at the root area ($r/R < 0{,}5$).

Root area dimensions based on formula (2.9.2.6.2.1), can be accepted, even if the FEM analysis would show greater stresses at the root area.

$$\sigma_{st} = C_1 M_{BL}/100ct^2, \text{ in MPa}, \qquad (2.9.2.6.2.1)$$

where:

constant C_1 is the actual stress/stress obtained from the beam equation. If the actual value is not available, C_1 should have a value of 1.6;

$M_{BL} = (0{,}75\text{-}r/R)\cdot R\cdot F$,

where: $F = F_b$ or F_f, whichever has greater absolute value.

2.9.2.6.2.2 Acceptability criterion.

The following criterion for calculated blade stresses must be fulfilled:

$$\sigma_{ref2}/\sigma_{st} \geq 1{,}3$$

If FEM analysis is used for estimating the stresses, von Mises stresses shall be used.

2.9.2.6.2.3 Fatigue design of propeller blade.

The fatigue design of the propeller blade is based on an estimated load distribution for the service life of the ship and the S-N curve for the blade material. An equivalent stress that produces the same fatigue damage as the expected load distribution shall be calculated and the acceptability criterion for fatigue should be fulfilled. The equivalent stress is normalised for 10^8 cycles

For materials with a two-slope SN curve, fatigue calculations in accordance with this chapter are not required if the following criterion is fulfilled.

$$\sigma_{exp} \geq B_1 \sigma_{ref2} B_2 \log(N_{ice}) B_3$$

where: B_1, B_2 and B_3 coefficients for open and ducted propellers are given in Table 2.9.2.6.2.3-1.

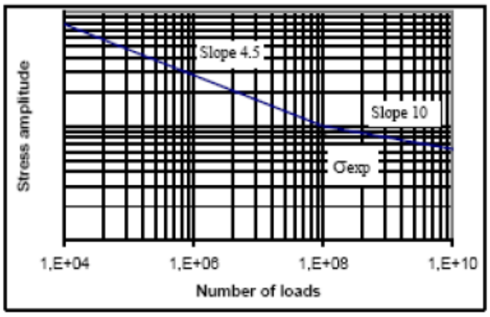


Fig. 2.9.2.6.2.3-1 Two-slope S-N curve

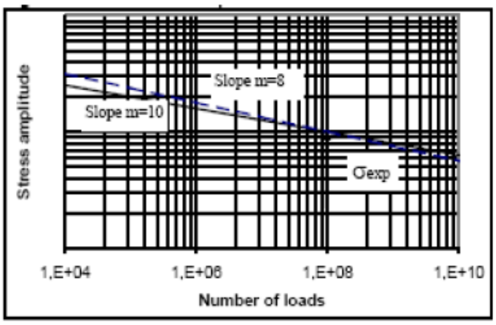


Fig. 2.9.2.6.2.3-2 Constant-slope S-N curve. Equivalent fatigue stress

Table 2.9.2.6.2.3-1

	Open propeller	Ducted propeller
B_1	0,00246	0,00167
B_2	0,947	0,956
B_3	2,101	2,470

For the calculation of equivalent stress, two types of SN curves are available.

Two slope SN curve (slopes 4.5 and 10), see Figure 2.9.2.6.2.3-1;

One slope SN curve (the slope can be chosen), see Figure 2.9.2.6.2.3-2.

The type of the SN-curve shall be selected to correspond with the material properties of the blade.

If the SN-curve is unknown, the two slope SN curve shall be used.

2.9.2.6.2.3.1 The equivalent fatigue stress.

The equivalent fatigue stress for 10^8 stress cycles, which produces the same fatigue damage as the load distribution for the service life of the ship, is:

$$\sigma_{fat} = \rho(\sigma_{ice})_{\max}, \quad (2.9.2.6.2.3.1)$$

where $(\sigma_{ice})_{\max} = 0{,}5((\sigma_{ice})_{f\max} - (\sigma_{ice})_{b\max})$.

In the calculation of $(\sigma_{ice})_{\max}$ case 1 and case 3 (or case 2 and case 4), specified in **2.9.2.5.1**, are considered a pair for $(\sigma_{ice})_{f\max}$ and $(\sigma_{ice})_{b\max}$ calculations. Case 5 is excluded from the fatigue analysis

.

2.9.2.6.2.3.2 Calculation of parameter ρ for two-slope S-N curve.

The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formula

$$\rho = C_1(\sigma_{ice})_{\max} C_2 \sigma_{fl} C_3 \log(N_{ice}) C_4, \quad (2.9.2.6.2.3.2)$$

where $\sigma_{fl} = \gamma_\varepsilon \gamma_v \gamma_m \sigma_{exp}$.

The following values should be used for the reduction factors if actual values are unavailable $\gamma_\varepsilon = 0{,}67$, $\gamma_v = 0{,}75$ and $\gamma_m = 0{,}75$.

The coefficients$C1$, $C2$, $C3$ and $C4$ are given in Table2.9.2.6.2.3.2.

Table 2.9.2.6.2.3.2

	Open propeller	Ducted propeller
C_1	0,000711	0,000534
C_2	0,0645	0,0533
C_3	-0,0565	-0,0459
C_4	2,22	2,584

2.9.2.6.2.3.3 Calculation of parameterρ for constant-slope S-N curve.

For materials with a constant-slope S-N curve, the factor ρ shall be calculated using the following formula

$$\rho = \left(G \frac{N_{ice}}{N_R}\right)^{1/m} (\ln(N_{ice}))^{-1/k}, \qquad (2.9.2.6.2.3.2)$$

where: k = 1,0 for ducted propellers;
k = 0,75 for open propellers.

Values for the parameter G are given in Table 2.9.6.2.2.3.3, Linear interpolation may be used to calculate the value of m/k ratios other than those given in Table 2.9.6.2.2.3.3.

Table 2.9.2.6.2.3.3 **Value of the parameter *G* for different *m/k* ratios**

m/k	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	9,5	10
G	6	11,6	24	52,3	120	287,9	720	1871	5040	14034	40320	119292	362880	$1{,}133 \cdot 10^6$	$3{,}623 \cdot 10^6$

2.9.2.6.2.4 Acceptability criterion for fatigue.
The equivalent fatigue stress at all locations on the blade must fulfil the following acceptability criterion:

$$(\sigma_{fð} / \sigma_{fat}) \geq 1{,}5$$

where: $\sigma_{fl} = \gamma_{\varepsilon 1}\gamma_{\varepsilon 2}\gamma_v\gamma_m\ \sigma_{exp}$.

The following values should be used for the reduction factors if actual values are unavailable: $\gamma_\varepsilon = \gamma_{\varepsilon 1}$ = 0,67, γ_v = 0,75 and γ_m = 0,75.

2.9.6.2.3 Propeller bossing and CP mechanism.
The blade bolts, the CP mechanism, the propeller boss, and the fitting of the propeller to the propeller shaft shall be designed to withstand the maximum and fatigue design loads, as defined in **2.9.2.5**.
The safety factor against yielding shall be greater than 1.3 and that against fatigue greater than 1.5. In addition, the safety factor for loads resulting from loss of the propeller blade through plastic bending, as defined in**2.9.2.5**, shall be greater than 1.0 against yielding.
2.9.2.6.4 Propulsion shaft line.
The shafts and shafting components, such as the thrust and stern tube bearings, couplings, flanges and sealings, shall be designed to withstand the propeller/ice interaction loads as given in **2.9.2.5**.
The safety factor must be at least 1.3.
2.9.2.6.4.1 Shafts and shafting components.
The ultimate load resulting from total blade failure, as defined in **2.9.2.5.4.1**, shall not cause yielding in shafts and shaft components.
The loading shall consist of the combined axial, bending, and torsion loads, wherever this is significant. The minimum safety factor against yielding must be 1.0 for bending and torsional stresses.
2.9.2.6.5 Azimuthing main propulsors.
2.9.2.6.5.1 Design principle.
In addition to the above requirements for propeller blade dimensioning, azimuthing thrusters must be designed for thruster body/ice interaction loads.
Load formulae are given for estimating once in a lifetime extreme loads on the thruster body, based on the estimated ice condition and ship operational parameters.
Two main ice load scenarios have been selected for defining the extreme ice loads. Examples of loads are illustrated in Figure2.9.2.6.5.1.
In addition, blade order thruster body vibration responses may be estimated for propeller excitation.
The following load scenario types are considered:
.1 Ice block impact on the thruster body or propeller hub;
.2 Thruster penetration into an ice ridge that has a thick consolidated layer;
.3 Vibratory response of the thruster at blade order frequency.
The steering mechanism, the fitting of the unit, and the body of the thruster shall be designed to withstand the plastic bending of a blade without damage.
The loss of a blade must be taken into account for the propeller blade orientation causing the maximum load on the component being studied. Top-down blade orientation typically places the maximum bending loads on the thruster body.
2.9.2.6.5.2 Extreme ice impact loads.

When the ship is operated in ice conditions, ice blocks formed in channel side walls or from the ridge consolidated layer may impact on the thruster body and the propeller hub.

Exposure to ice impact is very much dependent on the ship size and ship hull design, as well as the location of the thruster.

The contact force will grow in terms of thruster/ice contact until the ice block reaches the ship speed.

The thruster must withstand the loads occurring when the design ice block defined in 2.9.2.3-2, impacts on the thruster body when the ship is sailing at a typical ice operating speed.

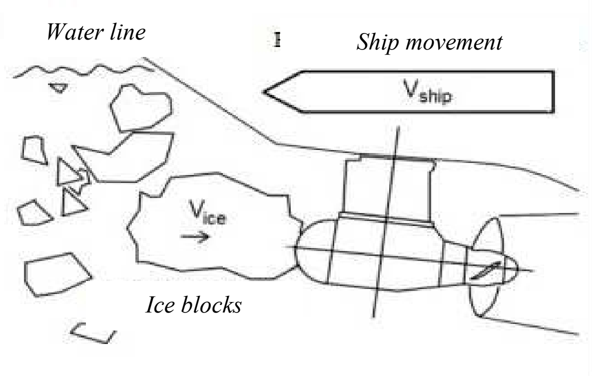
Load cases for impact loads are given in Table 2.9.2.6.5.2-1.

The contact geometry is estimated to be hemispherical in shape. If the actual contact geometry differs from the shape of the hemisphere, a sphere radius must be estimated so that the growth of the contact area as a function of penetration of ice corresponds as closely as possible to the actual geometrical shape penetration.

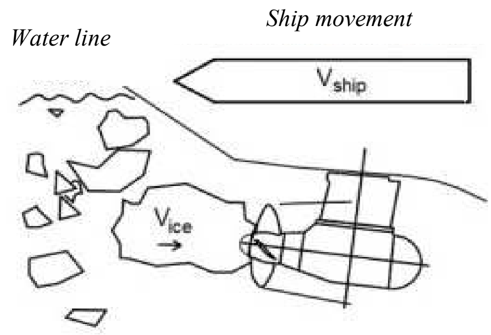
The ice impact contact load must be calculated using formula (2.9.2.6.5.2).

The related parameter values are given in Table 2.9.2.6.5.2-2.

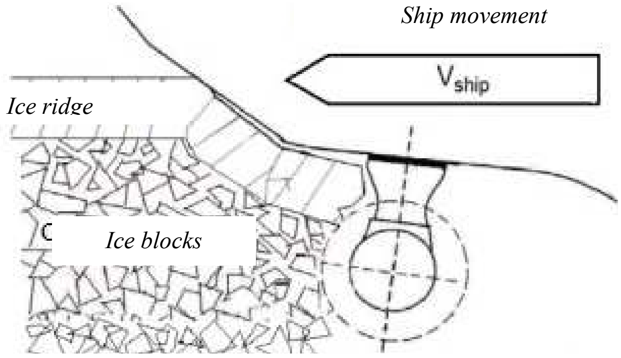
The design operation speed in ice can be derived from Tables 2.9.2.6.5.2-3 i 2.9.2.6.5.2-4 or the ship in question's actual design operation speed in ice can be used.



Impact on thruster body



Impact on propeller hub



Thruster penetration into the ice ridge

Fig. 2.9.2.6.5.1 Examples of load scenario types

2.9.2.6.5.2 Extreme ice impact loads.

When the ship is operated in ice conditions, ice blocks formed in channel side walls or from the ridge consolidated layer may impact on the thruster body and the propeller hub.

Exposure to ice impact is very much dependent on the ship size and ship hull design, as well as the location of the thruster. The contact force will grow in terms of thruster/ice contact until the ice block reaches the ship speed.

The thruster must withstand the loads occurring when the design ice block defined in Table2.9.2.3-2, impacts on the thruster body when the ship is sailing at a typical ice operating speed.

Load cases for impact loads are given in Table 2.9.2.6.5.2-1.

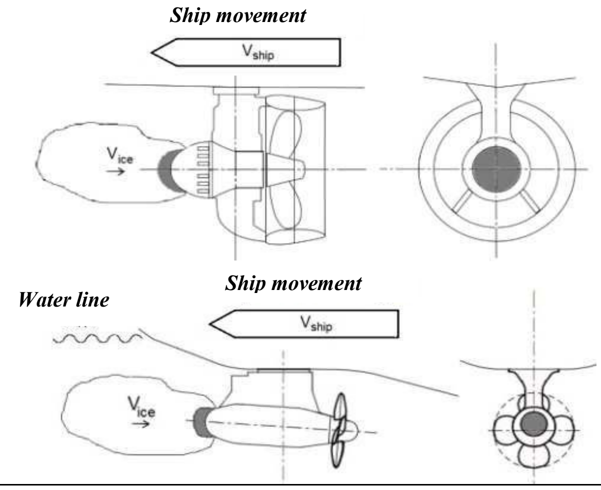
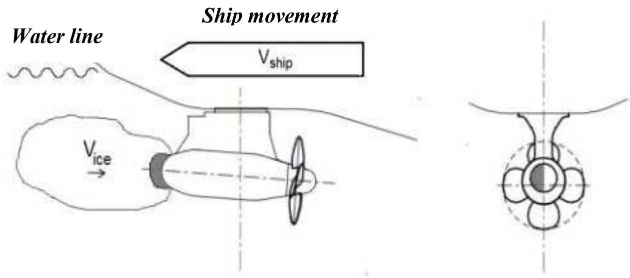
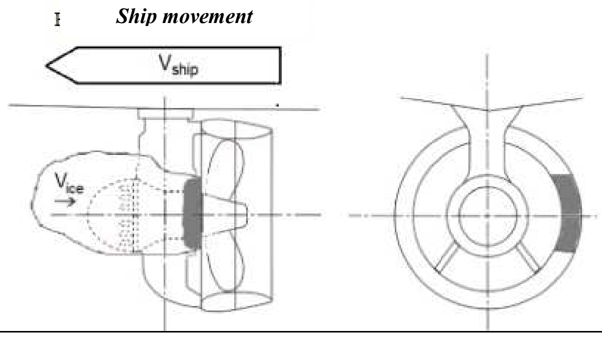
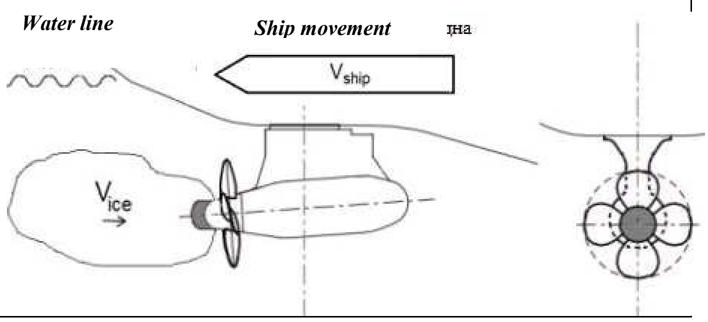
The contact geometry is estimated to be hemispherical in shape. If the actual contact geometry differs from the shape of the hemisphere, a sphere radius must be estimated so that the growth of the contact area as a function of penetration of ice corresponds as closely as possible to the actual geometrical shape penetration.

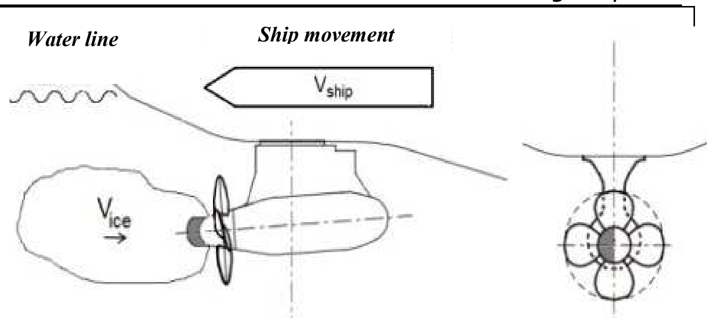
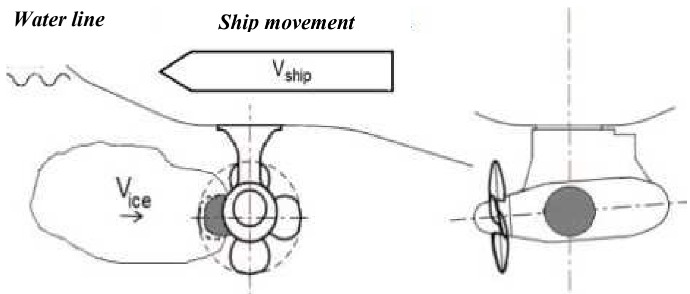
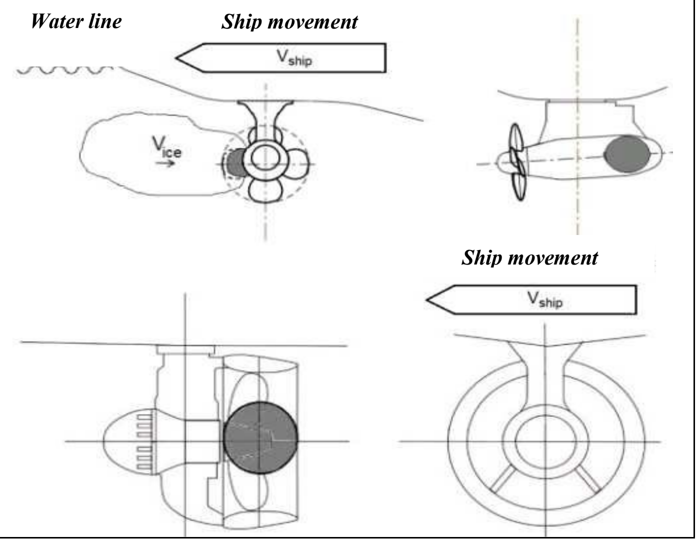
The ice impact contact load must be calculated using formula (2.9.2.6.5.2).

The related parameter values are given in Table 2.9.2.6.5.2-2.

The design operation speed in ice can be derived from Tables2.9.2.6.5.2-3 i 2.9.2.6.5.2-4 or the ship in question's actual design operation speed in ice can be used.

Table 2.9.2.6.5.2-1 **Load cases for impact loads**

Load case	Force	Loaded area	Interaction
1	**2**	**3**	**4**
Load case T1a Symmetric longitudinal ice impact on thruster	F_{ti}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T1b Non-symmetric longitudinal ice impact on thruster	50% of F_{ti}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area	
Load case T1c Non-symmetric longitudinal ice impact on nozzle	F_{ti}	Uniform distributed load or uniform pressure, which are applied on the impact area. Contact area is equal to the nozzle thickness (H_{nz}) the contact height H_{ice}	
Load case T2a Symmetric longitudinal ice impact on propeller hub	F_{ti}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	

Load case T2b Non-symmetric longitudinal ice impact on propeller hub	50% of F_{ti}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area.	
Load case T3a Symmetric lateral ice impact on thruster body	F_{ti}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T3b Non-symmetric lateral ice impact on thruster body or nozzle	F_{ti}	Uniform distributed load or uniform pressure, which are applied on the impact area. Nozzle contact radius R to be taken from the nozzle length (L_{nz})	

The longitudinal impact speed in Tables 2.9.2.6.5.2-3 i 2.9.2.6.5.2-4, refers to the impact in the thruster's main operational direction.

For the pulling propeller configuration, the longitudinal impact speed is used for load case T2, impact on hub; and for the pushing propeller unit, the longitudinal impact speed is used for load case T1, impact on thruster end cap. For the opposite direction, the impact speed for transversal impact is applied.

$$F_{ti}=C_{DMI}\,34{,}5R_c^{0{,}5}(m_{ice}v_s^2)^{0{,}333}, \text{ in kN} \qquad (2.9.2.6.5.2\text{-}1)$$

where:
R_c is the impacting part sphere radius, see Figure (10.7.6.5.2), in m;
m_{ice} is the ice block mass, in kg;
v_s is the ship speed at the time of contact, im m/s;
C_{DMI} is the dynamic magnification factor for impact loads.

C_{DMI} shall be taken from Table 2.9.2.6.5.2-2 if unknown.

For impacts on non-hemispherical areas, such as the impact on the nozzle, the equivalent impact sphere radius must be estimated using the equation below:

$$R_{ceq}= (A/\pi)^{1/2}, \text{ in m.} \qquad (2.9.2.6.5.2\text{-}2)$$

If the $2R_{ceq}$ is greater than the ice block thickness, the radius is set to half of the ice block thickness.

For the impact on the thruster side, the pod body diameter can be used as a basis for determining the radius.

For the impact on the propeller hub, the hub diameter can be used as a basis for the radius.

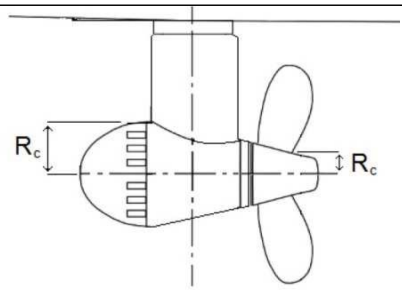


Fig. 2.9.2.6.5.2 Dimensions used for R_c

Table 2.9.2.6.5.2-2 **Parameter values for ice dimensions and dynamic magnification**

Baltic ice class	**IA Super**	**IA**	**IB**	**IC**
Thickness of the design ice block impacting thruster (2/3 of H_{ice}), in m	1.17	1,0	0,8	0,67
Extreme ice block mass m_{ice}, in k	8670	5460	2800	1600
C_{DMI} (if not known)	1,3	1,2	1,1	1,0

Table 2.9.2.6.5.2-3 **Impact speeds for aft centerline thruster**

Baltic ice class	**IA Super**	**IA**	**IB**	**IC**
Longitudinal impact in main operational direction	6	5	5	5
Longitudinal impact in reversing direction (pushing unit propeller hub or pulling unit cover end cap impact)	4	3	3	3
Transversal impact in bow first operation	3	2	2	2
Transversal impact in stern first operation (double acting ship)	4	3	3	3

Таблиця 2.9.2.6.5.2-4 **Impact speeds for aft wing, bow centerline and bow wing thrusters**

Baltic ice class	**IA Super**	**IA**	**IB**	**IC**
Longitudinal impact in main operational direction	6	5	5	5
Longitudinal impact in reversing direction (pushing unit propeller hub or pulling unit cover end cap impact)	4	3	3	3
Transversal impact	4	3	3	3

2.9.2.6.5.3 Extreme ice loads on thruster hull when penetrating an ice ridge.

In icy conditions, ships typically operate in ice channels.

When passing other ships, ships may be subject to loads caused by their thrusters penetrating ice channel walls. There is usually a consolidated layer at the ice surface, below which the ice blocks are loose. In addition, the thruster may penetrate ice ridges when backing. Such a situation is likely in the case of ships with notation **IA Super**, in particular, because they may operate independently in difficult ice conditions. However, the thrusters in ships with lower ice classes may also have to withstand such a situation, but at a remarkably lower ship speed.

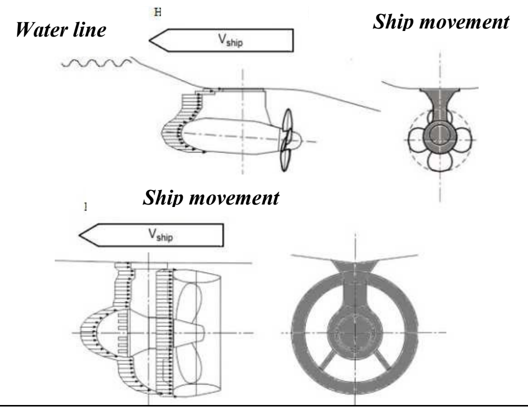
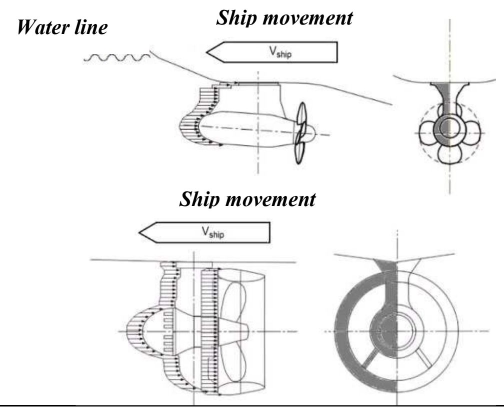
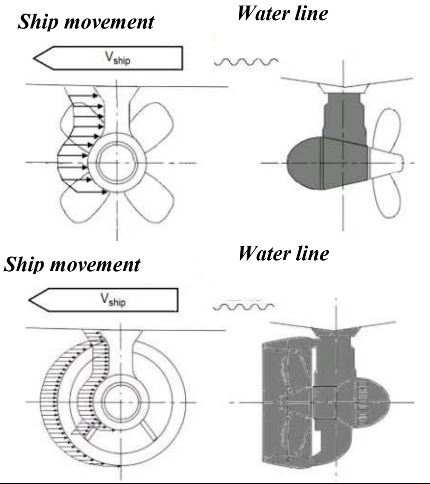
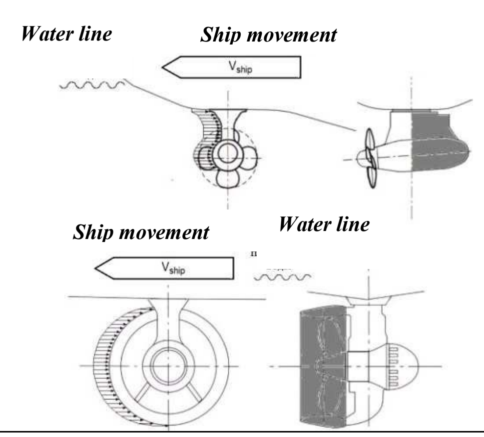
In this load scenario, the ship is penetrating a ridge in thruster first mode with an initial speed. This situation occurs when a ship with a thruster at the bow moves forward, or a ship with a thruster astern moves in backing mode. The maximum load during such an event is considered the extreme load. An event of this kind typically lasts several seconds, due to which the dynamic magnification is considered negligible and is not taken into account.

The load magnitude must be estimated for the load cases shown in Table 2.9.2.6.5.3-1, using formula (2.9.2.6.5.3).

The parameter values for calculations are given in Tables 2.9.2.6.5.3-2 and 2.9.2.6.5.3-3.

Table 2.9.2.6.5.3-1 **Load cases for ridge ice loads**

Load case	Force	Loaded area	Interaction

Load case T4a Symmetric longitudinal ridge penetration loads	F_{tr}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T4b Nonsymmetric longitudinal ridge penetration loads	50% of F_{tr}	Uniform distributed load or uniform pressure, which are applied on the other half of the contact area.	
Load case T5a Symmetric lateral ridge penetration loads for ducted azimuthing unit and pushing open propeller unit	F_{tr}	Uniform distributed load or uniform pressure, which are applied symmetrically on the contact area.	
Load case T5b Nonsymmetric lateral ridge penetration loads for all azimuthing units	50% of F_{tr}	Uniform distributed load or uniform pressure, which are applied on the other half of the contact area	

The loads must be applied as uniform distributed load or uniform pressure over the thruster surface.

The design operation speed in ice can be derived from Table 2.9.2.6.5.3-2 or Table 2.9.2.6.5.3-3. Alternatively, the actual design operation speed in ice of the ship in question can be used.

$$F_{tr}=32v_s^{0,66}\,H_r^{0,9}A_t^{0,74}, \quad \text{in kN}, \quad (2.9.2.6.5.3)$$

where:

v_s – ship speed, in m/s;

H_r – ice ridge design thickness (the thickness of the frozen ice layer is 18% of the total thickness of the ice ridge), in m;

A_t – CP design area , in m^2.

When calculating the loaded area of the CP interaction with ice ridge, the loaded area in vertical direction is restricted by the maximum ridge thickness, as is shown in Figure 2.9.2.6.5.3.

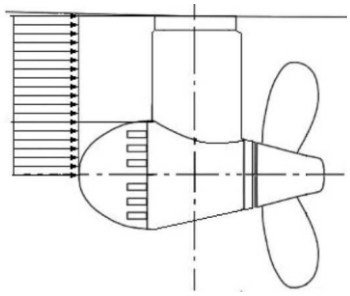


Fig. 2.9.2.6.5.3 Schematic figure showing the reduction of the contact area by the maximum ridge thickness

Table 2.9.2.6.5.3-2 **Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Aft thrusters. Bow first operation**

Baltic ice class	**IA Super**	**IA**	**IB**	**IC**
Thickness of the design ridge consolidated layer, in m	1,5	1,5	1,2	1,0
Total thickness of the design ridge *Hr*, in m	8	8	6,5	5
Initial ridge penetration speed (longitudinal loads)	4	2	2	2
Initial ridge penetration speed (transversal loads)	2	1	1	1

Таблиця 2.9.2.6.5.3-3 **Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Thruster first mode such as double acting ships.**

Baltic ice class	**IA Super**	**IA**	**IB**	**IC**
Thickness of the design ridge consolidated layer	1,5	1,5	1,2	1,0
Total thickness of the design ridge *Hr*, in m	8	8	6,5	5
Initial ridge penetration speed (longitudinal loads)	6	4	4	4
Initial ridge penetration speed (transversal loads)	3	2	2	2

2.9.2.6.5.4 Acceptability criterion for static loads.

The stresses on the thruster must be calculated for the extreme once-in-a-lifetime loads described in **2.9.2.6.5**.

The nominal von Mises stresses on the thruster body must have a safety margin of 1.3 against the yielding strength of the material. At areas of local stress concentrations, stresses must have a safety margin of 1.0 against yielding. The slewing bearing, bolt connections and other components must be able to maintain operability without incurring damage that requires repair when subject to the loads given in **2.9.2.6.5.2** and **2.9.2.6.5.3**, multiplied by a safety factor of 1.3.

2.9.2.6.5.5 Thruster body global vibration.

Evaluating the global vibratory behavior of the thruster body is important, if the first blade order excitations are in the same frequency range with the thruster global modes of vibration, which occur when the propeller rotational speeds are in the high power range of the propulsion line.

This evaluation is mandatory and it must be shown that there is either no global first blade order resonance at high operational propeller speeds (above 50% of maximum power) or that the structure is designed to withstand vibratory loads during resonance above 50% of maximum power.

When estimating thruster global natural frequencies in the longitudinal and transverse direction, the damping and added mass due to water must be taken into account. In addition to this, the effect of ship attachment stiffness must be modelled.

2.9.2.7 Alternative design procedure.

2.9.2.7.7.1 Scope.

As an alternative to **2.9.2.5** and **2.9.2.6**, a comprehensive design study may be performed to the satisfaction of the Register. The study must be based on the ice conditions given for different ice classes in

2.9.2.3. It must include both fatigue and maximum load design calculations and fulfil the pyramid strength principle, as given in **2.9.2.6.1**.

2.9.2.7.2 Loading.

Loads on the propeller blade and propulsion system shall be based on an acceptable estimation of hydrodynamic and ice loads.

2.9.2.7.3 Design levels.

The analysis must confirm that all components transmitting random (occasional) forces, excluding propeller blade, are not subjected to stress levels in excess of the yield stress of the component material, with a reasonable safety margin. Cumulative fatigue damage calculations must give a reasonable safety factor. Due account must be taken of material properties, stress raisers, and fatigue enhancements.

A vibration analysis must be performed and demonstrate that the overall dynamic system is free of the harmful torsional resonances resulting from propeller/ice interaction.

2.9.3 MISCELLANEOUS MACHINERY REQUIREMENTS.

2.9.3.1 Starting arrangements.

The capacity of the air receivers must be sufficient to provide no less than 12 consecutive starts of the propulsion engine without reloading, if it has to be reversed for moving astern, or 6 consecutive starts if the propulsion engine does not have to be reversed for moving astern.

If the air receivers serve any purposes other than starting the propulsion engine, they must have additional capacity sufficient for such purposes.

The capacity of the air compressors must be sufficient for charging the air receivers from atmospheric to full pressure in one (1) hour, except for a ship with ice class **IA Super**, if its propulsion engine has to be reversed for going astern, in which case the compressor must be able to charge the receivers in half an hour.

2.9.3.2 Sea inlet and cooling water systems.

The cooling water system shall be designed to secure the supply of cooling water when navigating in ice (refer also to **4.3.3**, Part VIII «Systems and piping»).

For this purpose, at least one cooling water inlet chest shall be arranged as follows:

.1 The sea inlet shall be situated near the centreline of the ship and well aft, if possibl;

.2 The volume of the chest shall be around one cubic metre for every 750 kW in engine output of the ship, including the output of auxiliary engines necessary for the operation of the ship;

.3 The chest shall be sufficiently high to allow ice to accumulate above the inlet pipe;

.4 A pipe for discharge cooling water, allowing full capacity discharge, shall be connected to the chest;

.5 The open area of the strainer plates shall be no less than four (4) times the inlet pipe sectional area.

If there are difficulties in meeting the requirements of **2.9.3.2.2** and **2.9.3.2.3** above, two smaller chests may be arranged for alternating the intake and discharge of cooling water. The requirements of **2.9.3.2.1**, **2.9.3.2.4** and **2.9.3.2.5** shall be met.

Heating coils may be installed in the upper part of the sea chest.

Arrangements for using ballast water for cooling purposes may be useful as a reserve in terms of ballast, but cannot be accepted as a substitute for an inlet chest as described above.

2.10 REQUIREMENTS FOR SHIPS EQUIPPED FOR USING GASES OR LOW-FLASHPOINT FUELS

2.10.1 GENERAL.

2.10.1.1 All dimensions of hull construction elements, except those specifically stipulated in this subsection, shall be determined in accordance with the requirements of Part II "Hull" depending on the purpose and design of the ship.

2.10.1.2 Definitions and explanations relating to the general terminology of this part are given in **1.2**.

For the purpose of this Chapter definitions and explanations, which are also valid for Parts VIII "Systems and piping" and IX "Machinery" havew been adopted.

Multi-fuel engine means an engine capable of using two or more different fuels that are separate from each other.

Non-hazardous atmosphere means air environment where gas concentration is lower than the level corresponding to activating an alarm on high gas concentration in the air.

Open space means a space open from one or several sides in all parts of which effective natural ventilation is arranged via permanently open openings in the side partitions and in the above located deck.

Secondary barrier means the liquid-resisting outer element of a fuel containment system designed to afford temporary containment of any envisaged leakage of liquid fuel through the primary barrier and to prevent the lowering of the temperature of the ship's structure to an unsafe level.

High pressure means maximum operating pressure over 1.0 MPa.

Gas means a fluid having a vapour pressure exceeding 0,28 MPa absolute at a temperature of 37,8 °C.

Gas area means an area where gas-containing systems and equipment are located, including the weather deck spaces above them.

Gas fuel means any hydrocarbon fuel having at the temperature of 37,8 8C the absolute pressure of saturated vapours according to Reid equal to 0,28 MPa and above.

Gas-safe machinery space means closed gas-safe space with gas fuel consumers, explosion safety of which is ensured by installation of gas-containing equipment in gastight enclosures (piping, ducting, partitions) for gas fuel bleed-off, and the inner space of partitions and ducting shall be considered gas-dangerous.

Gas-safe space means a space other than a gas-dangerous space.

Gas-dangerous space means a space in the gas area which is not equipped with approved device to ensure that its atmosphere is at all times maintained in a gas-safe condition. It is subdivided into explosion hazardous zones 0, 1, 2 the boundaries of which are specified in **19.12** Part XI «Electrical Equipment».

Gas-dangerous machinery space means enclosed gas-dangerous space with gas fuel consumers, explosion safety of which in case of gas fuel leakage is ensured by emergency shutdown (ESD) of all machinery and equipment which may be an ignition source.

Gas-containing systems mean systems intended for storage, feed, supply and discharge of gas to ship consumers.

Gas engine means an engine capable of operating only on gas, and not able to switch over to operation on any other type of fuel.

Dual fuel engine means a heat engine so designed that both gas and fuel oil may be used as fuel, simultaneously or separately.

Source of release means a point or location from which a gas, vapour, mist or liquid may be released into the atmosphere so that an explosive atmosphere could be formed.

Master gas fuel valve means an automatic valve installed at gas supply pipeline to each engine located outside machinery space where the equipment for gas fuel combustion is used.

Fuel storage tank means a tank designed as an initial gas fuel tank for storage on board the ship in liquid or compressed gaseous form.

CNG tank means compressed gas fuel storage tank.

LNG tank means liquefied gas fuel storage tank.

A , B and C type tanks mean independent fuel storage tanks complying with the requirements for A, B and C type independent tanks specified in the IGF Code.

ESD (*ESD/emergency shutdown*) – система аварійного відключення, завданням якої є зупинка потоку або витоку вантажу в надзвичайній ситуації, коли здійснюється передача рідкого вантажу або пари.

Enclosed space means any space inside of which, in the absence of mechanical ventilation, natural ventilation is restricted in such a way that any explosive atmosphere is not subject to natural dispersion.

Double block and bleed valve means a set of two valves in series in a pipe and a third valve enabling the pressure release from the pipe between those two valves. The arrangement may also consist of a two-way valve and a closing valve instead of three separate valves.

LNG means liquefied natural gas, consisting mainly of methane.

LPG eans liquefied petroleum gas consisting mainly of hydrocarbons (mixtures of propane and butane in any combination), which may contain small amounts of other components, such as hydrogen sulfide or alkyl lead.

CNG means compressed natural gas, consisting mainly of methane.

PRV/Pressure relief valve means pressure relief valve.

MARVS means maximum allowable releife valve setting of the cargo tank.

MAWP means the maximum allowable working pressure.

Filling Limit (Fl) means the maximum liquid volume in a fuel tank relative to the total tank volume when the liquid fuel has reached the reference temperature.

Membrane tanks are non-self-supporting tanks that consist of a thin liquid and gas tight layer (membrane) supported through insulation by the adjacent hull structure.

Semi-enclosed space means a space restricted by decks and bulkheads where natural ventilation is available but its efficiency sufficiently differs from normal at the weather deck.

Hazardous area means an area in which an explosive gas atmosphere or a flammable gas is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of electrical apparatus.

Unacceptable loss of power means that it is not possible to sustain or restore normal operation of the propulsion machinery in the event of one of the essential auxiliaries becoming inoperative, in accordance with SOLAS regulation II-1/26.3.

Low-flashpoint fuel - gaseous or liquid fuel with a flash point lower than otherwise permitted by 2.1.1 Reg II-2/4 SOLAS 74 , as amended.

Gas fuel storage room means a room where gas fuel storage tanks are located.

Tank connection space means a space surrounding all tank connections and tank valves that is required for tanks with such connections in enclosed spaces.

Fuel preparation room means any space containing pumps, compressors or vaporizers for fuel preparation purposes.

Fuel oil means liquid hydrocarbon petroleum-derived fuel which complies with the requirements specified in **1.1.2**.

Design temperature for selection of materials s the minimum temperature at which liquefied gas fuel may be loaded or transported in the liquefied gas fuel tanks.

Vapour pressure means the equilibrium pressure of the saturated vapour above the liquid, in MPa, absolute at a specified temperature.

Fuel containment system means the arrangement for the storage of fuel including tank connection spaces.

The fuel containment system includes a primary and, where fitted, a secondary barriers, associated insulation and any intervening spaces, and adjacent structures, if necessary for the support of these elements. If the secondary barrier is part of the hull structure, it may be a boundary of the fuel storage hold space.

The spaces around the fuel tank are defined as follows:

.1 fuel storage hold space means a space enclosed by the ship's structures in which a fuel containment system is situated. If tank connection spaces are located in the fuel storage hold space, it will also be a tank connection space;

.2 interbarrier space means the space between a primary and a secondary barrier, whether or not completely or partially occupied by insulation or other material; and

.3 fuel storage tank connection space means a space surrounding all fuel storage tank connections and tank valves that are required for such tanks in enclosed spaces.

Gas consumer means any ship equipment using gas as a fuel.

Vapour pressure means the equilibrium pressure of the saturated vapour above the liquid, in MPa, absolute at a specified temperature.

Reference temperature means the temperature corresponding to the vapour pressure of the fuel in a fuel tank at the set pressure of the pressure relief valves (PRVs).

2.10.2 Onboard location of fuel storage tanks.

2.10.2.1 Fuel storage tanks both in liquefied (LNG) and compressed (CNG) condition may be located directly on the open deck of the ship or in special enclosed spaces in the ship's hull.

In the enclosed spaces, liquefied gas fuel shall be stored at the pressure not exceeding 1 MPa.

Where a fuel storage tank is located on the weather deck or in a special enclosure designed as a semienclosed space, provision shall be made for sufficient natural ventilation to prevent accumulation of escaped gas.

Membranes ensuring a seal between a deck and fuel storage tank shall be provided where the fuel storage tank gets through the upper weather deck. Therewith, the space located below the membranes may be considered as an enclosed gas-dangerous space, and the space above the membranes may be considered as an open space.

Gas fuel storage tanks shall not be installed under the survival craft except for the liferafts in compliance with Regulation III/31 of the International Convention for the Safety of Life at Sea, 1974 with further amendments.

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2.10.2.2 Fuel storage tanks shall be protected against mechanical damage.

When fuel is carried in a fuel containment system requiring a complete or partial secondary barrier:

.1 fuel storage hold spaces shall be segregated from the sea by a double bottom/inner bottom; and

.2 ship shall have longitudinal bulkheads forming side tanks.

2.10.2.3 The fuel storage tanks shall be protected from external damage caused by collision or grounding in the following way:

.1 fuel tanks shall be located at a minimum distance of B/5 or 11,5 m, whichever is less, measured inboard from the ship side at right angles to the centreline at the level of the summer load line draught. where *B* = the greatest moulded breadth of the ship at the summer load line draught) (refer to SOLAS regulation II-1/2.8). As an alternative, the calculation method specified in **5.3.4** of the IGF Code may be used to determine the acceptable location of fuel tanks;

.2 boundaries of each fuel tank shall be taken as the extreme outer longitudinal, transverse and vertical limits of the tank structure including its valves;

.3 for independent tanks the protective distance shall be measured to the tank shell (the primary barrier of the tank containment system). For membrane tanks, such distance shall be measured to the bulkheads surrounding the tank insulation;

.4 in no case shall the boundary of the fuel tank be located closer to the shell plating or aft terminal of the ship than as follows:

.4.1 for passenger ships: *B*/10 but in no case less than 0,8 m. However, this distance shall not be greater than *B*/15 or 2 m, whichever is less, where the shell plating is located inboard for *B*/5 or 11,5 m, whichever is less, as specified in **2.10.3.1**;

.4.2 for cargo ship:

.4.2.1 for $V_c \leq 1000$ m^3- 0,8 m;

.4.2.2 for 1000м^3 < V_c < 5000 m^3- 0,75 + $V_c \times 0{,}2/4000$ m;

.4.2.3 for 5000м^3 ≤ V_c < 30000 m^3- 0,8 + V_c /25000 m; and

.4.2.4 for $V_c \geq 30000$ m^3 - 2 m,

where: V_c corresponds to 100 % of the gross design volume of the individual fuel storage tank at 20°C, including domes and appendages;

.4.5 the lowermost boundary of the fuel storage tank shall be located above the minimum distance of B/15 or 2,0 m, whichever is less, measured from the moulded line of the bottom shell plating at the centreline;

.4.6 for multi-hull ships, the value *B* may be specially considered;

.4.7 fuel storage tanks shall be located abaft a transverse plane at 0,08L measured from the forward perpendicular in accordance with SOLAS regulation II-1/8.1 for passenger ships, and abaft the collision bulkhead for cargo ships.

where: *L* - length as defined in the International Convention on Load Lines (refer to SOLAS regulation II-1/2.5).

2.10.3 Drip trays.

2.10.3.1 Drip trays for spilled liquefied gas shall be fitted where liquefied gas leakage may occur which can cause damage to the ship structure or where limitation of the area, which is effected from a spill, is necessary.

Drip trays for collection of leaks are necessary in the following cases:

.1 when the tank is located on the open deck, drip trays shall be provided to protect the deck from leakages from tank connections and other sources of leakage;

.2 when the tank is located below the open deck but the tank connections are on the open deck, drip trays shall be provided to protect the deck from leakages from tank connections and other sources of leakage;

.3 when the tank and the tank connections are located below the deck, all tank connections shall be located in a tank connection space. Drip trays in this case are not required.

2.10.3.2 Drip trays shall be made of suitable material.

2.10.3.3 The drip tray shall be thermally insulated from the ship's structure so that the surrounding hull or deck structures are not exposed to unacceptable cooling, in case of leakage of liquid fuel.

2.10.3.4 Each drip tray shall be fitted with a drain valve to enable rain water to be discharged overboard.

2.10.3.5 Each drip tray shall have sufficient capacity to ensure that the maximum amount of spill according to the risk assessment can be handled.

2.10.4 Machinery spaces.

2.10.4.1 In order to minimize the probability of gas explosion in a machinery space containing gasfuelled machinery one of the following two alternatives of machinery space arrangement may be applied:

.1 **gas-safe machinery spaces**: arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as unplanned conditions, i.e. inherently gas safe. In a gas-safe machinery space a single failure cannot lead to release of fuel gas into the machinery space;

.2 ESD protected machinery spaces: arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery shall be automatically executed while equipment or machinery in use or active during these conditions shall be of a certified safe type and have relevant certificates.

In an ESD protected machinery space, a single failure resulting in gas release into the space is allowable provided that the gas is removed by venting.

Failures leading to dangerous gas concentrations, e.g. gas pipe or gasket ruptures are covered by explosion pressure relief devices and ESD arrangements.

2.10.4.2 Requirements for gas-safe machinery spaces.

.1 single failure within the fuel system shall not lead to gas release into the machinery space;

.2 all gas piping within machinery space boundaries shall be enclosed in a gas tight enclosure.

2.10.4.3 Requirements for ESD protected machinery spaces.

.1 ESD protection shall be limited to machinery spaces that are intended for periodically unmanned operation.

.2 measures shall be applied to protect against explosion and damage of areas outside the machinery space and ensure redundancy of power supply.

At least the following measures and arrangements shall be provided:

gas detector;

shut-off valve;

redundancy;

efficient ventilation.

2.10.4.4 Gas supply piping without a gastight external enclosure within machinery spaces may be accepted under the following conditions:

.1 engines for generating propulsion power and electric power shall be located in two or more machinery spaces not having any common boundaries unless it can be documented that a single failure will not affect both spaces;

.2 gas machinery space shall contain only a minimum of such necessary equipment, components and systems as are required to ensure that the gas machinery maintains its function;

.3 fixed gas detection system arranged to automatically shutdown the gas supply, and disconnect all electrical equipment or installations not of a certified safe type, shall be fitted.

2.10.4.5 Distribution of engines between the different machinery spaces shall be such that shutdown of fuel supply to any one machinery space does not lead to an unacceptable loss of power.

2.10.4.6 ESD protected machinery spaces separated by a single adjacent bulkhead shall have sufficient strength to withstand the effects of local gas explosion in either space, without affecting the integrity of the adjacent space and equipment within that space.

2.10.4.7 ESD protected machinery spaces shall have a geometrical shape that will minimize the accumulation of gases or formation of gas pockets.

2.10.4.8 The ventilation system of ESD protected machinery spaces shall be arranged in accordance with **12.14**, Part VIII «Systems and piping».

2.10.4.9 Requirements for location and protection of fuel piping:

.1 fuel piping shall not be located less than 800 mm from the ship's side;

.2 fuel piping shall not pass directly through accommodation spaces, service spaces, electrical equipment rooms or control stations;

.3 fuel piping passing through ro-ro cargo spaces, special category spaces and on weather decks shall be protected against mechanical damage.

.4 gas fuel piping in ESD protected machinery spaces shall be located, as far as practicable, from the electrical installations and tanks containing flammable liquid.

2.10.4.10 Gas fuel piping in ESD protected machinery spaces shall be protected against mechanical damage.

2.10.4.11 Requirements for fuel preparation room design. Fuel preparation rooms shall be located on the open deck or within an open space unless those rooms are arranged and fitted in accordance with the requirements for tank connection spaces.

In such case, regardless of the room location the following requirements shall be complied with:

.1 fuel preparation room, regardless of location, shall be arranged to safely contain cryogenic leakages;

.2 material of the boundaries of the fuel preparation room shall have a design temperature corresponding with the lowest temperature it can be subjected to in a probable maximum leakage scenario unless the structures forming the boundaries of the space, i.e. bulkheads and decks, are provided with suitable thermal protection;

.3 a fuel preparation room shall be arranged to prevent surrounding hull structure from being exposed to unacceptable cooling, in case of leakage of cryogenic liquids;

.4 a fuel preparation room shall be designed to withstand the maximum pressure build up during such a leakage.

Alternatively, pressure relief venting to a safe location (mast) may be provided.

2.10.5 Requirements for bilge systems.

2.10.5.1 Bilge systems installed in areas where gas or other low-flashpoint fuels may be present shall comply woth the requirements of **7.15**, Part VIII «Systems and piping».

2.10.6 Requirements for arrangement of entrances and other openings in enclosed spaces.

2.10.6.1 Direct access shall not be permitted from a gas-safe area to a gas-dangerous area. Where such openings are necessary for operational reasons, an airlock, which complies with **2.10.7**, shall be provided.

2.10.6.2 If a fuel preparation room is approved to be located below deck, the room shall, as far as practicable, have an independent access directly from the open deck. Where a separate access from deck is not practicable, an airlock, which complies with the requirements of **2.10.7**, shall be provided.

2.10.6.3 Unless access to the tank connection space is independent and directly from the open deck, it shall be arranged as a bolted hatch. The space containing the bolted hatch is a hazardous space.

2.10.6.4 If access to an ESD protected machinery space is from another enclosed space of the ship, the entrances shall be arranged with an airlock, which complies with the requirements of **2.10.7**.

2.10.6.5 For inerted spaces, access arrangements shall be such that unintended entry by personnel shall be prevented. If access to such spaces is not from the open deck, sealing arrangements shall prevent leakages of inert gas to adjacent spaces.

2.10.7 Requirements for airlocks.

2.10.7.1 An airlock is a space enclosed by gastight bulkheads with two substantially gastight doors spaced at least 1,5 m and not more than 2,5 m apart.

Unless subject to the requirements of the International Convention on Load Lines, the door coaming shall not be less than 300 mm in height. The doors shall be self-closing without any holding back arrangements.

2.10.7.2 Airlocks shall be mechanically ventilated at overpressure relative to the adjacent hazardous area or space.

2.10.7.3 The airlock shall be designed in a way that no gas can be released to safe spaces in case of the most critical event in the gas-dangerous space separated by the airlock. The events shall be evaluated in the risk analysis according to **4.2.2.15**, Part I «Classification».

2.10.7.4 Airlocks shall have a simple geometrical form. They shall provide free and easy passage, and shall have a deck area not less than 1,5 m^2.

Airlocks shall not be used for other purposes, e.g. as store rooms.

2.10.7.5 An audible and visual alarm system to give a warning on both sides of the airlock shall be provided to indicate if more than one door is moved from the closed position.

2.10.7.6 For gas-safe spaces with access from hazardous spaces below deck where the access is protected by an airlock, upon loss of underpressure in the hazardous space access to the space shall be restricted until the ventilation is reinstated.

Audible and visual alarms shall be given at a manned location to indicate both loss of pressure and opening of the airlock doors when pressure is lost.

2.10.7.7 Essential equipment required for safety shall not be de-energized and shall be of a certified safe type. This may include lighting, fire detection, public address and general alarms systems.

2.10.8 Crew protection.

2.10.8.1 At least two sets of protective outfit, which ensures the safety of personnel when entering and working in spaces filled with natural gas, shall be provided on ships with gas containment system equipment installed in enclosed spaces of the hull.

2.10.8.2 Protective outfit, specified in **2.10.8.1**, shall include:

.1 air-breathing isolating apparatus with cylinders with a capacity of at least 1200l of free air;

.2 tightly fitted safety goggles, gloves, protective clothing and footwear made of spark-proof materials;

.3 steel core rescue line with intrinsically safe braid;

.4 explosion prof torch.

2.10.8.3 Breathing apparatus, specified in **2.10.8.2.1**, shall be fitted with filled air cylinders with a total capacity of at least 3600 liters of free air for each device.

2.10.8.4 The ship shall be provided with medicines and medical devices needed to provide first aid to victims of burns, frostbite (including cryogenic) and poisoning by natural gas or incomplete combustion products.

2.10.8.5 The ship shall be provided with the following operating documentation:

.1 instructions for gas fuel bunkering;

.2 instructions for inertization and degassing;

.3 instructions for the use of gaseous fuels;

.4 instructions describing the actions of the crew in emergencies that may occur during gas fuel operations.

2.10.8.6 The ship shall be provided with athe plan for periodic verifications and maintenance of equipment related to the use of gas as a fuel.

2.10.9 Design of gas fuel tanks.

2.10.9.1 General requirements for gas fuel storage.

2.10.9.1.1 Natural gas in a liquid state may be stored with a maximum allowable relief valve setting (MARVS) of up to 1,0 MPa.

2.10.9.1.2 The maximum allowable working pressure (MAWP) of the gas fuel tank shall not exceed 90 % of the maximum allowable relief valve setting (MARVS).

2.10.9.1.3 A fuel containment system located below deck shall be gastight towards adjacent spaces.

2.10.9.1.4 All tank connections, fittings, flanges and tank valves shall be enclosed in gastight tank connection spaces, unless the tank connections are on the open deck.

The space shall be able to contain leakage from the tank without overpressure in case of leakage from the tank connections.

A tank connection space may be required also for tanks on open deck for ships where restriction of hazardous areas is safety critical. A tank connection space may also be necessary in order to provide environmental protection for essential safety equipment related to the gas fuel system (tank valves, safety valves and instrumentation).

A tank connection space may also contain equipment such as vaporizers or heat exchangers. Such equipment is considered to only contain potential sources of release, but not sources of ignition. In such case, such a tank connection space shall not be considered as a fuel preparation room.

2.10.9.1.5 Pipe connections to the fuel storage tank shall be mounted above the highest liquid level in the tanks, except for fuel storage tanks of type C. Connections below the highest liquid level may, however, also be accepted for other tank types after special consideration.

2.10.9.1.6 Each gas fuel storage tank (LNG or CNG) shall be equipped with a remote operated isolation shutoff valve located at any piping connected to the tank or directly on the tank. A branch pipe between the tank and the isolation valve which release LNG in case of pipe failure shall have equivalent safety to the type C tank, with permissible stress not exceeding the least of values $R_m/2,5$ or $R_e/1,2$, where R_e is a minimum yield stress at room temperature, and R_m is a minimum tensile strength at room temperature.

2.10.9.1.7 The material of the structures of the tank connection space shall have a design temperature corresponding to the lowest temperature that can be subject to in a probable maximum leakage scenario. The tank connection space shall be designed to withstand the maximum pressure build up during such a leakage. Alternatively, pressure relief venting to a safe location (mast) may be provided.

2.10.9.1.8 The probable maximum leakage into the tank connection space shall be determined based on design calculations using the operating parameters of detection and shutdown systems.

2.10.9.1.9 If connected below the liquid level of the tank, piping shall be protected by a secondary barrier up to the first valve.

2.10.9.1.10 If LNG tanks are located on the open deck, steel structures shall be protected against potential leakages from tank connections and other sources of leakage by use of drip trays.

The material shall have a design temperature corresponding to the temperature of fuel carried at atmospheric pressure.

The normal operation pressure of tanks shall be taken into consideration for protecting the steel structures of the ship.

2.10.9.1.11 Means shall be provided to safely empty liquefied gas storage tanks.

2.10.9.1.12 It shall be possible to empty, purge and vent fuel storage tanks with fuel piping systems. Instructions for carrying out these procedures shall be available on board.

Inerting shall be performed with inert gas prior to venting with dry air to avoid an explosion hazardous atmosphere in tanks and fuel pipelines. Requirements to the inerting system are specified in **12.15**, Part VIII «Systems and piping».

2.10.9.1.13 For single fuel (gas only) main engines at least two gas fuel storage tanks of approximately equal capacity shall be provided and they shall be located in separate spaces.

2.10.9.1.14 All fuel storage tanks shall be provided with a pressure relief system appropriate to the design of the fuel containment system and the fuel being carried.

Fuel storage hold spaces, interbarrier spaces, tank connection spaces and tank cofferdams, which may be subject to pressures beyond their design capabilities, shall also be provided with a suitable pressure relief system.

Pressure relief system shall be independent of the pressure control systems specified in **2.10.10**.

2.10.9.2 Liquefied gas storage tanks (LNG tanks).

2.10.9.2.1 LNG tanks shall be designed in compliance with the requirements of Section **6.4** of the IGF Code and manufactured by the firms having a Recognition Certificate for Manufacturer.

2.10.9.2.2 All LNG tanks shall be fitted with safety valves in compliance with the requirements specified in **6.7** of the IGF Code.

2.10.9.2.3 The outlets of vent pipes from the pressure relief valves shall be located at least $B/3$ or 6 m, whichever is greater, above the weather deck and 6 m above the working area and forward and aft gangways.

Gas outlet piping system shall be designed so that the outgoing gas shall be directed upwards and the possibility of water and snow ingress into the system shall be kept to minimum.

2.10.9.2.4 All gas outlets shall be located at a distance of at least 10 m from:

the nearest air inlet or openings in the accommodation and service spaces and control stations or from other gas-safe spaces;

outlets in the machinery space.

2.10.9.2.5 LNG tanks shall be provided with the pressure control system specified in **2.10.10**.

2.10.9.3 Compressed gas storage tanks (CNG tanks).

2.10.9.3.1 CNG tanks shall be designed in compliance with the requirements of Part X "Boilers, Heat Exchangers and Pressure Vessels" or other applicable standards for design of gas storage pressure vessels agreed upon with the Administration.

Standard cylinders, for which it is necessary to make calculation of permitted pressure, and specially designed pressure vessels may be used as CNG tanks.

2.10.9.3.2 Each compressed gas storage tank shall be equipped with safety valves with cracking pressure less than design pressure of the tank.

Safety valves of CNG tanks located in the hull or on the open deck shall be connected with gas outlet pipes.

The outlets of vent pipes from the pressure relief valves shall comply with requirements specified in **2.10.9.2.3** and **2.10.9.2.4**.

2.10.9.3.3 Adequate means shall be provided to depressurize the tank in case of fire, which can affect the tank.

2.10.9.3.4 Storage of CNG in enclosed spaces is generally not acceptable, but may be permitted provided the following is fulfilled in addition to **2.10.9.1.4** and **2.10.9.1.6**:

.1 adequate means are provided to depressurize and inert the tank in case of fire which can affect the tank;

.2 all surfaces within such enclosed spaces containing the CNG storage are provided with suitable thermal protection against any high-pressure gas leakages and resulting condensation unless the bulkheads are designed for the lowest temperature that can arise from gas expansion leakage; and

.3 a fixed fire-extinguishing system is installed in the enclosed spaces containing the CNG storage. In addition, special arrangements for extinguishing of jet-fires shall be provided.

2.10.9.3.5 CNG tanks shall be secured on the hull in a manner which will prevent their movement under static or dynamic loads. Tanks with supports shall be designed for a static angle of heel of 30°. The supports and fittings shall be designed with due regard to loads determined in accordance with **6.4.9.4** of the IGF Code.

2.10.9.4 Regulations for portable liquefied gas fuel tanks.

2.10.9.4.1 The design of the tank shall comply with the requirements of IGF Code for type C independent tanks. The tank support (container frame or truck chassis) shall be designed for the intended purpose.

2.10.9.4.2 Portable fuel tanks shall be located in dedicated areas fitted with:

.1 mechanical protection of the tanks depending on location and damage hazard during cargo operations;

.2 if located on open deck: spill protection and water spray and cooling systems; and

.3 if located in an enclosed space: the space shall be considered as a tank connection space.

2.10.9.4.3 Portable fuel tanks shall be secured to the deck when connected to the ship systems.

The arrangement for supporting and fixing the tanks shall be designed for the maximum expected static and dynamic inclinations, as well as the maximum expected values of acceleration, taking into account the ship characteristics and the position of the tanks.

2.10.9.4.4 Consideration shall be given to the strength and the effect of the portable fuel tanks on the ship's stability.

2.10.9.4.5 Connections to the ship's fuel piping systems shall be made by means of approved flexible hoses or other suitable means designed to provide sufficient flexibility.

2.10.9.4.6 Arrangements shall be provided to limit the quantity of fuel spilled in case of inadvertent disconnection or rupture of the non-permanent connections.

2.10.9.4.7 The pressure relief system of portable tanks shall be connected to a fixed venting system.

2.10.9.4.8 Control and monitoring systems for portable fuel tanks shall be integrated in the ship's control and monitoring system.

A safety system for portable fuel tanks shall be integrated in the ship's safety system (e.g. shutdown systems for tank valves, gas detection systems).

2.10.9.4.9 Safe access to tank connections for the purpose of inspection and maintenance shall be ensured.

2.10.10 Stored fuel pressure and temperature control system.

2.10.10.1 With the exception of liquefied gas fuel tanks designed to withstand the full gauge vapour pressure of the fuel under conditions of the upper ambient design temperature, liquefied gas fuel tanks' pressure and temperature shall be maintained at all times within their design range by one of the following methods:

.1 reliquefaction of vapours;

.2 thermal oxidation of vapours;

.3 pressure accumulation;

.4 liquefied gas fuel cooling.

The method chosen shall ensure maintaining tank pressure below the set pressure of the tank pressure relief valves for a period of 15 days assuming the full tank at normal service pressure and the ship in nonworking condition, i.e. only power for domestic load is generated.

2.10.10.2 The overall capacity of the system shall be such that it can control the pressure within the design conditions without venting to atmosphere. The system shall be sized in a sufficient way also in case of no or low consumption. Venting of fuel vapour for controlling the tank pressure is not acceptable except in emergencies.

LNG tanks' pressure and temperature shall be controlled and maintained within the design range at all times including after activation of the safety system required in **7.23.3** Part XI «Electrical Equipment» for a period of minimum 15 days.

The activation of the safety system alone is not deemed as an emergency situation.

2.10.10.3 For worldwide service, the upper ambient design temperature shall be 32°C for sea water and 45°C for air.

For service in particularly hot or cold zones, these design temperatures shall be increased or decreased as agreed upon with the Register.

2.10.10.4 The reliquefaction system shall be designed and calculated in one of the following ways:

.1 a direct system where evaporated fuel is compressed, condensed and returned to the fuel tanks;

.2 an indirect system where fuel or evaporated fuel is cooled or condensed by refrigerant without being compressed;

.3 a combined system where evaporated fuel is compressed and condensed in a fuel/refrigerant heat exchanger and returned to the fuel tanks; or

.4 if the reliquefaction system produces a waste stream containing methane during pressure control operations within the design conditions, these waste gases shall, as far as reasonably practicable, be disposed of without venting to atmosphere.

2.10.10.5 Thermal oxidation can be done by either consumption of the vapours according to the regulations for consumers specified in**2.10.10**, or in a dedicated gas combustion unit (GCU).

It shall be demonstrated that the capacity of the oxidation system is sufficient to consume the required quantity of vapours. In this regard, periods of slow steaming and no consumption from propulsion plant or other consumers of the ship shall be considered.

2.10.10.6 Refrigerants or auxiliary agents used for cooling of fuel shall be compatible with the fuel they may come in contact with (not causing any hazardous reaction or excessively corrosive products). In addition, when several refrigerants or agents are used, these shall be compatible with each other.

2.10.10.7 The redundancy of the system and its supporting auxiliary services shall be such that in case of a single failure (of mechanical non-static component or a component of the control system) the fuel tank pressure and temperature can be maintained by another system or service.

2.10.10.8 Heat exchangers that are necessary for maintaining the pressure and temperature of the fuel tanks within their design ranges shall have redundancy unless they have a capacity in excess of 25 % of the largest required capacity for pressure control and they can be repaired on board without external sources.

2.11 REQUIREMENTS FOR SHIP EQUIPMENT TO ENSURE LONG-TERM OPERATION AT LOW TEMPERATURE

2.11.1 Application.

2.11.1.1 The requirements of this Section apply to the main propulsion plants, responsible emergency and auxiliary machinery and systems ensuring safety of the crew and the ship intended for long-term operation at low temperatures.

For ships complying with the requirements of this Section a distinguishing mark **WINTERIZATION(DAT)** may be added to the character of classification at the shipowner's request. Design ambient temperature shall be indicated in brackets, for example: **WINTERIZATION(-40)** (refer to **2.2.30**, Part I «Classification»).

2.11.1.2 Definitions and explanations related to the general terminology of this part are given **1.2**.

For the purpose of this Section the following definitions, explanations and abbreviations have been adopted, which are also valid for Parts VIII «Systems and Piping» and IX «Machinery».

Open space is a space with a direct access to the open deck which is not fitted with closure or shall be kept open for long periods as regards operational conditions of equipment installed in this space.

Enclosed space is a space with a direct access to the open deck which is fitted with an appropriate closure.

Working liquids mean fuel and lubricating materials, and hydraulic oils, except for marine fuel, necessary for normal operation of a ship and its equipment.

Design ambient temperature (DAT) is the outside air temperature, in °C, used as the criterion for selection and testing of materials and equipment subject to low temperatures.

Design temperature of the structure is the temperature, in °C, assumed for choosing of construction material. When the Rules or this Section contain no additional provisions, the design ambient temperature is assumed as a design temperature of the structure.

2.11.1.3 Design temperatures.

.1 Design ambient temperature value is established by the shipowner according to the ship purpose and service conditions.

.2 The following standard values of design ambient temperature are stipulated by this Section:

-30°C (the distinguishing mark **WINTERIZATION(-30)**);

- 40°C (the distinguishing mark **WINTERIZATION(-40)**);

-50°C (the distinguishing mark **WINTERIZATION(-50)**).

Application of this requirements for design ambient temperatures above -30°C and intermediate values shall be determined by the Register upon agreement with the shipowner.

.3 Design ambient temperature shall not be assumed above the temperature specified in 1.2.3.3 of Part II "Hull" for the appropriate ice class.

.4 For equipment and machinery installed on the open decks, as well as in the open spaces, the design ambient temperature shall be assumed as design temperature of structures.

For equipment and machinery installed in unheated enclosed spaces exposed to the environment and adjoining unheated adjacent enclosed spaces the design ambient temperature shall be assumed as the design temperature.

For equipment and machinery installed in unheated enclosed spaces exposed to the environment and adjoining heated adjacent enclosed spaces the temperature of 20°C above the design ambient temperature shall be assumed as the design temperature of structure.

2.11.2 Machinery installations.

2.11.2.1 Propulsion plants of ice class ships with distinguishing marks **WINTERI-ZATION(-30)**, **WINTERIZATION(-40)** and **WINTERIZATION(-50)** shall be capable of maintaining rated power and required rated torque at propeller shafts in a range of rotation speed corresponding to the appropriate operating conditions and modes in accordance with the assigned ice class.

2.11.2.2 Means shall be provided to ensure that machinery may be brought into operation from the dead ship condition without external aid, as well as storage and supply of fuel to the emergency diesel-generator with pour point temperature being 5°C lower than design ambient temperature indicated in brackets of the distinguishing mark **WINTERIZATION(DAT)**.

As an alternative, self-contained portable arrangements may be provided on board to ensure that machinery may be brought into operation from the dead ship condition.

2.11.2.3 Based on their design, the machinery, shafting, boilers and other pressure vessels, as well as pipelines of systems and fittings, shall remain operative during the ship stay at design ambient temperature.

2.11.2.4 Onboard the ships with distinguishing marks **WINTERIZATION(-40)** and **WINTERIZATION(-50)** air supply to main engines shall not lead to overcooling of machinery space.

Technical means shall be provided to exclude increase of mechanical load on cylinders and pistons and bearings of main engines due to the harmful effect of reduced temperatures of scavenging air.

2.11.2.5 When environmentally hazardous refrigerants are used, the sterntube seals shall be so designed as to prevent leakage out of the seal housing when operated within the specified modes. Permissible leakage of non-toxic and biologically neutral refrigerants are not considered as pollution from ships.

2.11.2.6 Technical means shall be provided for complete shaft line turning during the ship stay in close floating ice.

2.11.2.7 In general, at least two auxiliary boilers shall be provided onboard the ships with distinguishing marks **WINTERIZATION(-40)** and **WINTERIZATION(-50)**.

2.11.2.8 In general, steel four-bladed propellers with detachable blades shall be used.

2.11.2.9 Ships shall be provided with technical means for replacing defective blades afloat.

3. CONTROL DEVICES AND STATIONS. MEANS OF COMMUNICATION

3.1 CONTROL DEVICES

3.1.1 Main and auxiliary machinery essential for the propulsion, control and safety of the ship shall be provided with effective means for its operation and control.

control systems essential for the propulsion, control and safety of the ship shall be independent or so designed that failure of one of them does not degrade the performance of another.

3.1.2 The starting and reversing arrangements shall be so designed and placed that each engine can be started or reversed by one operator.

3.1.3 Proper working direction of control handles or handwheels shall be clearly indicated by arrows and relevant inscriptions.

3.1.4 The setting of manoeuvring handle in the direction from, or to the right of, the operator, or turning the handwheel clockwise, when controlling the main engines from the navigation bridge, shall correspond to the ahead speed direction of the ship.

In the case of control stations, from which only the stern is visible, such a setting shall correspond to the direction of astern speed of the ship.

3.1.5 Control arrangements shall be so designed as to eliminate the possibility of spontaneously changing the positions prescribed..

3.1.6 The control devices of main engines shall have an interlocking system to preclude starting of the main engine, with a mechanical shaft-turning gear engaged.

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

3.1.8 The main engine remote control system, with control from the bridge, shall be designed so as to provide an alarm in the event of failure.

As far as practicable, the present propeller speed and thrust direction shall remain unchanged until control is transferred to a local station.

Among other factors, the loss of power supply (electric, pneumatic or hydraulic power) shall not substantially affect the power of main engines or change the direction of propeller rotation.

3.1.9 The propulsion machinery remote control system with control from the wheel house shall be independent from the other order transmission system; however, one manoeuvring handle for systems may be accepted.

3.1.10 It shall be possible to control the propulsion machinery from the local control station, in the event of a failure of any unit of the remote control system.

3.1.11 For ships of river-sea navigation the duration of reversing (a period of time from the reversing of a steering control to the beginning of propeller operation with a thrust opposite in direction) shall not exceed:

25 s at full speed;

15 s at slow speed;

depending on the ship's speed.

3.1.12 Operation of auxiliary machinery required for the movement and safety of the ship, by means located on/or near such machinery shall be provided.

3.2 CONTROL STATIONS

3.2.1 The bridge control stations of main engines and propellers, as well as the main machinery control room, with any type of remote control, shall be equipped with:

.1 controls for the operation of main engines and propellers.

For installations comprising CP-propellers, vertical axis and similar type propellers, the navigation bridge may be equipped with means for remote control of propellers only. In such case, the alarm for low pressure of starting air, prescribed by 3.2.1.10, need not be provided;

.2 shaft speed and direction indicators if a fixed pitch propeller is installed; shaft speed and blade position indicators if the controllable pitch propeller is installed; main engines speed indicator if the disengaging coupling is provided;

.3 indicating means to show that the main machinery and remote control systems are ready for operation;

.4 indicating means to show which station is in control of the main propulsion machinery;

.5 means of communication (refer to **3.3**);

.6 main engine emergency stop device, independent of the control system. If disengaging couplings are provided for disconnection of main machinery from propellers, it is permissible that emergency shut-off of these couplings only is effected from the navigation bridge;

.7 device to override the automatic protection covering full range of parameters except those parameters which being exceeded, may result in serious damage, complete failure or explosion;

.8 indication for the override operation, alarms for activation of protection devices and the emergency stop;

.9 alarm for minimum oil pressure in pitch control system; overload alarm where the main engine operates with a CP-propeller, unless the recommendation of **6.5.3** is fulfilled;

.10 alarm for low starting air pressure, set at a level which still permits three starting attempts of reversible main engines duly prepared for operation;

.11 device to remote shut-off fuel oil supply to each engine for multi-engine installations in case where the fuel oil is supplied to all the engines from a single supply source (refer to **13.8.3.2**, Part VIII "Systems and Piping");

.12 speed repeater.

3.2.2 The control stations on the wings of navigation bridge shall be equipped with devices of waterproof construction with controlled illumination.

The control stations provided on the wings of the navigation bridge need not meet the requirements of **3.2.1.3**, **3.2.1.5**, **3.2.1.7 – 3.2.1.10**.

3.2.3 The emergency stop devices of main engine and the overrides of automatic controls shall be so constructed that inadvertent operation of such devices is not possible.

3.2.4 For the installations which consist of several main engines driving a single shafting, there shall be provided a common control station.

3.2.5 With a remote control system in use, provision shall also be made for local control stations of main machinery and propellers.

Where, however, mechnaical linkage is fitted for remote-controlling the main engine, the local control stations may be dispensed with on agreement with the Register.

3.2.6 Remote control of main machinery and propellers shall be performed only from one location.

The transfer of control between the navigation bridge and engine room shall be possible only in the engine room and the main machinery control room.

The means of transfer shall be so designed as to prevent the propelling thrust from altering significantly.

Where the control stations are arranged on the wings of navigation bridge, the remote control of the main machinery shall be possible from one control station only. Such control stations may be equipped with interconnected controls.

3.2.7 Main engines shall be remotely operated from the wheelhouse by means of a single control element per propeller. In installations with CP-propellers, systems with two control elements may be used.

3.2.8 The sequence of the main engine operation modes assigned from the wheelhouse, including reversal from the full ahead speed in case of emergency, shall be controlled with the time intervals admissible for main engines. The modes assigned shall be indicated at the main machinery control room and at the local control stations of the main machinery.

3.2.9 Main machinery control rooms of floating docks shall comprise the following equipment:

.1 controls of the pumps, including the suction and overboard discharge valves of ballast system;

.2 recording devices for heel, trim and deflection control of the dock;

.3 signals indicating the operation of pumps and the position ("open", "closed") of suction and discharge valves of the ballast system;

.4 alarms on limit values of list and trim;

.5 water level indicators of ballast compartments;

.6 dock’s communication facilities.

3.2.10 CCR shall be located as far from the machinery spaces as practicable. Onboard the tankers the CCR shall be arranged according to **2.4.9**, Part VI "Fire Protection".

Furthermore, arrangement of CCR onboard chemical tankers shall comply with the requirements of International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, 1983 with further amendments (IBC Code), and for gas carriers - the requirements of International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, 1983 with further amendments (IGC Code).

3.2.11 If CCR is provided on board the ship with assigning the distinguishing mark CCO (refer to **2.2.19**, Part I "Classification") added to the character of classification, besides compliance with the requirements of **3.2.10**, CCR shall be equipped with:

.1 means of communication according to **3.3.2**;

.2 control means of:

.2.1 cargo, stripping and ballast pumps;

.2.2 fans servicing cargo area spaces or cargo holds;

.2.3 remotely controlled valves of cargo and ballast systems;

.2.4 hydraulic system pumps (if provided);

.2.5 inert gas system;

.2.6 pumps and valves of heeling system (if provided);

.3 means for monitoring of:

.3.1 pressure in cargo manifolds;

.3.2 pressure in the manifold for vapour emission system (if provided);

.3.3 temperature in cargo and settling tanks;

.3.4 temperature and pressure of warming medium in the cargo heating system;

.3.5 actual value of ship's heel, trim and draught;

.3.6 actual value of level in the cargo and ballast tanks;

.4 larm devices on:

.4.1 fire alarm;

.4.2 exceeding of cargo temperature in cargo holds;

.4.3 high and low levels in cargo, ballast and settling tanks;

.4.4 extreme high level in cargo tanks;

.4.5 exceeding of permissible pressure in cargo manifolds of vapour emission system (80 per cent of pressure for actuating of high-velocity devices);

.4.6 exceeding the permissible fuel oil content in the discharge ballast and flushing water;

.4.7 exceeding the permissible temperature of pump casing according to **5.2.6**, Part IX "Machinery";

.4.8 increasing of gland and bearing temperature at bulkhead penetrations of pump shafts as per **4.2.5**;

.4.9 availability of cargo in segregated ballast tanks (for chemical tankers);

.4.10 increasing of level in the bilgeways of cargo pump rooms;

.4.11 parameters of inert gas system in compliance with **9.16.7.6**, Part VIII "Systems and Piping";

.4.12 status of technical aids stipulated in **3.2.10**;

.4.13 low water level in deck water seal (refer to **9.16.5**, Part VIII "Systems and Piping");

3.2.12 In ships carrying liquid gas in bulk, means for monitoring and alarm shall be additionally provided in CCR to meet the requirement of the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, 1983 with further amendments (IGC Code).

3.2.13 In ships carrying dangerous chemical cargo in bulk, the signalling shall be additionally provided in CCR to meet the requirements of International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, 1983 with further amendments (IBC Code).

3.2.14 If the main and other related machinery, including the main sources of power supply, have different degrees of automatic or remote control and are constantly supervised from the central control room, then the arrangements and controls shall be designed, fitted and installed so that the operation of the machinery was as safe and reliable as with direct control.

Particular attention shall be paid to protecting such spaces from fire and flooding.

3.3 MEANS OF COMMUNICATION

3.3.1 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 the 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 and which is fitted with a sound signal clearly audible in any part of the engine room while the machinery is at work, and distinct in tone from all other signals in the machinery space (refer also to **7.1**, Part XI "Electrical Equipment").

Appropriate means of communication shall be provided from the navigation bridge at the engine room to any other position, from which the speed or direction of thrust of the propellers may be controlled.

A single voice-communication device serving two control stations located in close proximity is permissible.

3.3.2 Two-way communication shall be provided between the engine room, auxiliary machinery spaces and boiler room. Onboard the ships equipped with CCR, two-way communication between CCR and navigation bridge, between CCR and the spaces, where cargo and ballast pumps are located, shall be additionally provided.

3.3.3 When installing a voice-communication device, measures shall be taken to ensure clear audibility, with the machinery at work.

3.3.4 Main machinery control rooms of floating docks shall have means of communication in accordance with 19.8, Part XI "Electrical Equipment".

3.3.5 In the case of ships with twin hulls, provision shall be made for voice communication between local control stations of the hulls in addition to communication between local control stations and the common control station in the wheelhouse and the main machinery control room.

4. MACHINERY SPACES, ARRANGEMENT OF MACHINERY AND EQUIPMENT

4.1 GENERAL

4.1.1 Ventilation of machinery spaces shall comply with the requirements of 12.5, Part VIII "Systems and Piping".

4.1.2 Machinery spaces with gas engines shall be fitted with gas concentration sensors and the ultimate concentration level alarm system (refer to **7.23**, Part XI «Electrical equipment».

4.1.3 The ventilation of machinery spaces shall be sufficient under normal conditions of ship operation to prevent accumulation of oil product vapour.

4.1.4 All moving parts of machinery, units, equipment and drives that can cause harm to service personnel and other persons onboard shall be fenced with handrails or enclosures.

Internal combustion engines equipped with safety valves of appropriate type for prevention of explosion in crankcase shall be equipped with appropriate means that direct the exhaust through the valves, which ensures minimum possibility of injuries to personnel.

4.1.5 Appropriate means shall be provided in ships for reducing noise down to the acceptable level in accordance with **8.9**, Part III, “Equipment, Arrangements and Outfit”.

4.2 ARRANGEMENT OF MACHINERY AND EQUIPMENT

4.2.1 Engines, boilers, equipment, pipes and valves shall be so arranged as to provide easy access for servicing and repair; the requirements stated in **4.5.3** shall also be met.

4.2.2 The arrangement of boilers shall be such that the distance between boilers and fuel tanks is sufficient for a free circulation of air necessary to keep the temperature of the fuel in the tanks below its flash point except as mentioned in **13.3.5**, Part VIII "Systems and Piping".

4.2.3 Where auxiliary boilers design installed in the same space with the internal combustion engines will not initiate sparks if flame is accidentally blown out from the furnace, their furnaces shall have metallic screens or other arrangements to protect the equipment of that space if flame is accidentally blown out from the furnace.

4.2.4 The auxiliary oil-fired boilers installed on platforms or on ’tween decks in non-watertight enclosures shall be protected by oil-tight coamings at least 200 mm in height.

4.2.5 Driving machinery of the pumps and fans in the cargo pump rooms of oil tankers, combination carriers designed for the carriage of oil products with a flash point 60 8C or less and of oil recovery vessels shall be installed in spaces fitted with mechanical ventilation and having no exits leading to the cargo pump rooms.

Driving machinery of the submerged pumps are allowed to be installed in the open deck, provided their design and location comply with the applicable requirements of **19.2.4.1.4** and **19.2.4.9** Part XI "Electrical Equipment".

Steam engines with working temperatures not exceeding 220°C and hydraulic motors may be installed in cargo pump rooms.

Drive shafts of pumps and fans shall be carried through bulkheads or decks in gastight sealing glands supplied with effective lubrication from outside the pump room. As far as practicable, the construction of sealing gland shall protect it against being overheated.

Those parts of gland, which may come in contact in case of eventual disalignment of drive shaft, or damage to the bearings, shall be made of such materials, which will not initiate sparks.

If bellows are incorporated in the design, they shall be subjected to test pressure before fitting.

Cargo pumps, ballast pumps and stripping pumps, installed in cargo pump-rooms, as well as in ballast pump-rooms where cargo containing equipment is fitted, and driven by shafts passing through pump-room bulkheads shall be fitted with temperature sensing devices for bulkhead shaft glands, bearings and pump cassings.

Alarm shall be initiated in the cargo control room or the pump control station.

4.2.6 Air compressors shall be installed in such places where air is least contaminated by vapours of combustible liquids.

4.2.7 Fuel oil units (refer to **1.2**) as well as hydraulic units containing flammable liquids with working pressure above 1,5 MPa and not being a part of main and auxiliary engines, boilers, etc., shall be placed in a separate rooms with self-closing steel doors.

If it is impracticable to locate the main components of such units and systems in a separate space, special consideration shall be given with regard to shielding of the components and location, containment of possible leakages.

4.2.8 Requirements for the arrangement of emergency diesel-generators are outlined in **9.2**, Part XI "Electrical Equipment".

4.2.9 In oil recovery ships, the internal combustion engines, boilers and equipment containing sources of ignition as well as relevant air inlets shall be installed in intrinsically safe spaces (refer to **19.2**, Part XI "Electrical Equipment").

4.2.10 A blowdown gas caps fitted with gas fuel leakage detectors shall be installed above the dualfuel internal combustion engines (refer to **9.1**, Part IX "Machinery").

4.3 ARRANGEMENT OF FUEL OIL TANKS

4.3.1 In general, fuel oil tanks shall be part of the ship’s structure and shall be located outside machinery spaces of category A.

Where fuel oil tanks, other than double bottom tanks, are necessarily located adjacent to or within machinery spaces of category A, their surfaces in machinery spaces shall be kept to a minimum and shall preferably have a common boundary with the double bottom tanks.

Where such tanks are situated within the boundaries of machinery spaces of category A, they shall not contain fuel oil having flash point less than 60°C. In general, the use of free standing fuel oil tanks shall be avoided.

Service fuel oil tanks shall comply with the requirements of **13.8.1**, Part VIII "Systems and Piping".

4.3.2 Where the use of free standing fuel oil tanks is permitted by the Register, they shall be placed in oil-tight spill trays, and on passenger ships and special purpose ships carrying more than 50 special personnel, outside machinery spaces of category A as well.

4.3.3 Fuel oil tanks located in the machinery space shall not be located immediately above the machinery and equipment with surface temperature under insulation over 220°C, boilers, internal combustion engines, electrical equipment and, as far as practicable, shall be arranged far apart therefrom.

4.3.4 The arrangement of fuel oil and oil tanks of tankers in way of accommodation, service and refrigerated spaces is permitted, provided they are separated by cofferdams (dimensions and structure of cofferdams - refer to **2.7.5.2**, Part II "Hull”) or subject to the adoption of other special measures aimed at preventing fuel, oils and their vapours from reaching the specified spaces.

When tanks of fuel and oils of other types of ships are located in way of accommodation, service and refrigerated spaces, the cofferdams are recommended for separating them.

The manholes of the cofferdams and tanks for fuel and oils, as well as detachable joints of the fuel and oil tanks piping in accommodation and service spaces are not allowed.

4.4 INSTALLATION OF MACHINERY AND EQUIPMENT

4.4.1 The machinery and equipment constituting the propulsion plant shall be installed on strong and rigid seatings and securely attached thereto.

The construction of the seatings shall comply with the requirements of **2.11**, Part II "Hull".

4.4.2 Boilers shall be installed on bearers in such a way that their welded joints do not rest on the bearer supports.

4.4.3 To prevent shifting of boilers, provision shall be made for efficient stops and securing for rough sea; thermal expansion of boiler structures shall be taken into account.

4.4.4 The main engines, their gears, thrust bearings of shafts shall be secured to seatings with fitted bolts throughout or in part. The bolts may be omitted, if appropriate stops or other means providing reliable protection of equipment from displacement are provided. Where necessary, fitted bolts shall be used to fasten auxiliary machinery to seatings.

4.4.5 The bolts securing the main and auxiliary machinery and shaft bearings to their seatings, end nuts of shafts as well as bolts connecting the lengths of shafting shall be fitted with appropriate lockers against spontaneous loosening.

4.4.6 Where the machinery shall be mounted on shock absorbers, the design of the latter shall be approved by the Register.

Shock absorbing fastenings of the machinery and equipment shall:

maintain vibration-proof insulation properties when the absorbed machinery and equipment are operated in the environmental conditions as per the requirement of **2.3.1**;

be resistant to the corrosive mediums, temperature and various kinds of radiation;

be equipped with the yielding grounding jumper of sufficient length to prevent radio reception interference and comply with the requirements of safety engineering;

eliminate the interference for operation of other equipment, devices and systems.

4.4.7 In case of installation of machinery, mechanical equipment, ship arrangements and their components on plastic pads or their assembly with the use of polymeric materials, their technology shall be submitted to the Register for approval. Polymeric materials used for the pads and assembly shall be agreed with the Register (refer to Section **6**, Part XIII "Materials").

4.4.8 The machinery with horizontal arrangement of the shaft shall be installed parallel to the centre line of the ship. Installing such machinery in any other direction is permitted if the construction of machinery provides for operation under the conditions specified in **2.3**.

4.4.9 The machinery for driving generators shall be mounted on the same seatings as the generators

4.5 MEANS OF ESCAPE FROM MACHINERY SPACES

4.5.1 Means of escape from machinery spaces, including ladders, corridors, doors and hatches, shall, if not expressly provided otherwise, provide safe escape to the lifeboat and liferaft embarkation decks.

4.5.2 All the doors as well as the covers of companionways and skylights, which may serve as means of escape from machinery spaces, shall permit of opening and closing both from inside and outside. The covers of companionways and skylights shall be marked, as appropriate, and bear a clear inscription prohibiting to stow any loads on them.

Lifts shall not be considered as forming one of the means of escape.

4.5.3 The main and auxiliary machinery shall be so arranged as to provide passageways from the control stations and servicing flats to the means of escape from the machinery spaces. The width of passageways shall not be less than 600 mm over the whole length. In ships of less than 1000 gross tonnage the width of passageways may be reduced to 500 mm. The width of passageways along the switchboards shall comply with the requirements of 4.6.7, Part XI "Electrical Equipment".

4.5.4 The width of ladders serving as escape routes and the width of doors providing access to embarkation decks shall be at least 600 mm. The width of ladders in ships of less than 1000 gross tonnage may be reduced to 500 mm.

4.5.5 In a passenger ship, each machinery space located below the bulkhead deck shall be provided with at least two means of escape, which shall comply with the requirements of either **4.5.5.1** or **4.5.5.2**, as follows:

.1 the means of escape shall consist of two sets of steel ladders as widely separated as possible, leading to doors (hatches) in the upper part of the space similarly separated and satisfying the requirements of **4.5.1**. One of these ladders shall be located within a protected enclosure that satisfies the requirements of 2.1.4.5, Part VI "Fire Protection", from the lower part of the space to a safe position outside the space. Self-closing fire doors of the same fire integrity standards shall be fitted in the enclosure. The ladder shall be fixed in such a way that the heat is not transferred into the enclosure through non-insulated fixing points. The protected enclosure shall have minimum internal dimensions of at least 800x800 mm, and shall have emergency lighting provisions, and a vertical ladder, complying with requirements of **8.5.4.4** Part III «Equipment, arrangements and outfit».

Notes: 1. A "safe position" can be any space, excluding lockers and storerooms irrespective of their area, cargo spaces and spaces where flammable liquids are stowed, but including special category spaces and ro-ro spaces, from which access is provided and maintained clear of obstacles to the decks according to **4.5.1** (categories of ship's spaces (refer to Chapter **1.5**, Part VI "Fire protection")).

2. Machinery spaces may include working platforms and passageways, or intermediate decks at more than one deck level. In such case, the lower part of the space shall be regarded as the lowest deck level, platform or passageway within the space. At deck levels, other than the lowest one, where only one means of escape other than the protected enclosure is provided, selfclosing fire doors shall be fitted in the protected enclosure at that deck level. Smaller working platforms in-between deck levels, or only for access to equipment or components, need not be provided with two means of escape.

3. A protected enclosure providing escape from machinery spaces to an open deck may be fitted with a hatch as means of egress from the enclosure to the open deck. The hatch shall have minimum internal dimensions of 800 mm x 800 mm.

4. Internal dimensions (refer to Note 3) shall be interpreted as clear width, so that a passage having diameter of 800 mm is available throughout the vertical enclosure, as shown in Fig. 4.5.5, clear of ship's structure, with insulation and equipment, if any. The ladder within the enclosure can be included in the internal dimensions of the enclosure. When protected enclosures include horizontal portions their clear width shall not be less than 600 mm (refer to Fig. 4.5.5).

.2 the means of escape shall consist of one steel ladder leading to a door (hatch) in the upper part of the space and satisfying the requirements of **4.5.1** and additionally, in the lower part of the space and in a position well separated from the ladder referred to, a steel door capable of being operated from each side and which provides access to a safe escape route from the lower part of the space in accordance with **4.5.1**.

.3 all inclined ladders/stairways with open treads fitted to comply with **4.5.5.1** and **4.5.5.2** in machinery spaces being part of or providing access to escape routes but not located within a protected enclosure shall be made of steel.

Such ladders/stairways shall be fitted with steel shields attached to their undersides, such as to provide escaping personnel protection against heat and flame from beneath.

Note. Inclined ladders/stairways in machinery spaces being part of, or providing access to, escape routes but not located within a protected enclosure shall not have an inclination greater than 608 and shall not be less than 600 mm in clear width.

Such requirement need not be applied to ladders/stairways not forming part of an escape route, only provided for access to equipment or components, or similar areas, from one of the main platforms or deck levels within the spaces subject to requirements **4.5.5**.

4.5.6 Where the machinery spaces in passenger ships are above the bulkhead deck, two means of escape shall be provided, which shall be as widely separated as possible, and the doors (hatches) leading from such means of escape shall be in a position satisfying the requirements of **4.5.1**. Where such means of escape require the use of ladders, these shall be of steel.

4.5.7 In passenger ships of less than 1000 gross tonnage, the Register may dispense with one of the means of escape from the spaces specified in **4.5.5** and **4.5.6**, due regard being paid to the width and disposition of the upper part of the space. In ships of 1000 gross tonnage and above, the Register may dispense with one means of escape from the above mentioned spaces, including a normally unattended auxiliary machinery space, so long as the provisions of **4.5.1** are satisfied, due regard being paid to the nature of the space and whether persons are normally absent in that space.

In ships of restricted navigation areas **B-R3-S**, **B-R3-RS**, **C-R3-S**, **C-R3-RS** and **D-R3-S**, D-R3-RS The Rregister may allow only one way of escape route from machinery space in such cases:

in ships of less than 24 meters in length, taking into account the width and location of the upper part of the space;

in ships of 24 meters in length and over, provided that the door or steel ladder provides a safe escape route to the lifeboat deck, and taking into account the number of people normally working in the space.

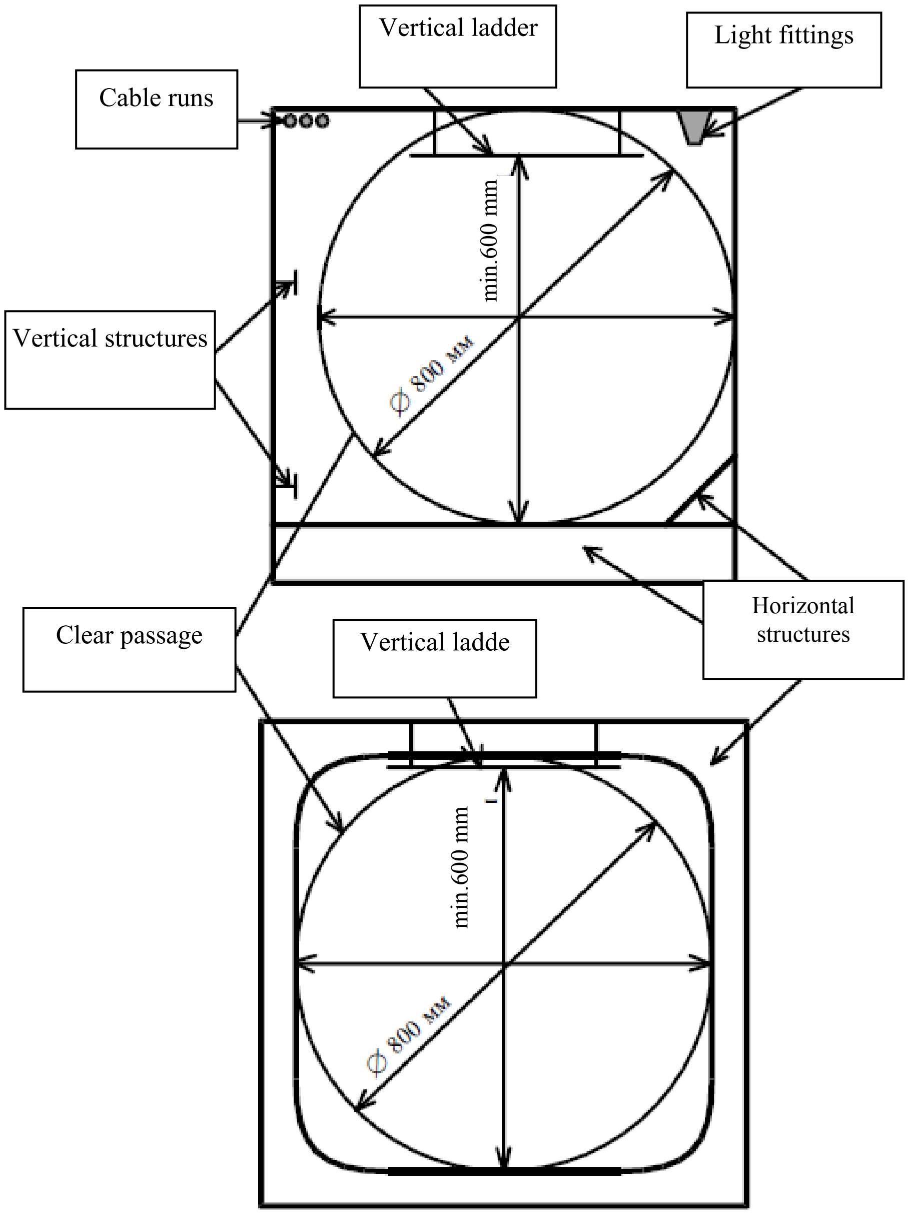

Fig. 4.5.5 An example of a possible exit through the hatch, taking into account the minimum internal clear dimensions

4.5.8 The second means of escape shall be provided from the steering gear space when the emergency steering position is located in this space unless there is a direct access to the open deck.

Note: The local steering position located in the steering gear space is considered to be an emergency steering position if a separate emergency steering position is not provided outside steering gear.

4.5.9 On passenger ships two means of escape shall be provided from the main machinery control room and main workshop within a machinery space. At least one of these escape routes shall provide a continuous fire shelter to a safe position outside the machinery space.

4.5.10 In a cargo ship, at least two means of escape shall be provided from each machinery space of category A, which shall comply with the requirements of either **4.5.10.1**, or **4.5.10.2**, as follows:

.1 the means of escape shall consist of two sets of steel ladders as widely separated as possible leading to doors (hatches), from which access is provided to the open deck. One of these means of escape shall be located within a protected enclosure that satisfies the requirements of **2.1.4.5**, Part VI "Fire Protection", from the lower part of the space to a safe position outside the space. Self-closing fire doors of the same fire integrity standards shall be fitted in the enclosure. The ladder shall be fixed in such a way that heat is not transferred into the enclosure through non-insulated fixing points. The protected enclosure shall have minimum internal dimensions of at least 800x800 mm, and shall have emergency lighting provisions, and a vertical ladder, complying with requirements of **8.5.4.4** Part III «Equipment, arrangements and outfit».

Notes: 1. A "safe position" can be any space, excluding cargo spaces, lockers and storerooms irrespective of their area, cargo pump-rooms and spaces where flammable liquids are stowed, but including vehicle and ro-ro spaces, from which access is provided and maintained clear of obstacles to the open deck in accordance with **4.5.1** (categories of ship's spaces (refer to **1.5.4.3** and **1.5.4.4**, Part VI "Fire Protection")).

2. Machinery spaces of category A may include working platforms and passageways, or intermediate decks at more than one deck level. In such case, the lower part of the space shall be regarded as the lowest deck level, platform or passageway within the space.

At deck levels, other than the lowest one, where only one means of escape other than the protected enclosure is provided, self-closing fire doors shall be fitted in the protected enclosure at that deck level.

Smaller working platforms in-between deck levels, or only for access to equipment or components, need not be provided with two means of escape.

3. A protected enclosure providing escape from machinery spaces to an open deck may be fitted with a hatch as means of egress from the enclosure to the open deck. The hatch shall have minimum internal dimensions of 800 mm x 800 mm.

4. Internal dimensions (refer to Note 3) shall be interpreted as clear width, so that a passage having diameter of 800 mm is available throughout the vertical enclosure, as shown in Fig. 4.5.5, clear of ship's structure, with insulation and equipment, if any. The ladder within the enclosure can be included in the internal dimensions of the enclosure. When protected enclosures include horizontal portions their clear width shall not be less than 600 mm (refer to Fig. 4.5.5).

.2 the means of escape shall consist of one steel ladder leading to a door (hatch) in the upper part of the space, from which access is provided to the open deck and, additionally, in the lower part of the space and in a position well separated from the ladder referred to, a steel door capable of being operated from each side and which provides access to a safe escape route from the lower part of the space to the open deck.

.3 all inclined ladders/stairways with open treads fitted to comply with **4.5.10.1** and **4.5.10.2** in machinery spaces of category A being part of or providing access to means of escape but not located within a protected enclosure shall be made of steel. Such ladders/stairways shall be fitted with steel shields attached to their undersides, such as to provide escaping personnel protection against heat and flame from beneath.

Note. Inclined ladders/stairways in machinery spaces being part of, or providing access to, escape routes but not located within a protected enclosure shall not have an inclination greater than 608 and shall not be less than 600 mm in clear width. Such requirement need not be applied to ladders/stairways not forming part of an escape route, only provided for access to equipment or components, or similar areas, from one of the main platforms or deck levels within the spaces (refer to requirements of **4.5.10**;

.4 two means of escape shall be provided from the main machinery control room and main workshop within a machinery space. At least one of these escape routes shall provide a continuous fire shelter to a safe position outside the machinery space.

4.5.11 In fishing vessels of more than 1000 gross tonnage one means of escape from machinery spaces of category A may be provided on the condition that it leads directly onto the open deck, the spaces are entered only periodically and the maximum travel distance to the door (hatch) leading directly onto open deck from the control stations of the equipment located in the space is 5 m or less.

In cargo ships of less than 1000 gross tonnage, the Register may dispense with one of the means of escape from machinery spaces of category A, due regard being paid to the dimension and disposition of the upper part of the space. In addition, the means of escape in these ships need not comply with the requirements for an enclosure listed in paragraph **4.5.10.1**.

4.5.12 From each machinery space other than that of category A, at least two escape routes shall be provided except for spaces that are entered only occasionally, and for spaces where the maximum travel distance to the door (hatch) is 5 m or less.

Note: The travel distance shall be measured from any point normally accessible to the crew, taking into account machinery and equipment within the space.

4.5.13 In addition to the requirements of **4.5.12**, the steering gear space of a cargo ship shall comply with the following requirements:

.1 steering gear spaces which do not contain the emergency steering position need only have one means of escape;

Note: The local steering position is considered to be an emergency steering position if a separate emergency steering position is not provided.

.2 steering gear spaces containing the emergency steering position can have one means of escape provided it leads directly onto the open deck.

Otherwise, two means of escape shall be provided but they do not need to lead directly onto the open deck;

.3 escape routes that pass only through stairways and/or corridors are considered as providing "direct access to the open deck" if outside the steering gear spaces they have continuous fire shelter equivalent to steering gear spaces or stairways and corridors, whichever is greater.

4.5.14 The escape routes from shaft tunnels and pipe ducts shall be enclosed in watertight trunks carried to above the bulkhead deck or the uppermost waterline.

Doors from shaft tunnels and pipe ducts leading in the machinery spaces and cargo pump rooms shall comply with the requirements of **7.12**, Part III "Equipment, Arrangements and Outfit".

4.5.15 In oil tankers and combination carriers, one of the escape routes from pipe ducts situated below the cargo tanks may lead in the cargo pump room.

Exit in the machinery space is not permitted.

4.5.16 The doors and hatch covers of cargo pump rooms in oil tankers shall be capable of being opened and closed both from inside and from outside; their design shall preclude the possibility of sparking.

4.5.17 Escape routes from cargo pump rooms shall lead directly to the open deck. Exit to other machinery spaces is not permitted.

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

4.6 INSULATION OF HEATED SURFACES

4.6.1 Surfaces of machinery, equipment and piping with temperatures above 220°C, which may be impinged as a result of a fuel system failure, shall be properly insulated.

4.6.2 The insulating materials and surface of insulation shall be in accordance with the requirements of **2.1.1.5**, Part VI "Fire Protection".

4.6.3 Structural measures shall be taken to prevent any oil that may escape under pressure from any pump, filter or heater from coming into contact with heated surfaces.

5. SHAFTING

5.1 GENERAL

5.1.1 Shafting is a solid unit connecting the engine with the propeller.

Optimum location of the shafting within the ship space shall be provided to ensure rational combination of loads of the shafting components, its supports and the engine.

For this a number of design, scientific, technical and engineering measures shall be taken which are unified by a concept "Shafting alignment" and approved by the Register.

5.1.2 The minimum shaft diameters without allowance for subsequent turning on lathe during service life shall be determined by formulae given in this Section. It is assumed that additional stresses from torsional vibration will not exceed permissible values stipulated in Section **8**.

Tensile strength of the shaft material shall be not less than 400 MPa and for shafts which may experience vibratory stresses close to the permissible stresses for transient operation _ not less than 500 MPa.

Alternative calculation methods are permitted. These methods shall take into account criteria of static and fatigue strength and include all the relevant loads under all permissible operating conditions.

The shaft diameters determined for ships of restricted navigation areas **R2**, **R2-S**, **R2-RS**, **R3-S**, **R3-RS**, **R3**, **R3-IN** and **A-R2**, **A-R2-S**, **A-R2-RS**, **B-R3-S**, **B-R3-RS**, **C-R3-S**, **C-R3-RS**, **D-R3-S**, and **D-R3-RS** according to **5.2.1** - 5.2.3 may be reduced by 5 per cent.

5.1.3 In icebreakers and ice class ships, the propeller shafts shall be protected from ice effects.

5.1.4 In ships with no obstruction for the propeller shaft to slip out of the sterntube, means shall be provided which, in the event of the propeller shaft breaking, will prevent its slipping out of the sterntube; alternative arrangements shall be made to preclude flooding of the engine room, should the propeller shaft be lost.

5.1.5 The areas between the sterntube, strut bearing (if any) and propeller boss shall be protected by a strong casing.

5.1.6 Arrangement of stern tubes shall comply with the requirements of **1.1.6.1.8**, **1.1.6.2.8** or **1.1.6.3.11**, depending on the case, Part II «Hull».

5.2 CONSTRUCTION AND DIAMETERS OF SHAFTS

5.2.1 The design diameter of the intermediate shaft d_{int}, in mm, shall not be less than

$$d_{int} = F\sqrt[3]{P/n}\ , \qquad (5.2.1)$$

where:

F – factor taken depending on the type of machinery installation as follows:

95 for installations with main machinery of rotary type or main internal combustion engines fitted with hydraulic or electromagnetic couplings;

100 for other machinery installations with internal combustion engines;

P – rated power of intermediate shaft, kW;

n – rated speed of intermediate shaft, rpm.

5.2.2 The diameter of thrust shaft in external bearing on a length equal to thrust shaft diameter on either side of the thrust collar and, where roller thrust bearings are used, on a length inside the housing of thrust bearing, shall not be less than 1,1 times the intermediate shaft diameter determined by Formulas (5.2.1), (5.2.4). Beyond the said lengths the diameter of the thrust shaft may be tapered to that of the intermediate shaft.

5.2.3 The design diameter of the propeller shaft, in mm, shall not be less than that determined by the following formula

$$d_{\text{rp}} = 100k\sqrt[3]{P/n}\,, \qquad (5.2.3)$$

where:

k – factor assumed as follows proceeding from the shaft design features: for the portion of propeller shaft between the propeller shaft cone base or the aft face of the propeller shaft flange and the forward edge of the aftermost shaft bearing, subject to a minimum of2,5d_{p}:

1,22 – where the propeller is keyless fitted onto the propeller shaft taper or is attached to an integral propeller shaft flange;

1,26 – where the propeller is keyed onto the propeller shaft taper;

for the portion of propeller shaft between the forward edge of the aftermost shaft bearing, or aft strut bush, and the forward edge of the forward sterntube seal k =1,15, for all types of design.

Other terms are as defined in **5.2.1**.

On the portion of propeller shaft forward of the forward edge of the forward sterntube seal the diameter of the propeller shaft may be tapered to the actual diameter of the intermediate shaft.

Where surface hardening is used, the diameters of propeller shafts may be reduced on agreement with the Register.

5.2.4 The diameter of the shaft made of steel with tensile strength of more than 400 MPa may be determined by the following formula

$$d_{red} = d\sqrt[3]{560/(R_{msh}+160)} \qquad (5.2.4)$$

where:

d_{red} – reduced diameter of the shaft, in mm;

d – design diameter of the shaft, mm;

R_{msh} – tensile strength of the shaft material.

In all cases the tensile strength in the formula shall be assumed not exceeding 760 MPa (for carbon and carbon-manganese steel)/800 MPa (for alloyed steel) for intermediate and thrust shafts and 600 MPa for propeller shaft.

However, where materials exhibit similar fatigue life as conventional steels, special approval of alloy steel used for intermediate shaft material (refer to Appendix **2**) shall be permitted.

5.2.5 The diameters of shafts in icebreakers and ice class ships shall exceed the design diameters by value indicated in Table 5.2.5.

Table 5.2.5 **Increase of shaft diameter, %**

Shafts	Icebreakers		Ice class ships				
	Side shaft	Centre shaft	**Ice6**	**Ice5**	**Ice4**	**Ice3**	**Ice2, Ice1**
Intermediate and thrust	20	18	15	12	8	4	0
Propeller	50	45	30	20	15	8	5

The diameter d of propeller shafts, in mm, for icebreakers and ice class ships (except for ships of ice class Ice1) shall, besides, meet the following condition in way of aft bearings

$$d \geqslant a\sqrt[3]{bs^2 R_{m_{bl}}/R_e}\,, \qquad (5.2.5)$$

where:

a – factor equal to:

10,8, with propeller boss diameter equal to, or less than 0,25D (D is the propeller diameter);

11,5, with propeller boss diameter greater than 0,25D;

b – actual width of expanded cylindrical section of the blade on the radius of 0,25R for unit-cast propellers and of 0,35R for CPP, m;

s – maximum thickness of expanded cylindrical section of the blade on the radii given for b, mm;

R_{mbl}– tensile strength of the blade material, MPa;

R_{eH} –yield stress of propeller shaft material, MPa.

5.2.6 If the shaft has a central hole, its bore shall not exceed 0,4 of the design diameter of the shaft.

If considered necessary, the diameter of central hole may be increased to the value obtained from the formula

$$d_c \leq (d_a^4 - 0{,}97 d^3\, d_a)^{1/4}\,, \qquad (5.2.6)$$

where:

d_c – diameter of central hole;

d_a – actual shaft diameter;

d – design diameter of the shaft without regard for central hole.

5.2.7 Where the shaft has a radial hole, the shaft diameter shall be increased over a length of at least seven diameters of the hole.

The hole shall be located at mid-length of the bossed portion of the shaft, and its diameter shall not exceed 0,3 of the shaft design diameter. In all cases, irrespective of the hole diameter, the diameter of the shaft shall be increased by not less than 0,1 times the design diameter.

The edges of the hole shall be rounded to a radius not less than 0,35 times its diameter and the inside surface shall have a smooth finish.

Note: This para does not consider a radial hole, intersection between a radial hole and an eccentric axial bore.

5.2.8 The diameter of a shaft having a longitudinal slot shall be increased by at least 0,2 of the design diameter of that shaft. The diameter ratio (refer to **5.2.6**) shall not exceed 0,7, the slot length shall not exceed 0,8 and slot width shall not exceed 0,15 of the design shaft diameter.

Up to three slots are permitted, with consideration for their equally-spaced location. The bossed portion of the shaft shall be of such length as to extend beyond the slot for not less than 0,25 of the design diameter of the shaft. The transition from one diameter to another shall be smooth.

The ends of the slot shall be rounded to a radius of half the width of the slot and the edges - to a radius of at least 0,35 times the width; the surface of the slot shall have a smooth finish.

5.2.9 The diameter of a shaft having a keyway shall be increased by at least 0,1 of its design diameter. After a length of not less than 0,2 of the design diameter from the ends of the keyway, no increase of the shaft diameter is required.

If the keyway is made on the outboard end of the propeller shaft, the diameter need not be increased.

Keyways are not recommended in the shafts with a barred speed range.

5.2.10 For intermediate shafts, thrust shafts and inboard end of propeller shafts the coupling flange shall have a minimum thickness of 0,2 times the required diameter of the intermediate shaft, or the thickness of the coupling bolt diameter (refer to Formula (5.3.2)) calculated for the material having the same tensile strength as the corresponding shaft, whichever is the greater.

The thickness of coupling flange of the outboard end of propeller shaft under the bolt heads shall not be less than 0,25 times the required diameter of the shaft at the flange.

5.2.11 The fillet radius at the base of aft flange of the propeller shaft shall not be less than 0,125 and for other flanges of shafts _ shall not be less than 0,08 of the required diameter at the flange. The fillet may be formed by multiradii in such a way that the stress concentration factor will not be greater than that for a constant fillet radius. The fillets shall have a smooth finish and shall not be recessed in way of nuts and bolt heads.

5.2.12 Fillet radii in the transverse section of the bottom of the keyway shall not be less than 0,0125 of the diameter of the shaft, but at least 1 mm.

5.2.13 Where keys are used to fit the propeller on the propeller shaft cone, the latter shall have a taper not in excess of 1:12, in case of keyless fitting _ according to **5.4.1**.

5.2.14 On the cone base side, the keyways in shaft cones shall be spoon-shaped, while in propeller shaft cones they shall be ski-shaped in addition.

Where the outboard end of a propeller shaft having the diameter in excess of 100 mm is concerned, the distance between the cone base and the spoon-shaped keyway end shall be at least 0,2 of the shaft diameter required, with the ratio of the keyway depth to the shaft diameter less than 0,1 and 0,5 at least of the shaft diameter required, with the ratio of the keyway depth to the shaft diameter exceeding 0,1.

In coupling shaft cones, the ski-shaped keyway end shall not extend beyond the cone base.

Where the key is secured by screws in the keyway, the first screw shall be positioned at least 1/3 of the shaft cone length from the shaft cone base. The bore length shall not exceed the propeller diameter. The bore edges shall be rounded off. Where the shaft has blind axial bores, the bore edges and end shall also be rounded off. The fillet radius shall not be less than specified in **5.2.12**.

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

5.2.16 Propeller shaft liners shall be made of such alloys, which possess sufficient corrosion resistance in sea water.

5.2.17 The thickness s of a bronze liner, in mm, shall not be less than

$$s = 0{,}03d'_r + 7{,}5, \qquad (5.2.17)$$

where: d'_r –diameter of the propeller shaft under the liner, mm.

The thickness of the liner between the bearings may be reduced to0,75s.

5.2.18 Continuous liners are recommended to be used.

Liners consisting of two or more lengths shall be joined by welding or by other methods approved by the Register.

The butt welded joints of the liner shall be arranged outside the region of bearings.

In case of non-continuous liners the portion of the shaft between the liners shall be protected against the action of sea water by a method approved by the Register.

5.2.19 To prevent water from reaching the propeller shaft cone, appropriate sealing shall be provided.

Structural provision shall be made for hydraulic testing of the sealing.

5.2.20 The liners shall be shrunk on the shaft in such a way as to provide tight interference between mating surfaces.

The use of pins or other parts for securing of liners to the shaft is not permitted.

5.3 SHAFT COUPLINGS

5.3.1 The bolts used at the coupling flanges of shafts shall be all fitted bolts of cylindrical section.

If using coupling flanges without fitted bolts the technical substantiation shall be submitted to the Register for review.

5.3.2 The coupling bolt diameter, in mm, shall not be less than

$$d_b = 0{,}65\sqrt{\frac{d_{int}^3\ (R_{m_{sh}} + 160)}{iDR_{m_b}}}\ , \qquad (5.3.2)$$

where:

d_{int} – diameter of intermediate shaft determined by Formula (5.2.1) taking into account the ice classes requirements under **5.2.5**, in mm.

If the shaft diameter is increased to account for torsional vibration, d_{int} will be taken as the increased diameter of intermediate shaft;;

R_{msh} – =tensile strength of the shaft material, in MPa;

R_{mb} – tensile strength of the fitted coupling bolt material, in MPa, taken $R_{msh} \le R_{mb} \le 1{,}7R_{msh}$, but not higher than 1000 MPa;

i – number of fitted coupling bolts;

D – pitch circle diameter of coupling bolts, in mm.

The diameter of bolts, by which the propeller is secured to the propeller shaft flange shall be agreed with the Register in each particular case.

5.4 KEYLESS FITTING OF PROPELLERS AND SHAFT COUPLINGS

5.4.1 In case of keyless fitted propellers and shaft couplings, the taper of the shaft cone shall not exceed 1:15.

Provided the taper does not exceed 1:50, the shafts may be assembled with the couplings without the use of an end nut or other means of securing the coupling.

The stoppers of the end nuts shall be secured to the shaft.

5.4.2 A keyless assembly shall generally be constructed without a sleeve between the propeller boss and the shaft.

If using constructions with intermediate sleeves the technical substantiation shall be submitted to the Register for review.

5.4.3 When fitting the keyless shrunk assembly, the axial pull-up of the boss in relation to the shaft or intermediate sleeve, as soon as the contact area between mating surfaces is checked after eliminating the clearance, shall be determined by the following formula

$$\Delta h = \left\{\frac{80B}{hz}\sqrt{\left(\frac{1910PL^3}{nD_\omega}\right)^2 + T^2} + \frac{D_\omega(\alpha_y - \alpha_\omega)(t_e - t_m)}{z}\right\}k, \qquad (5.4.3)$$

where:

Δh – axial pull-up of the boss in the course of fitting, cm;

B – material and shape factor of the assembly, MPa^{-1}, determined by the formula

$$B = \frac{1}{E_y}\left(\frac{y^2+1}{y^2-1} + \nu_y\right) + \frac{1}{E_\omega}\left(\frac{1+\omega^2}{1-\omega^2} - \nu_\omega\right).$$

For assemblies with a steel shaft having no axial bore, the factor B may be obtained from Table 5.4.3-1 using linear interpolation;

E_y – modulus of elasticity of the boss material, MPa;

E_ω – modulus of elasticity of shaft material, MPa

ν_y – Poisson's ratio for the boss material;

ν_ω – Poisson's ratio for the shaft material; for steel $\nu_\omega = 0{,}3$;

y – mean factor of outside boss diameter;

ω – mean factor of shaft bore;

D_ω – mean outside shaft diameter in way of contact with the boss or intermediate sleeve (refer to Fig. 5.4.3).

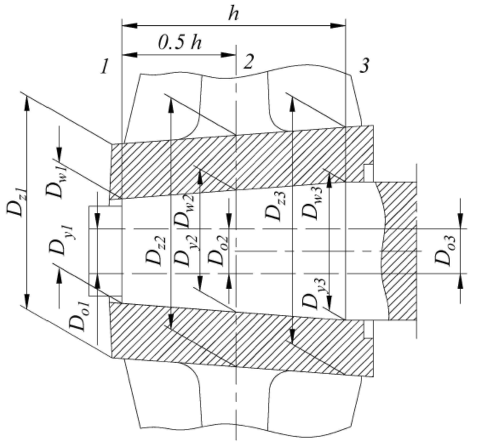

Fig. 5.4.3

without intermediate sleeve:

$D_{\omega 1} = D_{y1}$; $D_{\omega 2} = D_{y2}$, $D_{\omega 3} = D_{y3}$, $D_{\omega} = D_y$.

with intermediate sleeve:

$D_{\omega 1} \neq D_{y1}$; $D_{\omega 2} \neq D_{y2}$, $D_{\omega 3} \neq D_{y3}$, $D_{\omega} \neq D_y$.

$$y = \frac{D_{z1} + D_{z2} + D_{z3}}{D_{y1} + D_{y2} + D_{y3}}$$ – for the boss;

$$\omega = \frac{D_{01} + D_{02} + D_{03}}{D_{\omega 1} + D_{\omega 2} + D_{\omega 3}}$$ – for the shaft;

$D_{\omega} = (D_{\omega 1} + D_{\omega 2} + D_{\omega 3})/3$;

$D_y = (D_{y1} + D_{y2} + D_{y3})/3$;

D_y – mean internal boss diameter in way of contact with the shaft or intermediate sleeve, cm;

h – active length of the shaft cone or sleeve at the contact with the boss, cm;

z – taper of the boss;

P – power transmitted by the assembly, kW;

n – speed, rpm.

L – factor for ice class ships according to Table 5.4.3-2;

T – propeller thrust at ahead speed, in kN (where data are unavailable, refer to **2.2.2.6**, Part III "Equipment, Arrangements and Outfit");

α_y, α_{ω} – thermal coefficient of linear expansion of the boss and shaft material, 1/°C;

t_e, t_m – temperature of the assembly in service conditions and in the course of fitting, °C;

$k = 1$ – for assemblies without intermediate sleeve;

$k = 1{,}1$ – for assemblies without intermediate sleeve.

For ice class ships, the value Δh shall be chosen as the greater of the results obtained from calculations for extreme service temperatures, i.e.

$t_e = 35$ °C for$L = 1$;

$t_e = 0$ °C for $L > 1$.

In the absence of ice classes the calculation shall be made solely for the maximum service temperature $t_e = 35$°C for $L = 1$.

Table 5.4.3-1 **Factor $B \cdot 10^5$, MPa^{-1}, Steel shaft $\omega = 0$, $E_{\omega} = 2{,}059 \cdot 10^5$ MPa, $\nu_{\omega} = 0{,}3$**

Factor y	Copper alloy boss $\nu_y = 0{,}34$ with E_y, MPa:							Steel boss ν_y=0,3 with E_y=2,05·10^5, MPa
	0,98·10^5	1,078·10^5	1,176·10^5	1,274·10^5	1,373·10^5	1,471·10^5	1,569·10^5	

1,2	6,34	5,79	5,34	4,96	4,63	4,34	4,09	3,18
1,3	4,66	4,26	3,95	3,66	3,43	3,22	3,04	2,38
1,4	3,83	3,52	3,25	3,03	2,83	2,67	2,52	1,98
1,5	3,33	3,07	2,83	2,64	2,48	2,34	2,21	1,74
1,6	3,01	2,77	2,57	2,40	2,24	2,12	2.01	1,59
1,7	2,78	2,48	2,38	2,22	2,09	1,97	1,87	1,49
1,8	2,62	2,38	2,23	2,09	1,97	1,86	1,76	1,41
1,9	2,49	2,29	2,13	1,99	1,88	11,77	1,68	1,35
2,0	2,39	2,20	2,05	1,92	1,80	1,70	1,62	1.29
2,1	2,30	2,13	1,98	1,86	1,74	1,65	1,57	1,25
2,2	2,23	2,06	1,92	1,79	1,69	1,60	1,53	1,22
2,3	2,18	2,01	1,88	1,75	1,65	1,57	1,49	1,19
2,4	2,13	1,97	1,84	1,72	1,62	1,54	1,46	1,17

Table 5.4.3-2 **Factor *L***

Assembly	Ice class ships					Icebreakers	
	Ice1, Ice2	**Ice3**	**Ice4**	**Ice5**	**Ice6**	Centre shaft	Side shaft
Propeller with shaft	1,05	1,08	1,15	1,20	1,30	1,45	1,50
Coupling with shaft	1,0	1,04	1,08	1,12	1,15	1,18	1,20

5.4.4 When assembling steel couplings and shafts with cylindrical mating surfaces, the interference fit shall be determined by the following formula

$$\Delta D = \frac{80B}{h}\sqrt{\left(\frac{1910PL^3}{nD_\omega}\right)^2 + T^2}\ , \quad (5.4.4)$$

where: ΔD – interference fit for D_ω, cm.
Other terms are as defined in **5.4.3**.

5.4.5 Other terms are as defined in

$$\frac{A}{B}\left[\frac{C}{D_y} + (\alpha_y - \alpha_\omega)t_m\right] \le 0{,}75R_{eH}\ , \qquad (5.4.5)$$

where:
A – shape factor of the boss determined by the formula:

$$A = \frac{1}{y^2 - 1}\sqrt{1 + 3y^4}\ ;$$

$C = \Delta h_r z$ – for assemblies with conical mating surfaces;
$C = \Delta D_r$ – for assemblies with cylindrical mating surfaces;
Δh_r – actual pull-up of the boss in the course of fitting at a temperature t_m, cm,
$\Delta h_r \ge \Delta h$;
ΔD_r – actual interference fit of the assembly with cylindrical mating surfaces, in cm;
$\Delta D_r \ge \Delta D$;
R_{eH} – yield stress of the boss material, MPa.
The factor A may be obtained from Table 5.4.5 by linear interpolation.
Other terms are as defined in **5.4.3**.

Tabla 5.4.5 **Factor *A***

y	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2,02	2,1	2,2	2,3	2,4
A	6,11	4,48	3,69	3,22	2,92	2,70	2,54	2,42	,33	2,26	2,20	2,15	2,11

5.5 ARRANGEMENT OF SHAFTING SUPPORTS

5.5.1 The number of the shaftline supports, their position along the axis and in the vertical plane as well as the loads carried shall be determined on the basis of calculation made by a proven procedure agreed with the Register.

5.5.2 The distance between the reaction forces of the adjacent shaftline bearings with no concentrated masses in span shall meet the following condition:

$$5{,}5a\sqrt{d} \le l \le a\lambda\sqrt{d} \quad (5.5.2)$$

where:
l – span length (distance between the reactions of adjacent supports), m;
d – minimum outside shaft diameter in span, m;
λ – factor taken equal to:
$\lambda = 14$ — when $n \le 500$ rpm;
$\lambda = 300/\sqrt{n}$ — when $n > 500$ rpm.;
n – shaft speed, in rpm;
α –factor for bored shafts taken equal to:
$\alpha = \sqrt[4]{1+b^2}$
$b = d_0 / d$ — ratio of the bore diameter d_0 to the outside shaft diameter d.

Note. Restriction on the minimum length (the left part of equation (5.5.2)) is used for all spans except for that nearest to the propeller.

5.5.3 It is recommended to seek the minimum number of shaftline supports and the maximum possible length of the spans between them.

5.5.4 The lengths of the spans between the shaft supports shall be checked by the bending vibration calculation.

5.5.5 The shaftline supports shall be so installed that the engine or reduction gear components (bearings, gear wheels) take up loads within the permissible limits.

5.5.6 The reactions of all shaftline supports shall be positive.

5.6 SHAFT BEARINGS

5.6.1 The propeller shaft bearing nearest to the propeller shall meet the requirements of Table 5.6.1. Those propeller shaft bearings, which are located forward of the bearing mentioned above, shall meet the condition:

$$l \ge R / qd \quad (5.6.1)$$

where: here the symbols and values for q are taken from Table 5.6.1.

5.6.2 The water cooling of sterntube bearings shall be of forced type (refer to **15.1**, Part VIII "Systems and Piping"). The water supply system shall be provided with a flow indicator and with alarms for the minimum flow of water.

Where an open system of seawater lubrication is applied for the sternbush bearings of ships operating in shallow waters, and of specialized vessels, such as wet dredgers, suction dredgers, it is recommended that an efficient seawater cleaning device (filter, cyclone filter, etc.) shall be incorporated in the circulation system of the sternbush bearing, or sternbush bearings with mud collectors to be washed subsequently shall be fitted.

The non-return shut-off valve controlling the supply of water to sterntube bearings shall be fitted on the sterntube or the after peak bulkhead.

Table 5.6.1

Bearing material	l/d[1] , not less than	q[2], in MPa, not more than
Oily-lubricated white metal (babbit)	2[4]	1,0
Bakaut	4	0,25
Rubber or other water-lubricated materials approved by the Register	4[3]	0,25[3]
Rubber or other synthetic oil- or environment-friendly oily liquid-lubricated materials approved by the Register	2[4]	1,0

[1] l - length of bearing; d - design shaft journal diameter in way of bearing.
[2] q - contact pressure taken up by the bearing: $q = R/(l \times d)$, where R - reaction of suppor.
[3] Length of the bearing of synthetic material may be reduced to twice the design shaft diameter in way of the aft bearing, provided the results of the operational check (of the bearing design and material) are satisfactory.

[4] Length of the bearing may be reduced if the contact pressure does not exceed 0,8 MPa 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 and if the results of the operational check are satisfactory. In all cases, the length of the bearing shall not be less than 1,5 of the actual shaft diameter in way of the bearing.

5.6.3 The oil-lubricated sternbush bearings shall be provided with forced cooling arrangements unless the after peak tank is permanently filled with water.

Indication of temperature of oil or bearing bush shall be provided.

5.6.4 If a gravity system of lubrication is used for sternbush bearings, the lubricating oil tanks shall be fitted with oil level indicators and low level alarms.

5.7 STERNTUBE SEALING ARRANGEMENTS

5.7.1 Sterntube arrangements shall be fitted with sterntube sealing arrangements providing the efficient protection against emergency intrusion of sea water inside the hull, and the environmental safety of sterntube arrangement.

5.7.2 The minimum and the maximum permissible volumes of the refrigerant leakage into the ambient space and inside the hull shall be technically substantiated.

5.8 BRAKING DEVICES

5.8.1 The shaftline shall comprise appropriate braking devices.

Such devices may be a brake, a stopping or a shaft turning gear preventing rotation of the shaft in the event the main engine goes out of action.

5.9 HYDRAULIC TESTS

5.9.1 Propeller shaft liners and cast sterntubes shall be hydraulically tested to a pressure of 0,2 MPa upon completion of machining.

Hydraulic tests of welded and forged-and-welded sterntubes may be omitted, providing non-destructive testing of 100 per cent of welds.

5.9.2 After assembling, the seals of the sterntube when the closed lubrication system is used shall be tested for tightness by a pressure head up to the working level of liquid in gravity tanks. In general, the test shall be carried out while the propeller shaft is turning.

6. PROPELLERS

6.1 GENERAL

6.1.1 The requirements of this Section apply to metal fixed-pitch propellers (FPP), both solid and detachable-blade propellers, as well as to controllable-pitch propellers (CPP).

6.1.2 The design and size of propellers of the main active means of the ship's steering shall meet the requirements of the present Section.

The scope of requirements for the design and size of propellers of the auxiliary AMSS may be reduced, subject to agreement with the Register.

6.2 BLADE THICKNESS

6.2.1 Propeller blade thickness is checked in the design root section and in the blade section at the radius r=0,6R where R is propeller radius.

The location of the design root section is adopted as follows:

for solid propellers – at the radius 0,2R where the propeller boss radius is smaller than 0,2R, and at the radius 0,25R where the propeller boss radius is greater than or equal to 0,2R;

for detachable-blade propellers – at the radius 0,3R where the propeller boss radius is smaller than 0,3R, and at the propeller boss radius where the propeller boss radius is larger than or equal to 0,3R.

The values of the factors A and c are adopted as in the case of r = 0,25R;

for CPP – at the radius 0,35R where the propeller boss radius is smaller than 0,35R, at the propeller boss radius where the propeller boss radius is larger than or equal to 0,35R.

Note: In the design section, the blade thickness is determined the fillets neglected.

In solid propellers, detachable-blade propellers and CPP, the maximum thickness s, in mm, of an expanded cylindrical section shall not be less than

$$s = 9{,}8\left[A\sqrt{\frac{0{,}14kP}{zb\sigma n}} + c\frac{m}{\sigma}\left(\frac{Dn}{300}\right)^2\right], \qquad (6.2.1\text{-}1)$$

where:

A – coefficient to be determined by Formula (6.2.1-2) depending on the relative radius r/R of design section and the pitch ratio H/D at this radius (for a CP-propeller, take the pitch ratio of the basic design operating condition);

k – coefficient obtained from Table 6.2.1-1;

P – shaft power at the rated output of the main propulsion engine, kW;

z – number of blades;

b – width of the expanded cylindrical section of the blade on the design radius, m;

$\sigma = 0{,}6R_{mb} + 175$ MPa, but not more than 570 MPa for steels and not more than 610 MPa for copper alloys;

R_{mbl} – tensile strength of blade material, MPa;

n – speed at the rated output, rpm;

c – coefficient of centrifugal stresses to be determined by Formula (6.2.1-3) ;

m – blade rake, mm;

D – propeller diameter, m;

$$A = \sum_{j=0}^{4}\sum_{i=0}^{3} a_{ij}(\check{r})^i (H/D)^j, \qquad (6.2.1\text{-}2)$$

where:

a_{ij} – factor determined from Table 6.2.1-2;

$\check{r}$ – relative radius of design section**;**

$$c = \sum_{i=0}^{3} a_{ij}(\check{r})^i, \qquad (6.2.1\text{-}3)$$

where:

a_i – factor determined from Table 6.2.1-3;

$\check{r}$ – relative radius of design section.

The holes for the items securing the blades of built-up and CP-propellers shall not reduce the design root section.

The thickness of propeller blades in ships of river-sea navigation and in ships of restricted areas of navigation **R2, R3, A-R2** and **D-R3** may be reduced by 5 per cent.

Table 6.2.1-1 **Coefficient *k***

Ships without ice class	Ice class ships					Icebreakers	
	Ice1, Ice2	**Ice3**	**Ice4**	**Ice5**	**Ice6**	Centre propeller	Side propeller
8	9	10	11,2	12,5	14	16	$16+\frac{23500}{P^*}$

*P – shaft power, kW.

Notes: 1. If reciprocating engines with less than four cylinders are installed in the ship, k shall be increased by 7 per cent.

2. For reciprocating engines fitted with hydraulic or electromagnetic couplings, k may be reduced by 5 per cent.

3. For side propellers of ships without ice class and ships of ice classes **Ice1** and **Ice2**, k may be reduced by 7 per cent

Table 6.2.1-2 **Values of coefficient a_{ij}**

a_{ij}		*j*				
		0	1	2	3	4
i	0	709,29796	-1988,09402	2866,42279	-2021,48724	547,82587
	1	-3780,43298	14440,53576	-22809,83724	16918,28525	-4715,66016
	2	9066,98223	-36165,14189	59184,72549	-45171,89303	12819,32337
	3	-704,99029	29254,14486	-48753,36019	37837,58962	10848,55838

Table 6.2.1-3 **Values of coefficient a_i**

i	0	1	2	3
a_i	0,35	2,67381	-11,71429	10,47619

6.2.2 The blade tip thickness at the radius $D/2$ shall not be less than provided in Table 6.2.2.

The leading and trailing blade edge thickness measured at 0,05 of the blade width from the edges shall not be less than 50 per cent of blade tip thickness.

Table 6.2.2 **The blade tip thickness**

Ships without ice class	Ships with ice classes		Icebreakers
	Ice1 – Ice5	**Ice6**	
0,0035*D**	0,005*D*	0,006*D*	0,008*D*
**D* – diameter of the propeller.			

6.2.3 The blade thickness calculated in accordance with **6.2.1** and **6.2.2** may be reduced (e.g. for blades of particular shape), provided a detailed strength calculation is submitted for consideration to the Register.

6.2.4 The thickness of a high-skewed (θ > 25°) blade with an asymmetrical outline of the normal projection shall be checked in compliance with the requirements of **6.2.1**.

Besides, the blade thickness at the radius 0,6*R* at a distance of 0,8 of the width of section b shall not be less than determined from the following formula

$$s_k = 0{,}4s(1 + 0{,}064\sqrt{\theta - 25}), \qquad (6.2.4)$$

where:

s – to be determined from Formula (6.2.1) at the radius 0,6*R*;

θ – angle, in degrees, equal to angle θ_1 or θ_2, whichever is the greater (refer to Fig. 6.2.4).

If smoothness of the blade section profile at the radius 0,6*R* under condition of mandatory compliance with the requirements for the minimum thickness close to the trailing edge (on 0,8*b*) is not provided, thickness s at the radius 0,6*R* is increased.

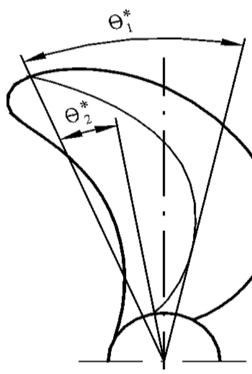

Fig. 6.2.4

θ_1^* – angle between the radius drawn through the blade tip and the radius tangent to the mid-chord;

θ_2^* – angle between radii drawn through the blade tip and root section centre of the blade.

Use of high-skewed blades (θ>5°) for icebreakers and ice ships of categories and of high-skewed blades (θ >10°) for ice ships of **Ice5** categories shall be substantiated.

6.2.5 In icebreakers and ships provided with ice strengthening, the stresses in the most loaded parts of pitch control gear shall not exceed yield stress of the material, if the blade is broken in direction of the weakest section by a force applied along the blade axis over 2/3 of its length from the boss and laterally over 2/3 from the blade spindle axis to the leading edge.

6.3 PROPELLER BOSS AND BLADE FASTENING PARTS

6.3.1 Fillet radii of the transition from the root of a blade to the boss shall not be less than 0,04*D* on the suction side of the blade and shall not be less than 0,03*D* on the pressure side.

If the blade has no rake, the fillet radius on both sides shall be at least 0,03*D*.

Smooth transition from the blade to the boss using a variable radius may be permitted.

6.3.2 The propeller boss shall be provided with holes through which the empty spaces between the boss and shaft cone are filled with non-corrosive mass; the latter shall also fill the space inside the propeller cap.

6.3.3 The diameter of the bolts (studs), by which the blades are secured to the propeller boss or the internal diameter of the thread of such bolts (studs), whichever is less, shall not be less than that determined by the following formula

$$d_{ш} = ks\sqrt{\frac{bR_{mл}}{dR_{mб}}}, \qquad (6.3.3)$$

where:
k = 0,33 in case of three bolts in blade flange, at thrust surface;
0,30 – in case of four bolts in blade flange, at thrust surface;
0,28 – in case of five bolts in blade flange, at thrust surface;
s – the maximum actual thickness of the blade at design root section (refer to 6.2.1), mm;
b – width of expanded cylindrical section of the blade at the design root section, m;
R_{mbl} – tensile strength of blade material, MPa;
R_{mb} – tensile strength of bolt/stud material, MPa;
d – diameter of bolt pitch circle; with other arrangement of bolts, $d = 0{,}85l$ where l = the distance between the most distant bolts, m.

6.3.4 The securing devices of the bolts (studs), by which the blades are fastened to the detachableblade propellers of ice class ships, shall be recessed in the blade flange.

6.4 PROPELLER BALANCING

6.4.1 The completely finished propeller shall be statically balanced.

The extent of balancing shall be checked by a test load, which when suspended from the tip of every blade in horizontal position, shall cause the propeller to rotate. The mass of the test load shall not be more than

$$m \le km_p/R, \qquad (6.4.1)$$

where:
m – mass of test load, kg;
m_p – =mass of propeller, t;
R – propeller radius, m;
k = 0,75 for $n \le 200$;
0,5 for $200 < n \le 500$;
0,25 for $n > 500$;
n – rated speed of propeller, rpm.

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

6.5 CONTROLLABLE PITCH PROPELLERS

6.5.1 The hydraulic power system of the controllable pitch propeller shall be supplied by two pumps of equal capacity, basic and standby, one of which may be driven from the main engine. The main engine driven pump shall provide turning of the blades under any operating mode of the main engines.

Where more than two pumps are available, their capacity shall be selected on the assumption that, if any of the pumps fails, the aggregate capacity of the rest would be sufficient to ensure the blade turningover time not longer than stipulated by **6.5.5**.

In ships with two CP-propellers one independent standby pump may be fitted for both CP-propellers.

6.5.2 The pitch control unit shall be designed so as to enable turning the blades into ahead speed position, shall the hydraulic power system fail.

In multi-screw ships, except icebreakers and ships with ice strengthening of categories **Ice 5** and **Ice 6**, this requirement need not be satisfied.

6.5.3 In ships with a CP-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.

6.5.4 The hydraulic power system of pitch control unit shall be constructed according to the requirements of Section **7**, Part IX "Machinery", and the pipes shall be tested according to Section **21**, Part VIII "Systems and Piping".

6.5.5 The time required for the blades to be turned over from full ahead to full astern speed position with main machinery inoperative shall not exceed 20 s for CP-propellers up to 2 m in diameter including, and 30 s for CP-propellers with diameters over 2 m.

6.5.6 In the gravity lubrication systems of CP-propellers, the gravity tanks shall be installed above the deepest load waterline and be provided with level indicators and low level alarms.

6.6 HYDRAULIC TESTS

6.6.1 The sealings fitted to the cone and flange casing of the propeller shaft (if such method of connection with the propeller boss is used) shall be tested to a pressure of at least 0,2 MPa after the propeller is fitted in place.

If the above sealings are under pressure of oil from the sterntube or the propeller boss, they shall be tested in conjunction with testing of the sterntubes or propeller boss.

6.6.2 After being assembled with the blades the boss of a CP-propeller shall be tested by internal pressure equal to a head up to the working level of oil in gravity tank, or by a pressure created by the lubricating pump of the boss. In general, the test shall be made during blade adjustment.

7. ACTIVE MEANS OF THE SHIP'S STEERING

7.1 GENERAL

7.1.1 The requirements of the present Section apply to steerable propellers with podded drives or with mechanical transmission of power to the propeller including retractable units of all types, waterjets, vertical-axis propellers, propellers in transverse tunnel (athwartship thrusters) and other devices of similar purpose.

7.1.2 Where AMSS is intended for main propulsion and steering of a ship, as a rule, minimum two AMSS shall be provided. Provision in this case shall be made for control stations equipped with necessary devices and means of communication as indicated in **2.5**, **3.1** to **3.3**.

Where one AMSS is intended for main propulsion and steering of a ship, the technical substantiation shall be submitted to the Register for review.

7.1.3 The type and structure of AMSS shall be selected during ship design considering the ship purpose and area of navigation, as well as operational peculiarities.

7.1.4 The requirements for installation of AMSS machinery and equipment, materials and welding are given in **1.3**, **2.4** and **4.4**.

7.1.5 For AMSS intended for the main propulsion and for the dynamic positioning, size and materials of shafts, couplings, connection bolts, propellers, gearing as well as electrical equipment shall meet the requirements of relevant parts and sections of the Rules.

All essential components used in steering arrangements for ship directional control shall be of sound reliable construction proved by appropriate calculations. Any such essential component shall, where appropriate, utilize anti-friction bearings such as ball bearings, roller bearings or sleeve bearings which shall be periodically lubricated or provided with perrmanent lubrication fittings.

Moreover, the main AMSS shall comply with the applicable requirements for the steering gears, set forth in the relevant sections of the Rules.

All essential components used in steering arrangements for ship directional control shall be duplicated. When not duplicated or when the Rules contain no requirements for particular AMSS components, possibility of using them shall be agreed upon with the Register.

7.1.6 Calculations of the AMSS gearing shall be made following the procedure outlined in **4.2**, Part IX "Machinery" or by other methods recognized by the Register. The safety factors of gearing shall not be less than those specified in 4.2, Part IX "Machinery". The values of these factors for the AMSS gearing intended for dynamic positioning duty shall be taken as for the main AMSS.

7.1.7 To support operating capacity of AMSS till special survey the service life of the rolling bearings shall be at least:

30000 h for the main AMSS;

10000 h for the AMSS used for dynamic positioning duty;

5000 h for the auxiliary AMSS.

7.1.8 Spaces containing the AMSS machinery shall be equipped with appropriate ventilating, fire extinguishing, drainage, heating and lighting arrangements.

7.2 CONSTRUCTION REQUIREMENTS

7.2.1 Steerable propellers shall be capable to be locked in all angular positions.

7.2.2 The main AMSS shall be provided with an emergency turning mechanism. The main AMSS angle indicator shall be provided. The difference between the indicated and actual positions shall comply with **2.9.15**, Part III "Equipment, Arrangements and Outfit".

7.2.3 For a ship fitted with multiple steering systems such as steerable propellers, water jet propulsion systems or other propulsion systems, each of the steering systems shall be equipped with its own dedicated steering gear, water jet guiding devices or other devices to change the propeller angle in accordance with requirements **2.9.1** of Part III "Equipment, Arrangements and Outfit" and **6.2.1.1** of Part IX "Machinery".

7.2.4 The main steering arrangements for ship directional control shall be:

.1 of adequate strength and capable of steering the ship at maximum ahead service speed which shall be demonstrated;

.2 capable of changing direction of the ship's directional control system from one side to the other at declared steering angle limits at an average rotational speed of not less than 2,3°/s with the ship running ahead at maximum ahead service speed (refer also to **2.9.2**, Part III "Equipment, Arrangements and Outfit");

.3 for all ships, operated by power;

.4 so designed that they will not be damaged at maximum astern speed.

Note. Declared steering angle limits (of steerable propeller, thrust angle changing arrangement) are the operational limits in terms of maximum steering angle, or equivalent, according to manufacturer's guidelines for safe operation, also taking into account the ship's speed or propeller torque/speed or other limitation. The declared steering angle limits shall be declared by the directional control system manufacturer for each ship specific non-traditional steering mean. Ship's manoeuvrability tests shall be carried out with steering angles not exceeding the declared steering angle limits.

7.2.5 In a ship fitted with two or more steering systems, such as but not limited to azimuthing propulsors or water jet propulsion systems, an auxiliary steering gear need not be fitted, provided that:

.1 in a passenger ship, each of the steering systems is capable of satisfying the requirements in **7.2.4.2**, while any one of the power units is out of operation;

.2 in a cargo ship, each of the steering systems is capable of satisfying the requirements in **7.2.4.2** while operating with all power units;

.3 each of the steering systems is arranged so that after a single failure in its piping or in one of the power units, ship steering capability (but not individual steering system operation) can be maintained or speedily regained (e.g. by the possibility of positioning the failed steering system in a neutral position in an emergency, if needed).

7.2.6 The requirements of the present paragraph apply to the steering systems having a certain proven steering capability due to ship speed also in case propulsion power has failed.

Where the propulsion power exceeds 2500 kW per thruster unit, an alternative power supply, sufficient at least to supply the steering arrangements which complies with the requirements of **7.2.14.2** and also its associated control system and the steering system response indicator, shall be provided automatically, within 45 s, either from the emergency source of electrical power or from an independent source of power located in the steering gear compartment. This independent source of power shall be used only for this purpose.

In every ship of 10000 gross tonnage and upwards, the alternative power supply shall have a capacity for at least 30 min of continuous operation and in any other ship for at least 10 min.

7.2.7 The ability of the machinery to change the thrust direction for stopping the ship making a full ahead speed on an agreeable distance shall be proven and recorded.

The steerable propeller designed for reversing the thrust by turning the unit shall provide an acceptable reversing time depending on the purpose of the ship. The time required for turning the unit through 180° shall not then exceed 20 s for the units with a propeller of 2 m and less in diameter and shall not exceed 30 s for the units with a propeller of more than 2 m in diameter.

The stopping times, ship headings and distances recorded on trials, together with the results of trials to determine the ability of ships having multiple propulsion/steering arrangements to navigate and manoeuvre with one or more.

7.2.8 Sealing boxes of a type approved by the Register shall be installed to prevent sea water from gaining access to internal parts of the AMSS. For the main and for the dynamic positioning AMSS such sealing arrangement shall contain at least two separate, closely effective sealing elements.

7.2.9 An easy access shall be provided to component parts of the AMSS to allow their maintenance within the scope stipulated by the Service Manual.

7.2.10 Where the design of the main AMSS does not insure against free rotation of the propeller and shafting in case of failure of the prime mover, provision shall be made for a braking device in accordance with the requirements of **5.8** (refer also to **17.3.4**, Part XI "Electrical Equipment"). On agreement with the Register, braking devices for the AMSS intended for the dynamic positioning and for the auxiliary AMSS may be dispensed with.

7.2.11 The strength of the parts of the main AMSS turning mechanism, casing components and securing items of the component parts, shafts, gearings, CPP components shall be so calculated that they can withstand without damage a load, which may cause breakdown of the propeller blade.

7.2.12 Main AMSS of icebreakers and ships with ice categories**Ice4** – **Ice6** shall be provided with a device to prevent the ice overload of turning mechanism.

7.2.13 Strength of the parts of main AMSS turning mechanism, components for securing to ship's hull shall be so calculated that they can withstand hydrodynamic and ice loads acting upon the propeller, nozzle and AMSS casing without damage.

It is permitted to determine hydrodynamic and ice loads on the AMSS components according to the results of hydrodynamic tests and testing of self-propelled models in the ice model basin according to the procedures approved by the Register.

7.2.14 The auxiliary steering arrangements for ship directional control shall be (refer also to Note **7.2.4**):

.1 of adequate strength and capable of steering the ship at navigable speed and of being brought speedily into action in an emergency;

.2 capable of changing direction of the ship directional control system from one side to the other at declared steering angle limits at an average rotational speed, of not less than 0,5°/s; with the ship running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater;

.3 for all ships, operated by power where necessary to meet the requirements of **7.2.11.2** and in any ship having power of more than 2500 kW propulsion power per thruster unit.

7.2.15 For technical condition monitoring of the main AMSS in service, they may be fitted with control facilities considering the requirements of Section **9** and Section **11**.

The technical condition monitoring system shall combine functions of built-in (fixed) systems and portable control facilities.

A list of the technical condition monitoring system equipment, controlled parameters and frequency of their measurements, as well as standards of technical condition of the AMSS control items are developed by manufacturers and/or suppliers of the equipment.

Technical substantiation of required control of the main AMSS shall be agreed upon with the Register in each particular case.

7.3 ALARMS

7.3.1 The AMSS shall be at least provided with alarms to be operated in the event of the following faults:

.1 overload and emergency stop of prime mover;

.2 power failure in remote control and alarm system;

.3 low level in lubricating oil tank (if provided);

.4 low lubricating oil pressure (if forced lubricating oil system);

.5 low oil level in hydraulic supply system for turning steerable propellers and CP-propeller blades;

.6 low oil level in head tank for sealing arrangements;

.7 high level in bilge wells of the hull and AMSS spaces.

7.3.2 Individual indication units shall be provided on the bridge for:

.1 overload of prime mover AMSS and servo mover for steerable propellers (if no automatic protection is provided);

.2 frequency of the propeller rotation, vertical-axis propeller or water jet impeller;

.3 blade turning angle or propeller pitch for CP-propeller plants;

.4 direction of thrust for fixed propeller plants, vertical-axis propeller or water jet;

.5 angular position of steerable propeller, water jet steering and reversing gear or vertical-axis propeller eccentricity;

.6 available power in the alarm system.

7.3.3 For auxiliary AMSS the number of parameters covered by the alarm system and indicator units may be reduced subject to agreement with the Register.

7.4 HYDRAULIC TESTS

7.4.1 Once assembled, the internal parts of the unit casing shall be subjected to test hydraulic pressure corresponding to the maximum operational depth of immersion with an allowance made for the overpressure of the sealing arrangements. For water-jet propellers pressure generated by water head shall be considered in case of reversing.

7.4.2 Once installed, the sealing arrangements shall be subjected to leak testing by pressure equal to the height of a liquid column in head tanks at an operational level.

7.4.3 In addition, it may be necessary to carry out non-destructive testing of welds on the steerable propeller components and other welded structures within the scope of requirements set forth in Part XIV "Welding".

8. TORSIONAL VIBRATION

8.1 GENERAL

8.1.1 The present Section applies to propulsion plants with the main engines having a power of not less than 75 kW when ICE are used and of not less than 110 kW when using turbo or electric drives, and to auxiliary diesel generators as well as to ICE-driven machinery having a primary engine power of not less than 110 kW.

8.1.2 Torsional vibration calculations shall be prepared both for the basic variant and for other variants and conditions possible in the operation of the installation, as follows:

.1 maximum power take-off and idling speed (with the propeller blades at zero position) for installations comprising CP-propellers or vertical axis propellers;

.2 individual and simultaneous operation of main engines with a common reduction gear;

.3 reverse gear (propulsion plant reversing mode);

.4 connection of additional power consumers if their moments of inertia are commensurate with the inertia moments of the working cylinder;

.5 running with one cylinder missfiring, for installations containing flexible couplings and reduction gear; to be assumed not firing is the cylinder the disconnection of which accounts to the greatest degree for the increase of stresses and alternating torques;

.6 damper jammed or removed where single main engine installations are concerned;

.7 flexible coupling blocked due to breakage of its elastic components (where single main engine installations are concerned).

8.1.3 For ships of restricted areas of navigation **R3, R3-IN, D-R3-S, D-R3-RS** calculations stipulated by **8.1.2.6** and **8.1.2.7** are not necessary.

No calculations shall be submitted if it is documented that the installation is similar to that approved earlier or that its mass inertia moments and torsion stiffness between masses do not differ from the basic ones by 10 per cent and 5 per cent accordingly or the calculation may be limited to determination of the natural frequencies if at this stage of the calculation it is established that the differences in the mass inertia moments and torsion stiffness between masses do not result in change of the natural frequency of any one of the modes under consideration by more than 5 per cent.

8.1.4 Torsional vibration calculations shall include:

.1 details of all the installation components:

particulars of engine, propeller, damper, flexible coupling, reduction gear, generator, etc.;

speeds corresponding to the principal long-term operating conditions specified for operation under partial loads (half speed, slow speed, dead slow speed, trawling operation, zero-speed operation for installations comprising CP-propellers, main diesel generator conditions, etc.);

layouts of all installation operating conditions possible;

initial data for the design torsional diagram of the installation;

.2 natural frequency tables for all basic modes of vibration having a resonance up to the 12th order inclusive within the speed range (0-1,2)n_r, with relative vibration amplitudes of masses and moments, and with scales of stresses (torques) for all sections of the system;

.3 for each order of all vibration modes under consideration:

resonance vibration amplitudes of the first mass of the system;

resonance stresses (torques) in all the system components (shafts, reduction gear, couplings, generators, compression or compression-key joints, etc.) and temperatures of the rubber components of flexible couplings as compared to relevant permissible values;

.4 total stresses (torques), where it is necessary to consider the simultaneous effect of disturbing moments of several orders, as compared to relevant permissible values;

.5 stress (torque) curves for the principal sections of the system with indication of permissible values for continuous running and rapid passage and of restricted speed ranges where these are assigned;

.6 conclusions based on the results of calculation.

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

8.2 PERMISSIBLE STRESSES FOR CRANKSHAFTS

8.2.1 For main engine crankshafts of icebreakers and of ships with ice categories **Ice4 – Ice6** within the speed range (0,7 - 1,05)n_r, and for main engine crankshafts of other types of ships and the crankshafts of engines driving generators and other auxiliary machinery for essential services within the speed range (0,9 - 1,05) n_r, the total stresses due to torsional vibration under conditions of continuous running shall not exceed the values determined by the following formulas:

when calculating a crankshaft in accordance with **2.4.5**, Part IX "Machinery"

$$\tau_1 = \pm\tau_N; \qquad (8.2.1\text{-}1)$$

when calculating a crankshaft by another method

$$\tau_1 = \pm 0{,}76\frac{R_m + 160}{18}C_d; \qquad (8.2.1\text{-}2)$$

within speed ranges lower than indicated

$$\tau_1 = \pm\frac{\tau_N\left[3 - 2(n/n_\text{p})^2\right]}{1{,}38}, \qquad (8.2.1\text{-}3)$$

or

$$\tau_1 = \pm 0{,}55\frac{R_m + 160}{18}C_d\left[3 - 2\left(n/n_\text{p}\right)^2\right], \qquad (8.2.1\text{-}4)$$

where:

τ_1 – permissible stresses, MPa;

τ_N – the maximum alternating torsional stress determined during crankshaft calculation from Formula (2.4.5.1), Part IX "Machinery" for the maximum value of W_p, in MPa;

R_m – tensile strength of shaft material, MPa. When using materials with the tensile strength above 800 MPa R_m = 800 MPa shall be adopted for calculation purposes.

n – speed under consideration, rpm.

For tugs, trawlers and other ships which main engines run continuously under conditions of maximum torque at speeds below the rated speed throughout the speed range $n = n_\text{r}$ shall be adopted and Formulas (8.2.1-1) and (8.2.1-2) shall be used. For the main diesel generators of ships with electric propulsion plants, all the specified values of n_r shall, by turn, be adopted as n, and in each of the ranges (0,9 - 1,05) n_r, Formulas (8.2.1-3) and (8.2.1-4) shall be used for partial loads;

n_r– rated speed, rpm;

$C_d = 0{,}35 + 0{,}93d^{-0{,}2}$ – scale factor;

d – shaft diameter, mm.

8.2.2 The total stresses due to torsional vibration within speed ranges prohibited for continuous running, but which may only be rapidly passed through shall not exceed the values determined by the following formulas:

for the crankshafts of main engines

$$\tau_2 = 2\tau_1; \qquad (8.2.2\text{-}1)$$

for the crankshafts of engines driving generators or other auxiliary machinery for essential services

$$\tau_2 = 5\tau_1, \qquad (8.2.2\text{-}2)$$

where:

τ_2 – permissible stresses for speed ranges to be rapidly passed through, MPa;

τ_1 – permissible stresses determined by one of Formulas (8.2.1-1) to (8.2.1-4).

8.3 PERMISSIBLE STRESSES FOR INTERMEDIATE, THRUST, PROPELLER SHAFTS AND

GENERATOR SHAFTS

8.3.1 Under conditions of continuous running, the total stresses due to torsional vibration shall not exceed the values determined by the formulas:

for the shafts of icebreakers and **Ice4 – Ice6** ice class ships within the speed range (0,7-1,05) n_r, and for the shafts of all other ships and generator shafts within the speed range (0,9 - 1,05) n_r

$$\tau_1 = \pm 1{,}38 \frac{R_m + 160}{18} C_k \; C_d \, ; \quad (8.3.1\text{-}1)$$

within speed ranges lower than indicated

$$\tau_1 = \pm \frac{R_m + 160}{18} C_k C_d \left[3 - 2\left(n / n_p\right)^2\right], \qquad (8.3.1\text{-}2)$$

where:

τ_1 – допустимі напруження, МПа;

R_m – tensile strength of the shaft material, MPa.

When using the material with the tensile strength over 800 MPa (for intermediate and thrust shafts of alloyed steel) and over 600 MPa (for intermediate and thrust shafts of carbon and carbon-manganese steel, as well as for propeller shaft) R_m =800 MPa and R_m =600 MPa shall be assumed in the calculations accordingly;

C_k – factor obtained from Table 8.3.1;

for C_d, n, n_p – refer to 8.2.1.

Table 8.3.1 **Coefficient C_k**

Structural shaft type		C_k
Intermediate shaft, thrust shaft in external thrust bearing outside the area of roller bearing or the collar area, generator shaft	with integral coupling flanges or shrink fit couplings [1]	1,0
	with a radial hole (refer to **5.2.7**)	0,50
	with a taper joint keyway (refer to **5.2.9**)	0,60
	with a cylindrical joint keyway (refer to. **5.2.9**)	0,45
	with a longitudinal slot (refer to **5.2.8**)	0,30[2]
Thrust shaft in way of the collar or the roller thrust bearing (refer to **5.2.2**)		0,85
Гребний вал	forward sections (k=1,15, refer to **5.2.3**)	0,80
	sections in way of the aft stern-tube bearing and propeller (k=1,22, k=1,26, refer to **5.2.3**)	0,55

[1] when shafts may experience vibratory stresses close to the permissible stresses for continuous operation, the diameter increase in the compression joint shall be provided.

[2] other C_k value may be substantiated and calculated. C_k = 1,45/*scf*,

where: *scf* 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).

8.3.2 The total stresses due to torsional vibration within speed ranges prohibited for continuous running, but which may only be rapidly passed through shall not exceed:

for intermediate, thrust, propeller shafts and shafts of generators driven by the main engine

$$\tau_2 = \frac{1{,}7\tau_1}{\sqrt{C_k}} \, ; \qquad (8.3.2)$$

for the shafts of generators driven by auxiliary engines, the value determined by Formula (8.2.2-2).

8.4 PERMISSIBLE TORQUE IN REDUCTION GEAR

8.4.1 For the case of continuous running or rapid passage, the alternating torques in any reduction gear step shall not exceed the permissible values established for the operating conditions by the manufacturer.

8.4.2 Where the values mentioned under **8.4.1** are not available, the alternating torque in any reduction gear step for the case of continuous running shall satisfy the following conditions:

within the speed range (0,7 to 1,05) n_r - for the main propulsion plants of icebreakers and ice class ships **Ice4 – Ice6** and (0,9 to 1,05) n_r - for other ships

$$M_{alt} \leqslant 0{,}3 M_{nom} \, ; \qquad (8.4.2\text{-}1)$$

within speed ranges lower than indicated, the permissible value of alternating torque calculations shall be submitted to the Register review but in any case

$$M_{alt} \leqslant 1{,}3M_{nom} - M, \qquad (8.4.2\text{-}2)$$

where:
M_{nom} – average torque in the step under consideration at nominal speed, N/m;
M – average torque at the speed under consideration, N/m.

For the case of rapid passage, the alternating torque value shall also be submitted to the Register review.

8.5 PERMISSIBLE TORQUE AND TEMPERATURE OF FLEXIBLE COUPLINGS

8.5.1 For the case of continuous running or rapid passage, the alternating torque in a coupling, relevant stresses in and temperatures of the flexible component material due to torsional vibration shall not exceed the permissible values established for the operating conditions by the manufacturer.

8.5.2 Where the values mentioned under **8.5.1** are not available, the torque, stress and temperature values permissible for continuous running and rapid passage shall be determined by the procedures approved by the Register.

8.6 OTHER INSTALLATION COMPONENTS

8.6.1 Under conditions of continuous running, the total torque (average torque plus alternating torque) shall not exceed the frictional torque in the keyless fitting of the propeller and shaft or shafting couplings.

8.6.2 Where, for generator rotors, the manufacturer's permissible values are not available, the alternating torque shall not exceed twice, in the case of continuous running, or six times, in the case of rapid passage, the nominal generator torque.

8.7 TORSIONAL VIBRATION MEASUREMENT

8.7.1 Data obtained from torsional vibration calculations for machinery installations with the main engines shall be confirmed by measurements.

The measurements shall cover all the variants and operation conditions of the installation, for which calculations were made in accordance with **8.1.2**, except emergency operation conditions listed in **8.1.2.6** and **8.1.2.7**.

In well-grounded cases, the Register may require torsional vibrations to be measured in auxiliary diesel generators and ICE-driven auxiliary machinery for essential services.

8.7.2 The results of measurement obtained on the first ship (unit) of a series apply to all the ships (units) of that series, provided their engine-shafting-propeller (driven machinery) systems are identical.

8.7.3 The free resonance vibration frequencies obtained as a result of measurement shall not differ from the design values by more than 5 per cent. Otherwise, the calculation shall be corrected accordingly.

8.7.4 The stresses shall be determined proceeding from the greatest vibration or stress amplitudes measured in the respective section of the torsiogram or oscillogram.

When estimating the total stresses due to vibration of several orders, the registered parameters shall undergo harmonic analysis.

8.8 RESTRICTED SPEED RANGES

8.8.1 Where the shaft stresses, torques in some installation components or temperature of the rubber componenets of flexible couplings arising due to torsional vibration exceed the relevant permissible values for continuous running determined in accordance with **8.2.1**, **8.3.1**, **8.4 – 8.6**, restricted speed ranges are assigned.

8.8.2 No restricted speed ranges are permitted for the following speeds:

$n \geq 0{,}7n_r$ – with respect to icebreakers and **Ice4 – Ice6** ice class ships;

$n \geq 0{,}8n_r$ – with respect to other ships;

$n = (0{,}9\text{–}1{,}05)n_r$ – with respect to diesel generators and other auxiliary diesel machinery for essential services.

Where the main diesel generators of ships with electric propulsion plants are concerned, all the fixed speed values corresponding to the specified conditions of partial loading shall alternately be adopted for n_r.

In icebreakers and **Ice6** ice class ships fitted with a FPP, blade frequency resonance is recommended tobe avoided within the range $(0{,}5\text{–}0{,}8)n_r$.

Barred speed range with one cylinder misfiring in case of one main engine on board the ship shall not influence the ship's steerability.

8.8.3 If all the other methods of lowering stresses (torques) due to torsional vibration prove ineffective, a vibration damper or antivibrator may be fitted where the values permitted by **8.2** to **8.6** are exceeded:

in the case of continuous running, within speed ranges where restricted speed range is not permitted or undesirable;

in the case of rapid passage, in any point of the speed range $(0–1,2)n_r$.

8.8.4 The vibration damper or antivibrator shall ensure lowering of stresses (torques) by not less than 85 per cent of the relevant permissible values at the resonance to which it is adjusted.

8.8.5 For icebreakers and **Ice4 – Ice6** ice class ships within the main engine speed range (0,771,05)nr and for other ships and diesel generators within the speed range $(0,9–1,05)n_r$, vibration dampers or antivibrators may be used to eliminate restricted speed ranges shall be agreed upon with the Register.

8.8.6 A restricted speed range is established proceeding from the speed range, in which the stresses (torques, temperature) exceed the permissible values increased by 0,02 of n_{res} on both sides (with regard to tachometer tolerance). The engine shall be stable in operation at the barred range boundaries.

For calculation purposes, the restricted speed range borders may be determined by the following formula

$$\frac{16n_{res}}{18 - n_{res}/n_r} \leqslant n \leqslant \frac{(18 - n_{res}/n_r)n_{res}}{16}, \qquad (8.8.6)$$

where: n_{res} – resonance speed, rpm.

For CPP with the possibility of individual pitch and speed control, both full and zero pitch conditions shall be considered.

8.8.7 Restricted speed ranges shall be marked off on the tachometer in accordance with **2.5.2**. Information on restricted speed ranges and their borders shall be made available on plates fastened at all the stations, from which the installation may be controlled.

8.8.8 For the case of remote control of the main machinery from the wheelhouse, the requirements of **4.2.2.4**, Part XV "Automation" shall be complied with.

9. VIBRATION OF MACHINERY AND EQUIPMENT. VIBRATION STANDARDS

9.1 GENERAL

9.1.1 This Section sets down the limits of vibration levels (vibration standards) for ships machinery and equipment.

The standards are intended to determine whether actual vibration levels in machinery and equipment installed onboard the ships during construction (after repair) and ships in service are permissible proceeding from vibration parameter measurements. The vibration standards provide three categories of technical condition of ship machinery and equipment:

A - condition of machinery and equipment after manufacturing (construction of the ship) or repair at the commissioning;

B - condition of machinery and equipment during normal operation;

C - condition of machinery and equipment when technical maintenance or repair is required.

The standards determine the upper limits of categories A and B.

For machinery and equipment, not mentioned in this section but affecting the safe operation of the ship, if it is required to assess their levels of vibration, one shall be guided by the standards specified by the manufacturer, or applicable national and international standards.

Manufacturer of ships machinery and equipment may apply other standards provided convincing data are available that the product is capable of operating under other vibration conditions.

9.1.2 Vibration measurements shall be taken on all the first ships of a series being built at each shipyard, on the first ship of modified design, on the single buildings and on the ships undergone conversion.

Vibration measurements of machinery and equipment shall be taken during construction of the ship according to the program approved by the Register.

Technical documentation on the results of measurements is submitted in accordance with the requirements of **1.5**, Part II «Hull».

9.1.3 During construction of the ship (or after repair) the vibration level of the machinery and equipment shall not exceed the upper limit of category A, determined as to ensure sufficient margin for changing of vibration level in operation.

Under conditions of long-term service of the ship the vibration level of the machinery and equipment shall not exceed the upper limit of category B, determined as to ensure vibration strength and reliability of ship machinery and equipment.

9.1.4 The measurement results shall be compared with the permissible vibration levels. Where vibration exceeds the standards, measures shall be taken to reduce it to permissible level.

9.1.5 Vibration levels of machinery and equipment shall not exceed the standards both when the ships is lying and at specified ahead speeds under different loading conditions.

At non-specified rates of speed vibration exceeding established standards may be permitted, when these rates are not continuous.

9.1.6 In case of withdrawal from the present standards the technical substatiation shall be submitted to the Register review.

9.2 STANDARDIZED VIBRATION PARAMETERS

9.2.1 The root-mean square value of vibration rate, measured in 1/3-octave band, is assumed as the basic vibration parameter.

Measuring of vibration in octave band is allowed.

9.2.2 Alongside with the vibration rate the root-mean square value of vibration acceleration may also be a parameter measured.

9.2.3 Vibration parameters are measured in absolute units or in decibels relatively to standard limiting values of speed or acceleration being equal to $5 \cdot 10^{-5}$ mm/s, and $3 \cdot 10^{-4}$ m/s^2, , accordingly..

Conversion of the measured values of vibration rate into relative units shall be made using the formula

$$L = 20\lg \frac{v_e}{v_{eo}} , \qquad (9.2.3)$$

where:

v_e – the measured root-mean square value of vibration rate, mm/s;

v_{eo} – $5 \cdot 10^{-5}$ mm/s.

9.2.4 When vibration is measured in octave bands, the permissible values of the parameter measured may be increased by $\sqrt{2} = 1{,}41$ times (3 dB) as compared to those stated in 9.3 to 9.8 for bands with geometric mean frequency values of 2; 4; 8; 16; 31,5; 63; 125; 250 and 500 Hz.

9.2.5 Measurements of vibration of the machinery and equipment shall be taken for each of the three inter-perpendicular direction about the ship axes: vertical, horizontal-transverse and horizontal-longitudinal.

For internal combustion engines, measurements of vibration shall be taken according to direction of axes:

X - axial (coincident with the direction of the crankshaft),

Y - horizontal-transverse,

Z - vertical. Such designation shall be applied for main diesel engines and diesel engines of diesel-generators. The points of vibration measuring are indicated in Fig. 9.2.5.

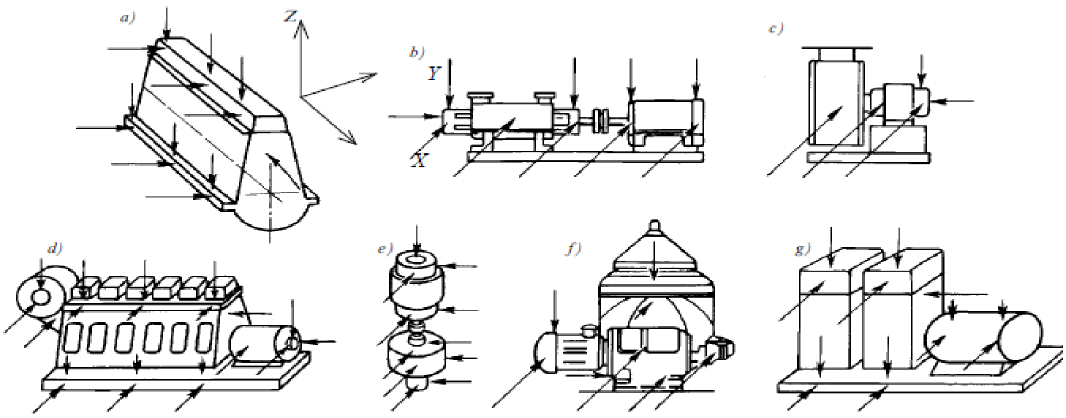

Fig. 9.2.5 Points of vibration measuring:
a - internal comb[illegible] engine; *b* - horizontal pump; *c* - fan; *d* - diesel-generator; *e* - vertical pump; *f* - separator; *g* - pisto[illegible]ressor. The points and directions of vibration measurement are shown by arrows.

9.2.6 Vibration standards of machinery are specified in the relative chapters for rigid and yielding supports to which machinery can be attached under shipboard conditions.

Rigid supports are those supports where the first natural frequency of the "support - machinery" system exceeds the basic exciting frequency (working frequency of revolution) in the vibration measurement direction by more than 25 per cent.

Yielding support is a support where the first natural frequency is less than 25 per cent of the machinery working frequency of revolution.

Yielding of the support is ensured by resilient mounting of the machinery or support (vibration insulators of various design - shock absorbers, springs, rubber insulators, etc.).

The vibration standards of categories A and B for machinery installed on rigid supports are specified in the relevant tables and figures. When the machinery is attached to yielding supports, the values of permissible vibration standards are increased. To determine the values of permissible vibration rate, multiplication factor for the particular type of machinery shall be applied.

9.3 VIBRATION STANDARDS FOR INTERNAL COMBUSTION ENGINES

9.3.1 Vibration standards are extended to cover ICE with 55 kW and above in power and rotation frequency ≤ 3000 m^{-1}.

9.3.2 Vibration of low-speed internal combustion engines installed on rigid supports is considered permissible for categories A and B, provided the root-means quare values of vibration rate and vibration acceleration measured in the direction of axes x and z do not exceed the values specified in Table 9.3.2 and Fig. 9.3.2.

When vibration is measured along the axis y (in horizontal-transverse direction) the permissible vibration rate standards for categories A and B shall be increased by 1,4 times.

When the internal combustion engines are installed on yielding supports (main medium-speed diesel engines and diesel engines of diesel-generators) the permissible vibration standards for categories A and B in the direction of axes x, y and z specified in Table 9.3.2 and Fig. 9.3.2 shall be increased by 1,4 times.

9.3.3 Vibration of machinery and devices hung on ICE shall not exceed the levels given in **9.3.2**.

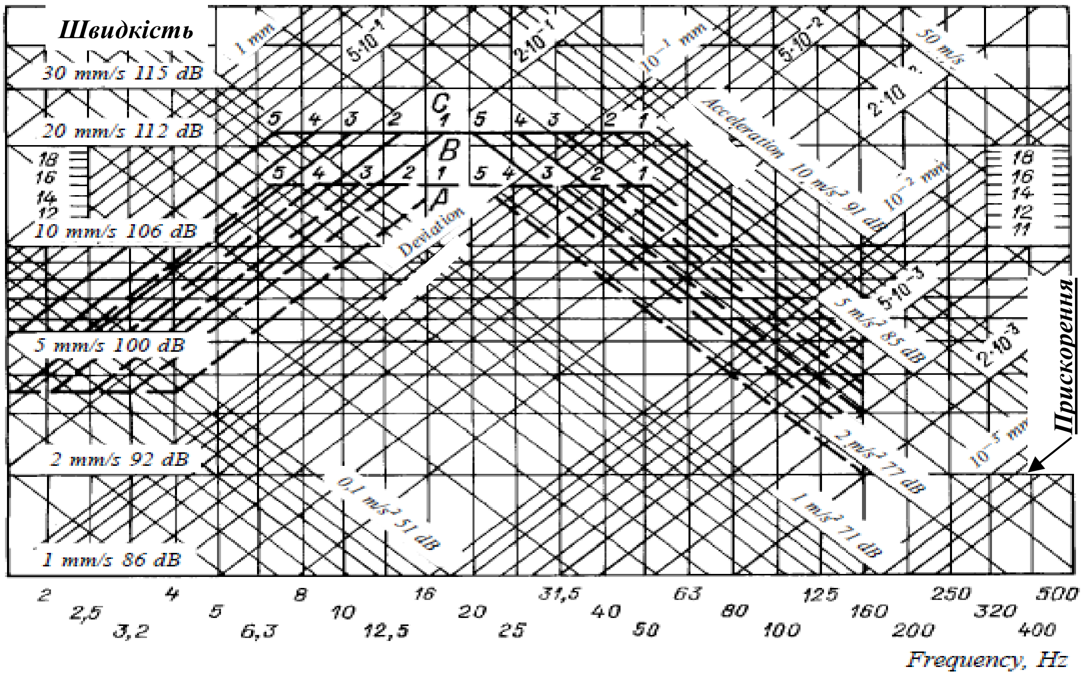

Fig.9.3.2. Vibration standards for internal combustion engines with a piston stroke:
1 – under 30 cm; 2 – 30 to 70 cm; 3 –71 to 140 cm; 4 –141 – 240 cm; 5 – over 240 cm;
.... Upper limit of category *A*; ——— Upper limit of category *B*.

9.3.4 Vibration of turbo-compressors measured on bearing housings is considered permissible for categories A and B, provided the root-meansquare values of vibration rate or vibration acceleration do not exceed the values specified in Table 9.3.4 and Fig. 9.3.4.

Table 9.3.2 **Vibration standards for internal combustion engines**

Line	Geometric mean frequencies of 1/3-octave bands, Hz	Engines with piston stroke, cm											
		under 30				30 to 70				71 to 140			
		Permissible values of vibration rate											
		category A		category B		category A		category B		category A		category B	
		mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	1,6	4	98	5,6	101	4	98	5.6	101	4	98	5,6	101
2	2	4	98	5,6	101	4	98	5.6	101	4	98	5,6	101
3	2,5	4	98	5,6	101	4	98	5,6	101	4	98	5,6	101
4	3,2	4	98	5.6	101	4	98	5.6	101	4.5	99	6,3	102
5	4	4	98	5.6	101	4.5	99	6,3	102	5,6	101	8,0	104
6	5	4,5	99	6.3	102	5.6	101	8,0	104	7.1	103	10	106
7	6,3	5,6	101	8.0	104	7,1	103	10	106	8.9	105	12,5	108
8	8	7,1	103	10	106	8.9	105	12.5	108	11	107	16	110
9	10	8,9	105	12.5	108	11	107	16	110	14	109	20	112
10	12,5	11	107	16	110	14	109	20	112	16	110	22	113
11	16	14	109	20	112	16	110	22	113	16	110	22	113
12	20	16	110	22	113	16	110	22	113	16	110	22	113
13	25	16	110	22	113	16	110	22	113	16	110	22	113
14	31,5	16	110	22	113	16	110	22	113	16	110	22	113
15	40	16	110	22	113	16	110	22	113	12,5	108	18	111
16	50	16	110	22	113	12,5	108	18	111	10	106	14	109
17	63	12,5	108	18	111	10	106	14	109	8	104	11	107
18	80	10	106	14	109	8	104	11	107	6,3	102	8,9	105
19	100	8	104	11	107	6.3	102	8.9	105	5	100	7.1	103
20	125	6,3	102	8.9	105	5	100	7,1	103	4	98	5.6	101
21	160	5	100	7.1	103	4	98	5.6	101	3,2	96	4,5	99

Line	Geometric mean frequencies of 1/3-octave bands, Hz	Engines with piston stroke, cm							
		141 to 240				over 240			
		Permissible values of vibration rate							
		category A		category B		category A		category B	
		mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB
1	**2**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	1,6	4	98	5,6	101	4	98	5,6	101
2	2	4	98	5.6	101	4,5	99	6.3	102
3	2,5	4.6	99	6,3	102	5,6	101	8,0	104
4	3,2	5.6	101	8,0	104	7,1	103	10	106
5	4	7.1	103	10	106	8.9	105	12,5	108
6	5	8.9	105	12,5	108	11	107	16	110
7	6,3	11	107	16	110	14	109	20	112
8	8	14	109	20	112	16	110	22	113
9	10	16	110	22	113	16	110	22	113
10	12,5	16	110	22	113	16	110	22	113
11	16	16	110	22	113	16	110	22	113
12	20	16	110	22	113	16	110	22	113
13	25	16	110	22	113	12,5	108	18	111
14	31,5	12,5	108	18	111	10	106	14	109
15	40	10	106	14	109	8	104	11	107
16	50	8	104	11	107	6,3	102	8,9	105
17	63	6,3	102	8,9	105	5	100	7,1	103
18	80	5	100	7,1	103	4	98	5,6	101
19	100	4	98	5,6	101	3,2	96	4.5	99
20	125	3.2	96	4,5	99	2,5	94	3,6	97
21	160	2.5	94	3,6	97	2	92	2,8	95

Table 9.3.4 **Vibration standards for turbo-compressors**

Line	Geometric mean frequencies of 1/3-octave band, Hz	Значення віброшвидкості, які є допустимими			
		category A		category B	
		mm/s	dB	mm/s	dB
1	2	3	4	5	6
1	1,6	10	106	1	109
2	2	12,5	108	16	110
3	2,5	14	109	20	112
4	3,2	20	112	25,5	114
5	4	24	114	34	116
6	5	24	114	34	116
7	6,3	24	114	34	116
8	8	24	11	34	116
9	10	24	114	34	116
10	12,5	24	114	34	116
11	16	24	114	34	116
12	20	24	114	34	116
13	25	24	114	34	116
14	31,5	24	114	34	116
15	40	24	114	34	116
16	50	24	114	34	116
17	63	24	114	34	116
18	80	24	114	34	116
19	125	24	114	34	116
20	160	24	114	34	116
21	200	24	114	34	116
22	250	18	111	26	116
24	320	14	109	20	112
24	400	11	107	16	110
25	500	9	106	13	109

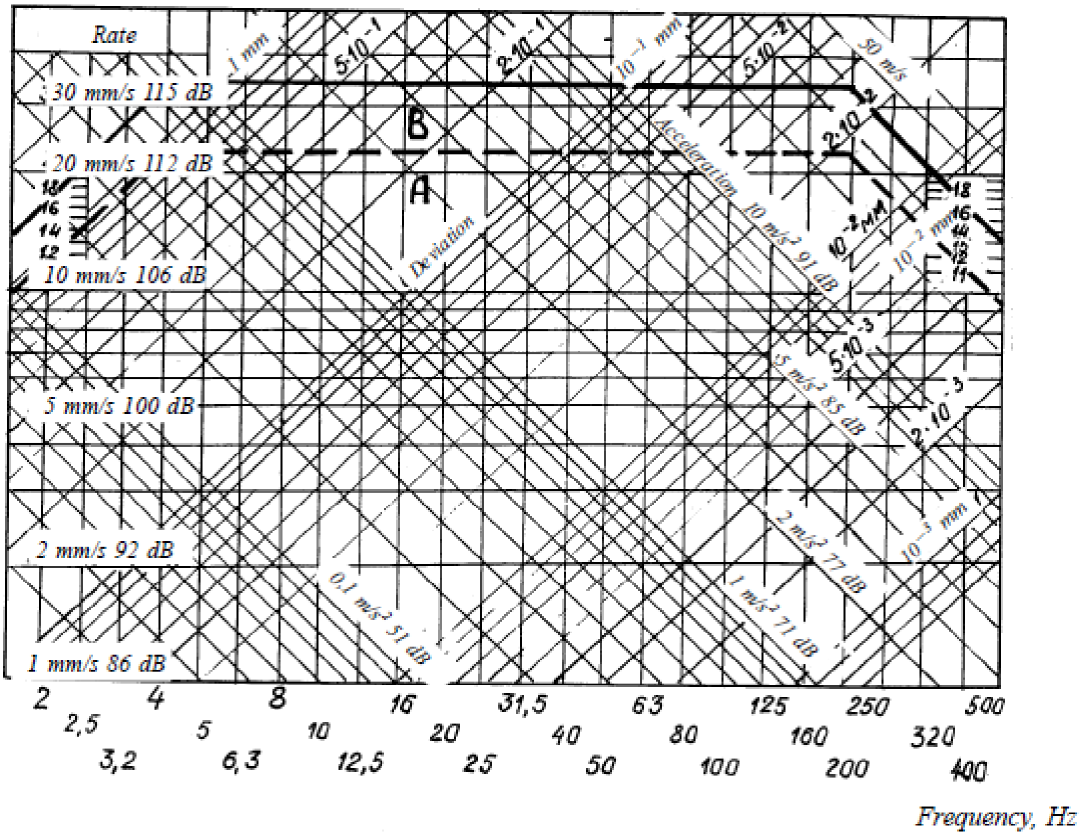

Fig.9.3.4. Vibration standards for turbo-compressors of internal combustion engines:
- - - - - - - - - - Upper limit of category *A*; ———————— Upper limit of category *B*.

9.4 VIBRATION STANDARDS FOR MAIN GEARED TURBINES AND THRUST BEARINGS

9.4.1 The running vibration of 15000 to 3000 kW horse power main geared turbines measured on the bearing housings is considered permissible for categories *A* and *B*, provided the root-means quare values of vibration rate or vibration acceleration do not exceed the values specified in Table 9.4.1 and Fig. 9.4.1.

The vibration standards specified in Table 9.4.1 and Fig. 9.4.1 shall be applied to the main geared turbines when installed both on rigid and on yielding supports.

Table 9.4.1 **Vibration standards for main geared turbines, thrust bearings, boilers, heat exchangers, ICE-driven generators, shaft-generators, turbo-drives, turbo-generators and piston compressors**

Line	Geometric mean frequencies of 1/3-octave bands, Hz	Main geared turbines and trust bearings				Boilers and heat exchangers			
		Permissible values of vibration rate							
		category A		category B		category A		category B	
		mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1.6	1,5	90	2,5	94	3,5	97	5,6	101
2	2	1,9	92	3,1	96	3,5	97	5,6	101
3	2,5	2,4	94	3,8	98	3,5	97	5,6	101
4	3,2	3	96	4,8	100	4,4	99	7,1	103
5	4	3,7	97	6	102	5,6	101	8,9	105
6	5	4,6	99	7,5	104	7	103	11	107
7	6,3	5,7	101	9,3	105	8,8	105	14	109
8	8	7	103	11.5	107	10	106	16	110
9	10	8,8	105	14,5	109	10	106	16	110
10	12,5	11	107	18	111	10	106	16	110
11	16	11	107	18	111	10	106	16	110
12	20	11	107	18	111	10	106	16	110
13	25	11	107	18	111	10	106	16	110
14	31,5	11	107	18	111	10	106	16	110
15	40	11	107	18	111	10	106	16	110
16	50	8,8	105	14,5	109	8	104	12,5	106
17	63	7	103	11,5	107	6.3	102	10	106
18	80	5,7	101	9,3	105	5,2	100	8	104
19	100	4,6	99	7,5	104	–	–	–	–
20	125	–	–	–	–	–	–	–	–
21	160	–	–	–	–	–	–	–	–
22	200	–	–	–	–	–	–	–	–
23	250	–	–	–	–	–	–	–	–

Line	Geometric mean frequencies of 1/3-octave bands, Hz	ICE-driven generators, turbodrives and turbo-generators [1]			Piston compressors				
		Permissible values of vibration rate							
		category A		category B	category A			category B	
		mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB
1	**2**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	1.6	1	86	1,6	90	2	92	3,2	96
2	2	1,3	88	1,9	92	2,5	94	4	98
3	2,5	1,5	90	2,4	94	3,1	96	5,1	100
4	3,2	1,9	92	3	96	4	98	6.4	102
5	4	2,3	93	3,7	97	5	100	8	104
6	5	2,9	95	4,6	99	6,2	102	10	106
7	6,3	3,6	97	5,7	101	7,9	104	12,5	108
8	8	4,5	99	7,1	103	10	106	16	110
9	10	5,6	101	8,9	105	10	106	16	110
10	12,5	7	103	11	107	10	106	16	110
11	16	7	103	11	107	10	106	16	110
12	20	7	103	11	107	10	106	16	110
13	25	7	103	11	107	10	106	16	110
14	31,5	7	103	11	107	10	106	16	110
15	40	7	103	11	107	10	106	16	110
16	50	7	103	11	107	10	106	16	110
17	63	7	103	11	107	7.9	104	12,5	108
18	80	7	103	11	107	6.2	102	10	106
19	100	5,6	101	8,9	105	5	100	8	104
20	125	4,5	99	7,1	103	4	98	6,4	102
21	160	3,6	97	5,7	101	3,1	96	5,1	100
22	200	2,9	95	4,6	99	2,5	94	4	98
23	250	2,3	93	3,7	97	2	92	3,2	96
24	320	1,9	92	3	96	1,6	90	2,5	94
25	400	–	–	–	–	1,3	88	2,1	92
26	500	–	–	–	–	1	86	1,6	90

[1] Refer to 9.5.4

9.4.2 For main geared turbines of less than 15000 kW power the vibration standards are 3 dB lower than the values specified in Table 9.4.1 and Fig. 9.4.1.

9.4.3 Vibration of thrust bearings shall not exceed the standards given in **9.4.1** and **9.4.2**.

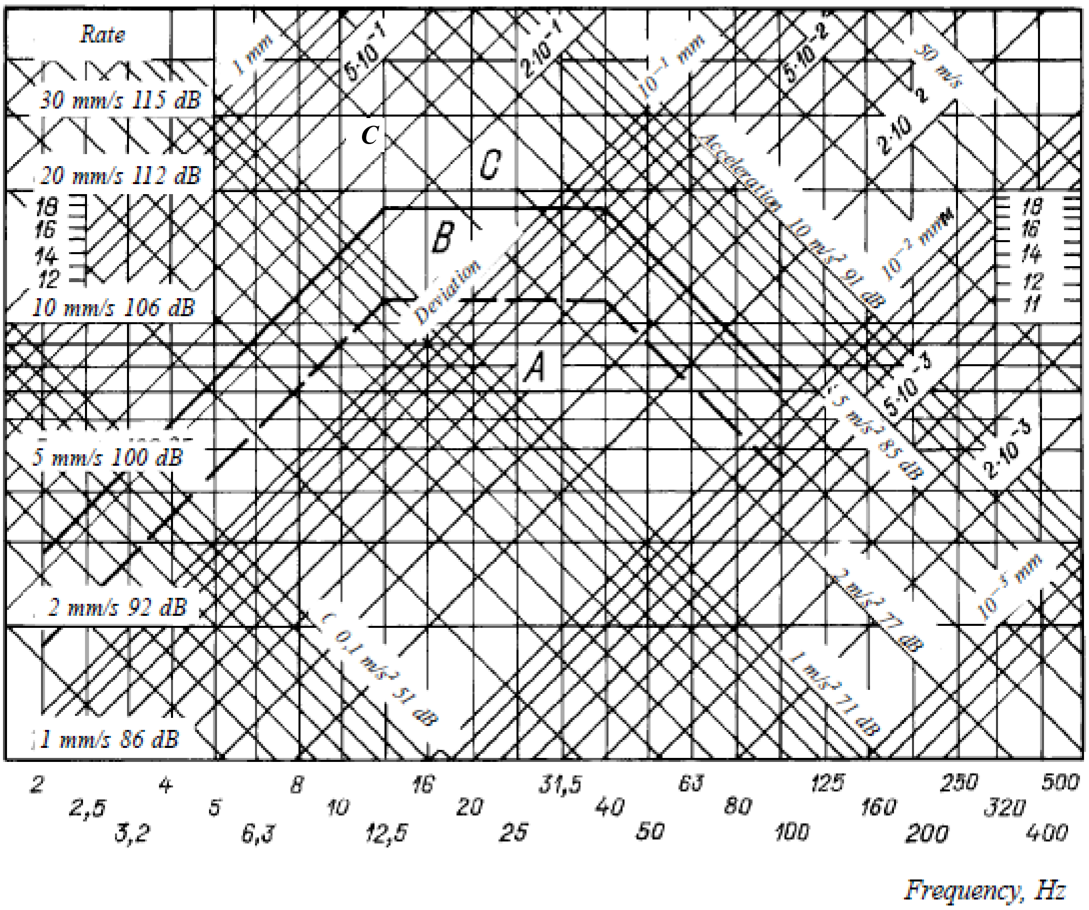

Fig. 9.4.1. Vibration standards for main steam geared turbines of 15000 to 30000 kW capacity and thrust bearings:

- - - - - - - - - - Upper limit of category A;

———————— Upper limit of category B.

9.5 VIBRATION STANDARDS FOR AUXILIARY MACHINERY OF ROTARY TYPE

9.5.1 Vibration of vertical pumps with the capacity of 15 to 75 kW, including their electric drive, is assumed permissible for categories A and B, when the root-mean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.5.1 and in Fig. 9.5.1.

For pumps having the capacity of 2 to 15 kW the vibration standards for categories A and B are assumed being 3 dB lower compared with the vibration standards for the pumps hewing the capacity of 15 to 75 kW, and for the pumps with the capacity of 75 to 300 kW such standards shall be raised by 2 dB. Vibration standards for horizontal pumps for the above mentioned capacity range are assumed being 2 dB lower.

The vibration standards specified in Table 9.5.1 and Fig. 9.5.1 shall be applied to all pumps when installed on rigid support.

In case when the pumps are installed on yielding support, the permissible vibration standards shall be increased by 1,4 times for categories A and B.

9.5.2 Vibration of centrifugal separators is assumed permissible for categories A and B, when the rootmean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.5.1 and in Fig. 9.5.2.

The vibration standards are specified considering the installation of separators on shock absorbers.

9.5.3 Vibration of fans and gas blowers of the inert gas systems is assumed permissible for categories A and B, when the root-mean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.5.1 and in Fig. 9.5.3.

The vibration standards are specified considering the installation of fans and gas blowers on shock absorbers.

In case of rigid fixing, these standards shall also be applied.

Table 9.5.1 **Vibration standards for pumps, centrifugal separators and fans**

Geometric mean frequencies of 1/3-octave bands, Hz	Pumps with the capacity of 15 to 75 kW				Centrifugal separators				Fans			
	Permissible values of vibration rate											
	category *A*		category *B*		category *A*		category *B*		category *A*		category *B*	
	mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB	mm/s	dB
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1.6	1	86	1	86	1	86	1,3	88	1	86	1,3	88
2	1	86	1,2	88	1	86	1,6	90	1	86	1,6	90
2,5	1.1	87	1,4	89	1.3	88	2	92	1,3	88	2	92
3,2	1,4	89	2	92	1,6	90	2,5	94	1,6	90	2.5	94
4	1,7	91	2,5	94	2	92	3,2	96	2	92	3.2	96
1	2	3	4	5	6	7	8	9	10	11	12	13
5	2.2	93	3,3	96	2.5	94	4	98	2.6	94	4	98
6,3	2,7	95	4	98	3,2	96	5	100	3,3	96	5	100
8	3.5	97	5	100	4	98	6,4	102	4.1	98	6.4	102
10	4,3	99	6,3	102	5	100	8	104	5.2	100	8	104
12,5	5,5	101	8	104	5	100	8	104	6.7	103	10,3	106
16	7	103	10	106	5	100	8	104	8,5	105	13	108
20	7	103	10	106	5	100	8	104	8,5	105	13	108
25	7	103	10	106	5	100	8	104	8,5	105	13	108
31,5	7	103	10	106	5	100	8	104	8,5	105	13	108
40	7	103	10	106	5	100	8	104	8,5	105	13	108
50	7	103	10	106	5	100	8	104	8.5	105	13	108
63	7	103	10	106	5	100	8	104	6.7	103	10,3	106
80	5,5	101	8	104	5	100	8	104	5.2	100	8	104
100	4,3	99	6,3	102	5	100	8	104	4,1	98	6,4	102
125	3,5	97	5	100	4	98	6.4	102	3.3	96	5	100
160	2,7	95	4	98	3,2	96	5	100	2.6	94	4	98
200	2.2	93	3,3	96	2,5	94	4	98	2	92	3,2	96
250	1.7	91	2,5	94	2	92	3,2	96	1.6	90	2,5	94
320	1,4	89	2	92	1,6	90	2.5	94	1,3	88	2	92
400	–	–	–	–	1,3	88	2	92	1	86	1,6	90
500	–	–	–	–	1	86	1,6	90	1	86	1,3	88

9.5.4 Vibration of turbo-drives, turbo-generators and generators of diesel-generators (ICE-driven generators) with the capacity of 1000 to 2000 kW, measured on the bearing housings, is assumed permissible for categories A and B, when the root-mean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.4.1 and in Fig. 9.5.4.

For the turbo-drives, turbo-generators and generators of diesel-generators with the capacity under 1000 kW the vibration standards for categories A and B are by 4 dB lower than the values stated in Table 9.4.1 and in Fig. 9.5.4.

The vibration standards for turbo-drives and turbo-generators shall be applied when these are installed both on rigid and on yielding supports.

The vibration standards for generators of diesel-generators when installed on yielding supports shall be doubled.

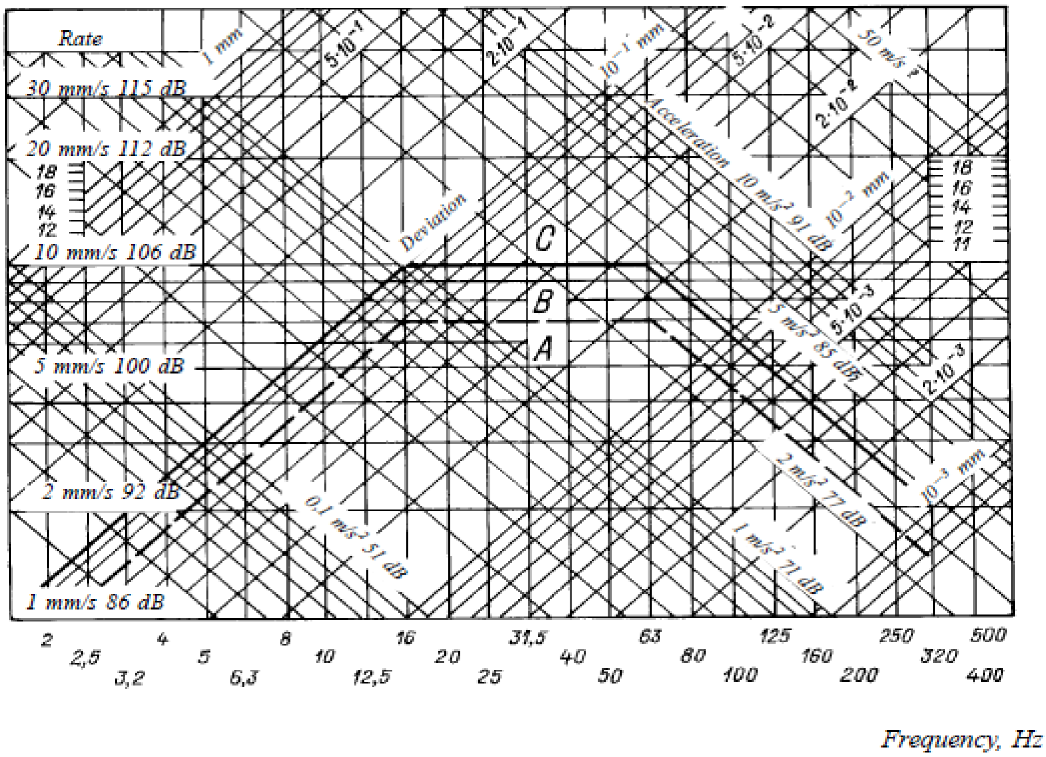

Fig.9.5.1. Vibration standards for pumps with the capacity of 15 to 75 kW

- - - - - - - - - - Upper limit of category A; ———— Upper limit of category B.

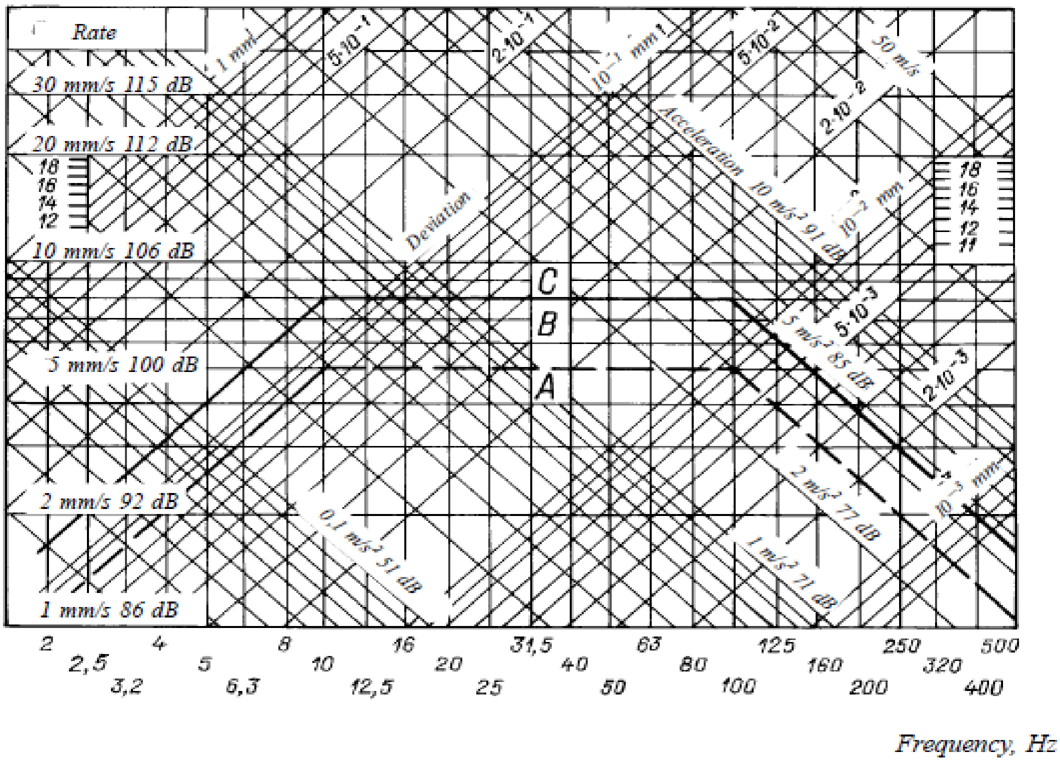

Fig.9.5.2. Vibration standards for centrifugal separators

- - - - - - - - - - Upper limit of category A; ———— Upper limit of category B.

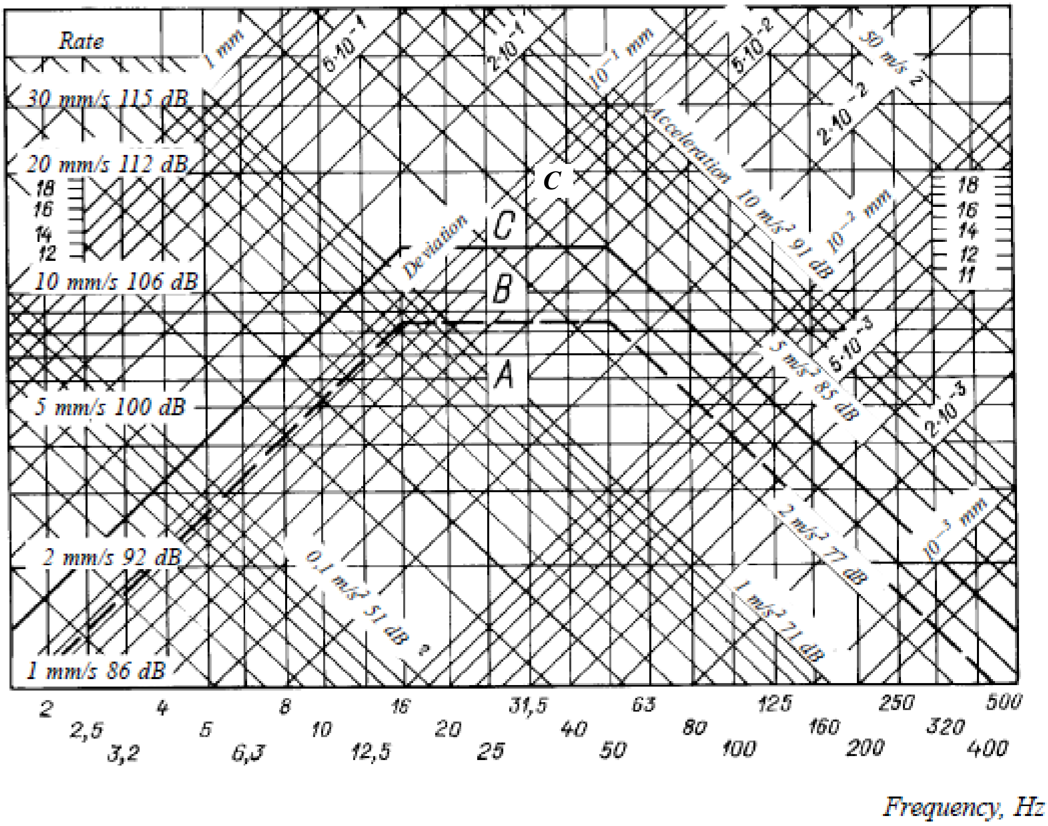

Fig.9.5.3. Vibration standards for fans

- - - - - - - - - - Upper limit of category A; ———————— Upper limit of category B.

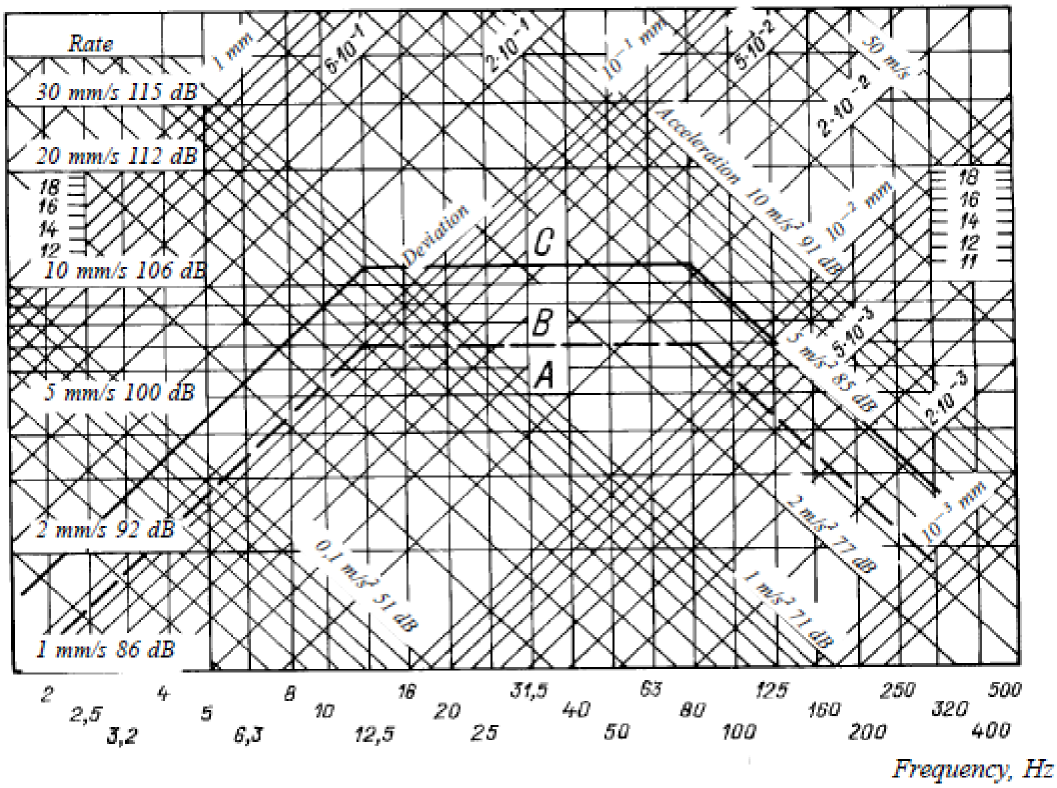

Fig.9.5.4. Vibration standards for ICE-driven generators, shaft-generators, turbo-drives and turbo-generators of 1000 to 2000 kW capacity

- - - - - - - - - - Upper limit of category A; ———————— Upper limit of category B.

9.6 VIBRATION STANDARDS FOR PISTON AIR COMPRESSORS

9.6.1 Vibration of piston air compressors is assumed permissible for categories A and B, when the rootmean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.4.1 and in Fig. 9.6.1.

When the compressor is mounted on the shock-absorbers, the vibration standards shall be raised by 4 dB.

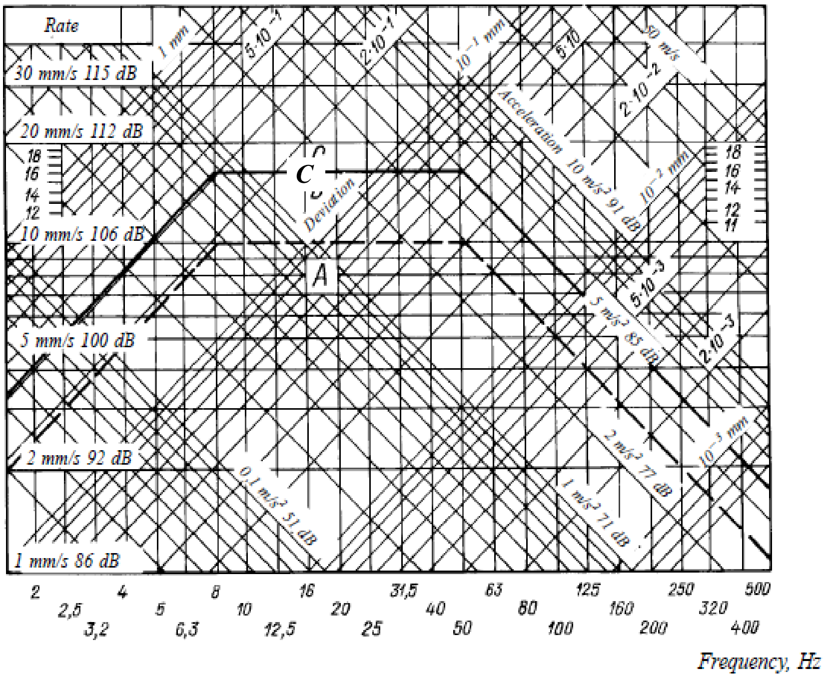

Fig.9.6.1. Vibration standards for piston compressors

- - - - - - - - - - Upper limit of category A; ———————— Upper limit of category B.

9.7 VIBRATION STANDARDS FOR BOILERS AND HEAT EXCHANGERS

9.7.1 Vibration of boilers and heat exchangers is assumed permissible for categories A and B, when the root-mean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.4.1 and in Fig. 9.7.1.

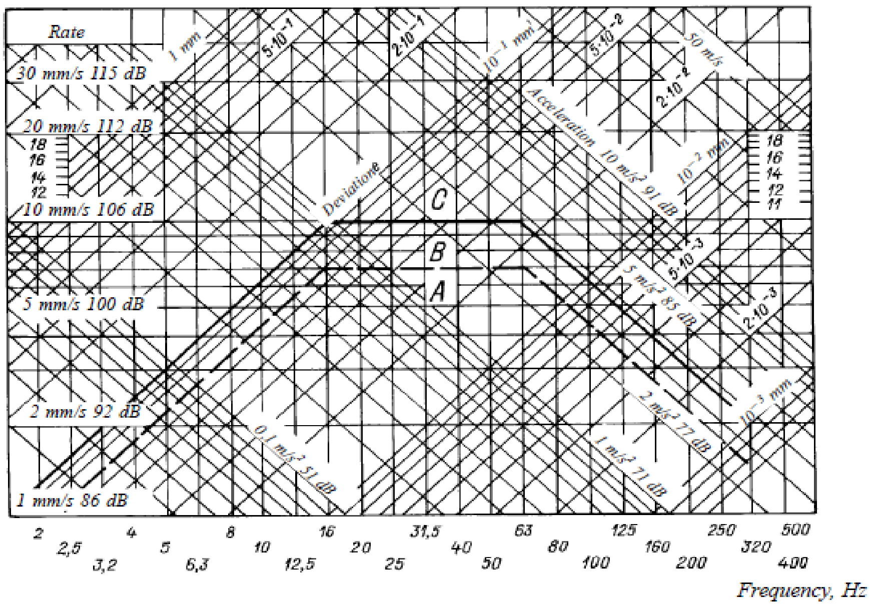

Fig.9.7.1. Vibration standards for boilers, auxiliary machinery and equipment

- - - - - - - - - - Upper limit of category *A*;

———————— Upper limit of category *B*.

9.7.2 Vibration standards for auxiliary machinery and equipments, not covered by **9.5** and **9.6**, shall be chosen based on **9.7.1**.

9.8 VIBRATION STANDARDS FOR GEARED GAS TURBINES

9.8.1 Vibration of 250 to 25000 kW main geared gas turbines measured on the gas turbine supports and reduction gear bearings is considered permissible, provided the root-mean square values of vibration rate and vibration acceleration do not exceed the values stated in Table 9.8.1 and shown in Fig. 9.8.1.

9.8.2 Vibration standards for auxiliary gas turbines of less than 250 kW power shall be subject to special consideration by the Register and shall be submitted by the gas turbine manufacturer.

9.8.3 Vibration of gas-turbine-driven servo-machinery and devices shall not exceed the levels given in**9.8.1** and **9.8.2**.

9.8.4 Виробник ГТД може відступати від цих норм у випадку наявності переконливих даних щодо працездатності ГТД при інших рівнях вібрації.

Table 9.8.1 **Vibration standards for geared gas turbines**

Line	Geometric mean frequencies of 1/3-octave bands, Hz	Permissible values of vibration rate			
		category *A*		category *B*	
		mm/s	dB	mm/s	dB
1	**2**	**3**	**4**	**5**	**6**
1	1,6	1,6	90	2,9	96
2	2	1,8	91	3,5	97
3	2.5	2,2	93	4,3	9
4	3,2	2,7	95	5,3	100
5	4	3.2	96	7,0	103
6	5	4	98	9	105
7	6,3	5	100	11	107
8	8	6,7	103	13	108
9	10	8	104	16,5	1 0
10	12,5	8	104	16,5	110
11	16	8	104	16,5	110
12	20	8	104	16,5	110
13	25	8	104	16,5	110
14	31,5	8	104	16,5	110
15	40	8	104	16,5	110
16	50	8	104	16,5	110
17	63	8	104	16,5	110
18	80	8	104	16,5	110
19	100	8	104	16,5	110
20	125	8	104	16,5	110
21	160	8	104	16,5	110
22	200	8	104	16,5	110
23	250	8	104	16,5	110
24	320	8	104	16,5	110
25	400	8	104	16,5	110
26	500	8	104	16,5	110
27	640	6,5	102	12,5	108
28	800	4,8	100	10	106
29	1000	4	98	8	104
30	1280	3	96	7	103
31	1600	2,6	94	5	100
32	2000	2,1	92	3,9	98
33	2560	1,8	91	3	96
34	3200	1,5	90	2.4	95
35	4000	1	86	2	92
36	5120			1,7	91
37	6400			1,4	89
38	8000			1	86

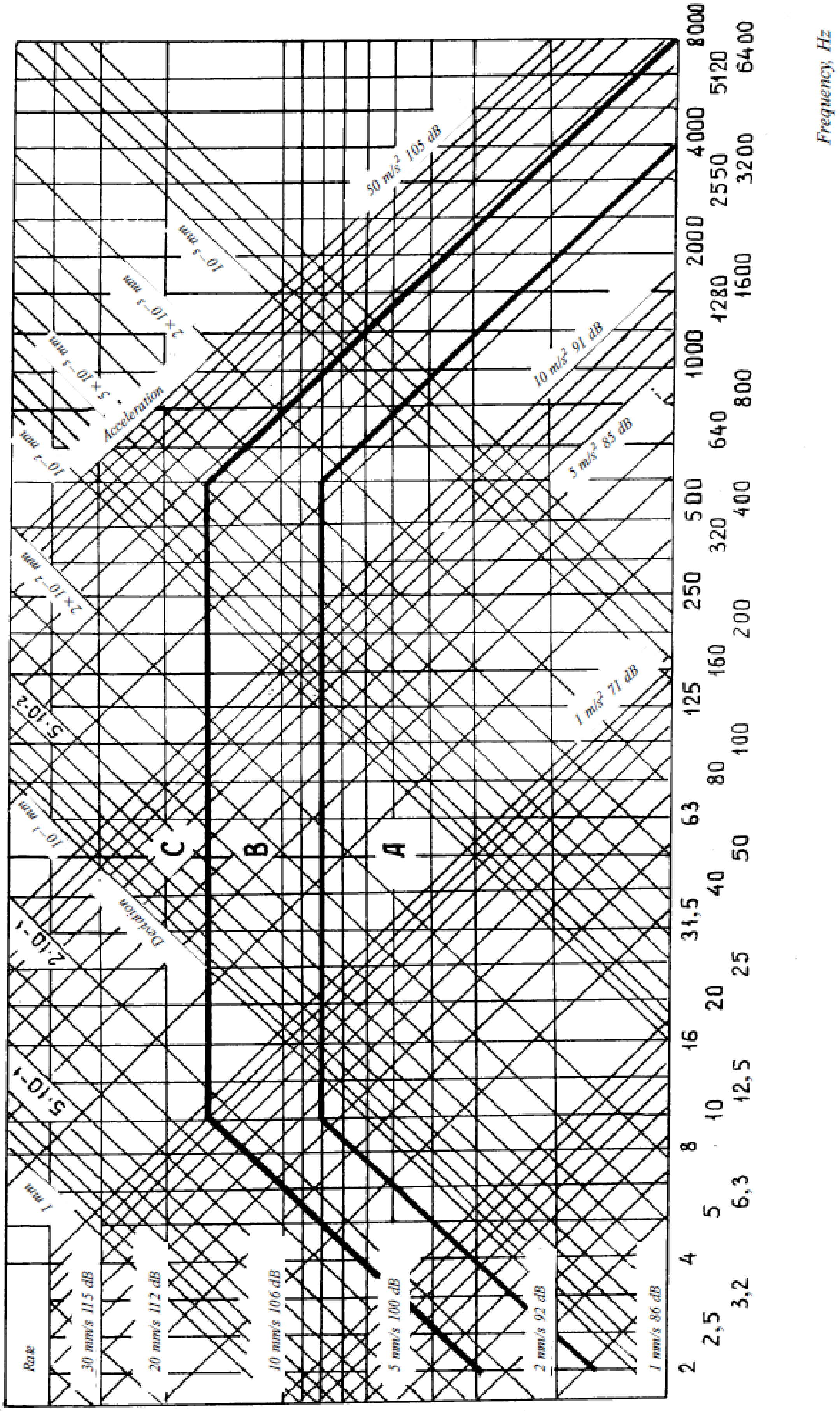

Fig. 9.8.1-1
Vibration standards for geared gas turbines

9.9 VIBRATION STANDARDS FOR MAIN AZIMUTH THRUSTERS

9.9.1 Vibration standards are extended to cover main azimuth thrusters driven by ICE- or electric motor wuth capacity 3000 kW with the main azimuth thruster speed of the inlett (drive) shaft 2000 rpm.

9.9.3 Vibration of main azimuth thrusters is considered admissible for the categories as follows A and B, if the root-mean square values of vibration rate measured in the range of 10 - 1000 Hz, calculated in accordance with ISO 10816-1, do not exceed the values specified in Table 9.9.3 and in Fig. 9.9.3.

9.9.4 Deviations from these standards, as, for example, in the case of the use of cardan shafts on the shaft line, shall in each case be the subject of special consideration by the Register.

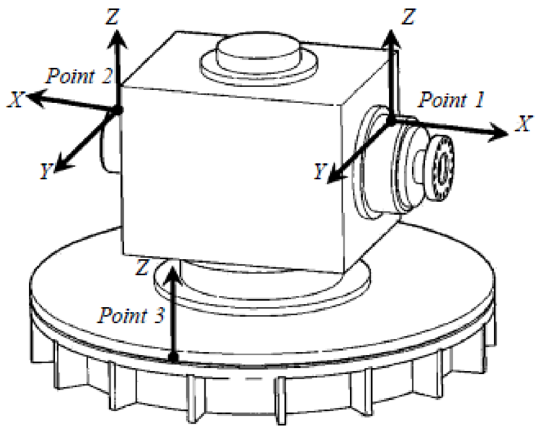

Fig. 9.9.2 Points of vibration measuring of main azimuth thrusters

Vibration measurements are carried out in three mutually perpendicular directions relative to the axes of the vessel: vertical, horizontal-traverse and horizontal-longitudinal.

The direction of vibration measurements is indicated by the direction of the axes:

X – axial (coinciding with the direction of the input shaft from the mechanical drive);

Y - horizontal-traverse;

Z – vertical.

Table 9.9.3 **Vibration standards of azimuth thrusters**

The relative speed of the input (drive) shaft, *n*	Permissible RMS Vibration speed[1]			
	category *A*		category *B*	
	mm/s	dB	mm/s	dB
1	**2**	**3**	**4**	**5**
0,54	0,83	84	1,06	86
0,61	1,98	92	2,70	95
0,67	3,01	96	4,16	98
0,73	3,92	98	5,44	101
0,79	4,71	99	6,54	102
0,85	5,38	101	7,46	103
0,91	5,91	101	8,20	104
0,97	6,36	102	8,76	105
1,03	6,67	102	9,14	105
1,10	6,86	103	9,34	105

[1]root-mean square values rate measured in the range of 10 - 1000 Hz in accordance with ISO 10816-1 (in Ukraine - ISO 10816-1:1995).

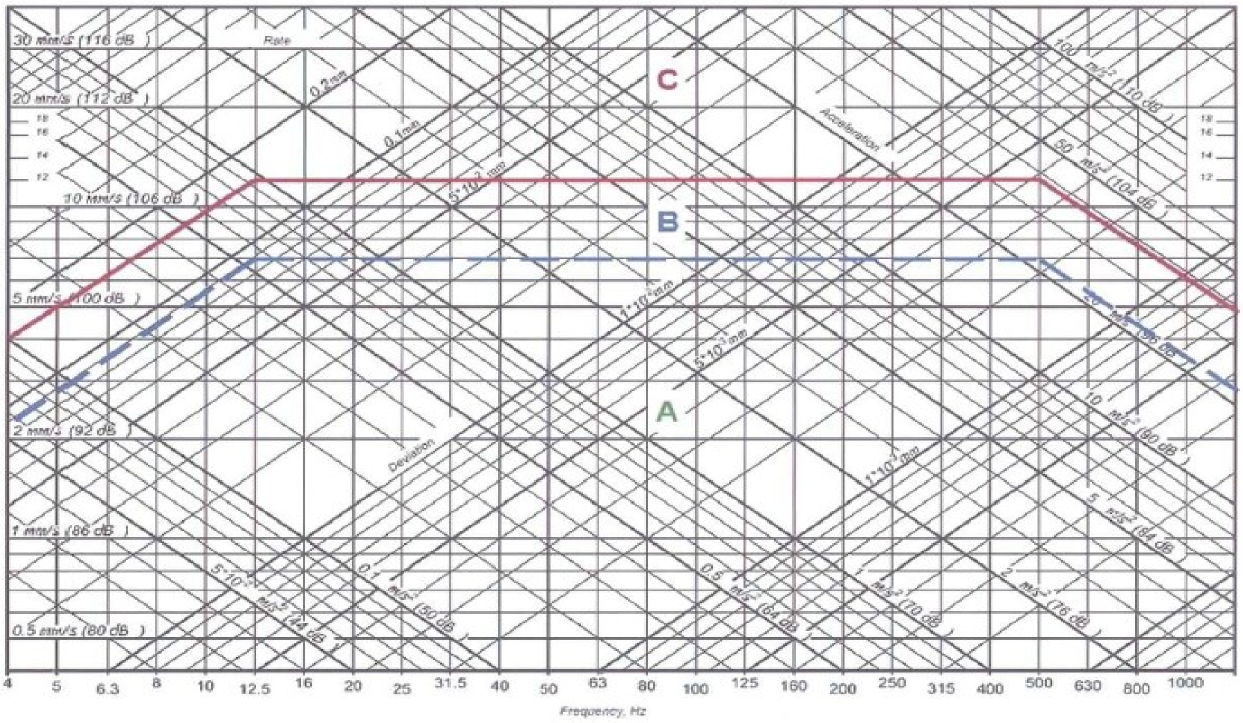

Fig. 9.9.3 Vibration standards of main azimuth thrusters

10. SPARE PARTS

10.1 GENERAL

10.1.1 The spare part standards given in this section set the minimum number of spare parts stored on board relating to the equipment essential to the propulsion and safety of the ship.

10.1.2 The nomenclature and the amount of spare parts for icebreakers and ships equipped with machinery of the types other than those indicated in 10.2 shall, in each case, be submitted for consideration to the Register with regard to the manufacturers' recommendations.

The availability of other spare parts on board the ship in addition to those specified in the Tables 10.2-1 to 10.2-8 is up to the shipowner's discretion.

10.1.3 Each ship shall be provided with a set of appropriate tools and appliances necessary for dismantling and assembling of the machinery in service conditions.

When dismantling and assembly of machinery can be carried out by the manufacturer's service or dedicated coastal service only, the amount of spare parts on board the ship shall be specially considered by the Register.

10.1.4 Each ship shall be provided with a set of flexible joints of every type and size used in the ship's systems and machinery.

10.1.5 The spare parts shall be properly secured in easily accessible places, marked and efficiently protected against corrosion.

When using spare parts, it is recommended to replenish them at the earliest opportunity.

10.1.6 If the number of spare parts determined according to the list given below is a fraction, then to define the amount of spares, the nearest greatest whole number shall be taken.

10.1.7 For ships of restricted navigation areas **R2**, **R2-S**, **R2-RS**, **R3-S**, **R3-RS**, **R3**, **R3-IN**, **A-R2**, **A-R2-S**, **A-R2-RS**, **B-R3-S**, **B-R3-RS**, **C-R3-S**, **C-R3-RS**, **D-R3-S**, **D-R3-RS** and for floating docks, the required minimum of spare parts is not regulated.

For the definitions of restricted areas of navigation, refer to **2.2.5**, Part I "Classification"..

10.2 LIST OF MINIMUM RECOMENDED SPARE PARTS

Table 10.2-1 **List of minimum recommended spare parts for main internal combustion engines**

№	Spare parts	Main engines of ships considered with regard to navigation area [1,2,3]		Supply of spare parts	Auxiliary engines of ships considered with regard to navigation area [1,3,4]		Supply of spare parts
		Unrestricted, **A**	Restricted **R1, A-R1**		Unrestricted, **A**	Restricted **R1, A-R1**	
1	2	3	4	5	6	7	8
1	Main bearings or shells of each type and size fitted, complete with shims, studs (bolts) and nuts	1 set		M	1 set	–	–
2	Cylinder liner with valves, joint rings and gaskets	1		M	Joint rings and gaskets only — 1 set		R
3	Cylinder cover with valves, joint rings and gaskets	1		M	Joint rings and gaskets only — 1 set		R
3.1	Cylinder cover bolts and nuts	1/2 set per cover		R	–	–	–
4	Cylinder valves						
4.1	Exhaust valves, complete with casings, seats, springs and other valves, per cylinder	2 sets	1 set	R	2 sets	1 set	R
4.2	Air inlet valves: as for item 4.1	1 set		R	1 set	–	–
4.3	Starting air valve, complete with casing, seats, springs and other valves	1		M	1	–	R
4.4	Cylinder overpressure sentinel valve, complete	1		M	1	–	R
4.5[5]	Fuel valves of each size and type fitted, complete with all fittings, for one engine	1 set	¼ set	M	½ set	¼ set	R
5	Connecting rod bearings						
5.1	Bottom end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinder	1 set		M	1 set		R
5.2	Top end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinder	1 set		M	1 set		R
6	Pistons						
6.1	Crosshead type internal combustion engine; piston of each type fitted, complete with piston rod, stuffing box, skirt, rings, studs and nuts	1		M	1		-
6.2	Trunk piston type internal combustion engine: piston of each type fitted, complete with skirt, rings, studs, nuts, gudgeon pin and connecting rod	1		M	1		R
7	Piston rings, for one cylinder	1 set		M	1 set		R
8	Telescopic cooling pipes and fittings or their equivalent, for one cylinder unit	1 set		M	1 set		R
9	Lubricator, complete, of the largest size, with its chain drive or gear wheels, or equivalent spare part kit	1	–	M	–		–
10	Fuel injection pumps						
10.1	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		M	1		R
10.2	High pressure double wall fuel pipe of each size and shape fitted, complete with couplings	1	–	M	–	–	R
11[6]	Scavenge blower (including turbo chargers)						

№	Spare parts	Main engines of ships considered with regard to navigation area [1,2,3]		Supply of spare parts	Auxiliary engines of ships considered with regard to navigation area [1,3,4]		Supply of spare parts
		Unrestricted, **A**	Restricted **R1, A-R1**		Unrestricted, **A**	Restricted **R1, A-R1**	
11.1	Rotors, rotor shafts, bearings, nozzle rings and gear wheels or equivalent working parts if other types	1 комплект	–	R	–		–

[1] For an installation comprising several engines of the same type, spare parts stock intended for one engine is sufficient. Engines of the same means the identical parts of which are interchangeable.

[2] For a thrust bearing built in main engine, see the requirements of item 1 of Table 10.2-4.

[3] The necessity of stocking further spares such as gear wheels, camshaft drive chains shall be determined by the shipowner with regard to the recommendations of engine manufacturers.

[4] For emergency engines, spare parts are not compulsory.

[5] Engines with one or two fuel valves per cylinder: one set of fuel valves, complete.

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.

[6] Locking devices shall be provided for the case of turbocharger being damaged. Spare parts may not be provided when the possibility of the internal combustion engine of this type operation without one turbocharger was demonstrated during the type tests with the satisfactory manoeuvring characteristics retained.

Note. For internal combustion engines with electronic control systems spare parts shall be supplied based on the recommendations of designer or manufacturer of the internal combustion engine

Table 10.2-2 **Steam turbines (main and auxiliary)1 [1,2]**

№	Spare part	Number of spare parts depending on the navigation area	
		Unrestricted **A**	Restricted **R1, A-R1**
1	Carbon sealing rings, where fitted, with springs, for each size and sealing rings type of gland, for one turbine	1 set	
2	Strainer baskets or inserts, for filters of special design, of each type and size	1 set per filter	

[1] Recommended minimum.

[2] When the installation consists of several turbines of the same type, the recommended minimum is assumed for one turbine only. By turbines of the same type, turbines are meant the identical parts of which are interchangeable.

Table 10.2-3 **Gears and couplings of main machinery [1,2,3]**

№	Spare part	Number of spare parts depending on the navigation area	
		Unrestricted, **A**	Restricted **R1, A-R1**
1	Plain bearing bushes of gears and couplings of each type and size fitted	1 set per bearing	
2	Pads of thrust block with liners or adjusting rings of each type and size fitted, with assorted liners for one face of thrust	1 set	
3	Roller type bearings of each type and size fitted, if used	1 set	

[1] Spare parts are necessary for the case of eventual replacement at sea by the crew.

[2] When several gears and couplings of the same type are used, spare parts are required for one gear or coupling, respectively. By gears and couplings of the same type, those gears and couplings are meant the identical parts of which are interchangeable.

[3] Supply is mandatory.

Table 10.2-4 **Shafting, propellers and active means of the ship's steering**

№	Spare part	Number of spare parts depending on the navigation area		Supply of spare parts
		Unrestricted, **A**	Restricted **R1, A-R1**	
1	2	3	4	**5**
1	Shafting			
1.1	Thrust block of shaftline			
1.1.1	Pads for ahead face of Mitchel type thrust block, where used	1		M
1.1.2	Inner and outer race with rollers where roller thrust bearings are used	1 set		R
1.2	Coupling bolts with nuts for flanges and shaft couplings, each type and size fitted	1 set of fittings		R
2	Propellers			
2.1[1]	Detachable propeller blades complete with securing items (for icebreakers and ships with ice categories **Ice4 - Ice6** only)	2 per propeller	–	M
2.2[1]	CPP blades complete with securing items (for icebreakers and ships with ice categories **Ice4**– **Ice6** only)	2 per propeller	–	M
2.3	Spare parts for arrangements of CP-propellers, steerable propellers, vertical axis propellers and servicing systems except those mentioned in items 2.1 and 2.2, depending on propeller type	On agreement with the Register	–	M

[1] Detachable blades are necessary for the case of eventual replacement by the crew when afloat.

Table 10.2-5 **Auxiliary machinery** [1]

№	Spare part	Number of spare parts depending on the navigation area	
		Unrestricted, **A**	Restricted **R1, A-R1**
1	**2**	**3**	**4**
1	Piston pumps		
1.1	Valves with seats and springs, each type and size fitted	1 set	–
1.2	Piston rings of each type and size fitted	1 set	1 set
2	Centrifugial pumps		
2.1	Bearings of each type and size fitted	1	
2.2	Rotor seals of each type and size fitted	1	
3	Rotary pumps (screw and gear pumps)		
3.1	Bearings of each type and size fitted	1	
3.2	Rotor seals of each type and size fitted	1	
4	Compressors		
4.1	Suction and delivery valves, each type and size fitted in one unit	½ set	
4.2	Piston rings of each type and size fitted in one piston	1 set	

[1] Supply is recommended.

Table 10.2-6 **Ship equipment and deck machinery**

№	Spare part	Number of spare parts depending on the navigation area		Supply of spare parts
		Unrestricted, **A**	Restricted **R1, A-R1**	
	Hydraulic steering gears			
1	Cylinder plunger seals, sealing rings for pumps of each type and size fitted	1 set		M
2[1]	Valve springs of each type and size fitted	1		M
3[1]	Safety and non-return valves of each type and size fitted	1	–	M
4	Ball or roller bearings	1 set for 1 pump		M
5	Special pipe connections of steering gear	1 set		M

[1] The list of spare parts is drawn up on agreement with the Register.

Table 10.2-7 **Steam boilers, thermal fluid boilers, pressure vessels and heat exchangers**

№	Spare part	Number of spare parts depending on the navigation area	Supply of spare parts
		Unrestricted, **A**, Restricted **R1**, **A-R1**	
1	2	3	4
1	Steam boilers (main and auxiliary for essential services), thermal fluid boilers		
1.1	Springs of safety valves of each type and size fitted 1	1 per boiler	M
1.2	Water gauge glasses, complete	1 per boiler	M
1.3[1]	Oil fuel burners, complete, each type and size fitted	1 per boiler	M
1.4[1]	Fuel atomizers complete with washers	1 per boiler	M
1.5	Tube plugs of each diameter fitted, including superheater plugs	For 4% of tubes but at most 20 pcs.	M
1.6	Boiler pressure gauge of each type and size fitted	1 set for 1 boiler unit	M
1.7	Metal gaskets of special type for superheater and economizer valves	1 set per boiler	R
1.8	Gaskets for manholes and other openings, each type and size fitted	1 set	R
2	Pressure vessels and heat exchangers		
2.1	Level gauge glasses of each type and size fitted	1	R
2.2	Gaskets and glands of special type for covers, manholes, openings and valves of each type and size fitted	1 set for 1 heat exchanger (pressure vessel)	R
2.3	Plugs for heat exchanger tubes	For 5% of tubes	M

[1]For boilers with automated burning units, the list of spare parts as per items **1.3** and **1.4** is drawn up on agreement with the Register.

Table 10.2-8 **Gas turbines (main and auxiliary)**

№	Spare part[1]	Number of spare parts depending on the navigation area		Supply of spare parts
		Unrestricted, **A**	Restricted **R1**, **A-R1**	
1	2	3		4
1	Flame tubes	1 set for 1 engine		M
2	Main burners	1 set for 1 engine		M
3	Auxiliary burners	1 set for 1 engine		M
4	Ignition arrangements, complete	1 set for 1 engine		M
5	Plasma igniters or ignition plugs	1 set for 1 engine		M
6	Spare parts for burners	1 set per 1 burner		M

[1] Additional spare parts as well as replaceable units (gas turbine-driven servo-machinery), the lifetime of which is less than the lifetime of the gas turbine, before shop repair shall be supplied by the gas turbine manufacturer on approval by the Register.

Symbols for Tables 10.2-1–10.2-8:
M — mandatory, R — recommended.

11 MACHINERY TECHNICAL CONDITION MONITORING SYSTEMS

11.1 GENERAL

11.1.1 The requirements of this Section apply to the machinery technical condition monitoring systems, which have been approved by the Register as the classification survey items on the basis of the Planned Maintenance Scheme (PMS) and condition control (CC).

11.1.2 Data of the machinery technical condition monitoring are intended for use:

by the Register surveyor, when carrying out surveys on the basis of PMS and CC;

by the ship crew to establish the terms for performing the machinery maintenance operations, i. e. providing maintenance on the “condition” basis;

by the Shipowner to assess the technical condition and to manage maintenance of ships, to schedule terms and scope of their repairs.

11.1.3 The composition of the equipment of the technical condition monitoring system, controlled parameters and frequency of their measurements, standards of the control item technical condition shall be approved by the Register when the survey system on the basis of PMS and CC is implemented on board the ship.

11.1.4 If the ship is fitted with machinery installation technical condition monitoring system, complying with the requirements of **11** with the introduction / application on the ship of Planned Maintenance Scheme for Machinery, then descriptive notation **PMS** (Planned Maintenance Scheme for Machinery) is added to the character of class in accordance with **2.2.28**, Part **I** «Classification».

11.2 CONTROL ITEMS AND PARAMETERS

11.2.1 The technical condition monitoring system may cover the following equipment:

main diesel engine, including turbocharger; main turbine;

AMSS; reduction gear;

shafting;

sterntube gear;

auxiliary diesel generators (turbogenerators);

systems maintaining operation of the main diesel engine (compressed air, fuel oil, lubricating oil and cooling);

steering gear.

11.2.2 On agreement with the Register, the ship may be equipped with the technical condition monitoring systems exercising control over:

the working process and wear of the cylinder and piston assembly of the main diesel engine;

the working process of the turbine;

the lubricating oil condition;

the vibration condition of the machinery;

the shock pulses of the roller bearings;

the electric values of the electrical equipment.

11.2.3 The conditions for acceptance of the technical condition monitoring results when carrying out surveys of the PMS and CC items are as follows:

the diagnostic parameters define the technical condition of the controlled item and are approved by the Register;

the limiting values of the diagnostic parameters have been determined on the basis of the requirements of the controlled item manufacturers and/or the Register;

the parameters used for the technical condition prediction shall be brought to standard conditions. The measured parameter values are brought to the standard conditions in accordance with **2.2.7**, Part IX “Machinery”;

the results of measurements, trend analysis and prediction of parameters shall be kept in a form accessible for the Surveyor:

in the tabular form, in the form of graphs on paper media or, preferably, on the PC media;

the frequency of the diagnostic parameter measurements shall provide reliability of determination of the control item technical condition;

the measuring instruments used in the technical condition monitoring systems shall have appropriate documents on verification by a competent authority.

11.3 GENERAL REQUIREMENTS FOR TECHNICAL CONDITION MONITORING SYSTEMS

11.3.1 The technical condition monitoring systems may be constructed on the basis of built-in (fixed) condition monitoring systems, portable control facilities or may combine both.

11.3.2 The built-in technical condition monitoring systems of the main engines, as a rule, shall be integrated structurally with the centralized monitoring systems and be capable of using the data obtained from the sensors of the centralized control system.

Technical condition monitoring system integrated with the centralized control system shall not affect the centralized monitoring functions.

11.3.3 The technical condition monitoring system integrated with the centralized control system shall incorporate the technical condition diagnosis functions with the aim to perform the maintenance and repair of the control item on the actual condition basis.

11.3.4 The built-in monitoring systems and their elements shall meet the requirements imposed on the ship automation systems (refer to Section **2**, Part XV "Automation").

The built-in monitoring systems installed on board the ships under construction or while in service shall be approved by the Register.

The built-in monitoring systems installed on board the ships are subject to the technical supervision with respect to:

check for functioning;

selection of cable cross-section;

protection, insulation and earthing means;

zero influence exerted by these systems on the operation of the equipment related to the items of the technical supervision of the Register.

Failures in the operation of the built-in monitoring system shall not adversely affect the operation of the equipment.

11.3.5 The portable control facilities and procedures for their application may be provided on board the ships under construction (or in service) after agreement with the Register.

The basis for the agreement is the attestation thereof and conclusion (on the basis of examination of the necessary materials and/or carrying out of tests) of a competent organization regarding techniques and means for diagnosis of the ship facilities.

11.3.6 The technical condition monitoring system shall provide for recording the diagnostic parameter values, their trend analysis, prediction of the control item technical condition. The condition prediction is performed on the basis of the previous history of diagnostic parameters with sufficient number of their measurements.

11.3.7 The requirements for computers used in the technical condition monitoring systems are similar to the requirements of Section **7**, Part XV "Automation".

11.3.8 The basic values of the diagnostic parameters used as initial (reference) data during the technical condition monitoring shall be obtained under the specific conditions of draught and the ship speed (at sea) and under operating conditions of the main engines and auxiliaries.

The basic data may be obtained on acceptance trials or on maiden voyage for a newbuilding or on another operational voyage under steady operating modes of the control items agreed with the Register.

11.4 TECHNICAL DOCUMENTATION

11.4.1 The following types of documentation on the technical condition monitoring system shall be submitted to the Register for review and approval:

.1 functional description with indication of the technical data and operating conditions (no approval stamp is affixed);

.2 methodological guidelines (instructions) for making measurements and control data processing (no approval stamp is affixed);

.3 test program for the built-in monitoring systems.

11.5 REQUIREMENTS FOR WORKING LUBRICATING OIL PARAMETERS

11.5.1 The requirements for the controlled parameters of working lubricating oils shall be consistent with the type of equipment to be surveyed.

Oil grades and methods of oil sampling for analysis shall be indicated for each machinery.

The oil sampling location shall be clearly described.

11.5.2 The range of the characteristics and rejected parameter values of the oils to be analysed are established by a developer of the monitoring system and agreed with the Register.

11.5.3 The oil sample shall be analyzed by a recognized shore-based laboratory. On board the ships the ship rapid analysis attested by a competent organization shall be used (refer to **11.3.5**).

11.5.4 The results of the oil analysis are submitted according to **11.2.3**.

11.6 REQUIREMENTS FOR CONTROL OF THE DIESEL ENGINE WORKING PROCESS PARAMETERS

11.6.1 The requirements apply to the equipment for measuring pressure in the engine cylinder and fuel supply parameters.

11.6.2 To process the measurement results of the working process parameters, use is also made of the parameters measured in the alarm system.

In this case, interference shall not be introduced into the operation of the alarm system.

11.6.3 The Register shall be given specifications of sensors, measuring equipment and measurement results processing program (including list of calculated parameters and method of presentation thereof).

11.6.4 The electronic unit used for measurement of the working process parameters shall have dynamic characteristics providing for the measurement of the maximum gas pressure in cylinder.

11.6.5 Measurement of the pressure in cylinder and fuel supply parameters with the use of the sensors presented is allowed to be made not on all cylinders simultaneously, but for all that the steady operating conditions of the diesel engine shall be maintained.

11.6.6 The equipment for measurement, processing and presentation of the cylinder pressure curve (indicator diagram) and the fuel supply characteristics shall provide for the analysis thereof with a resolution of not less than one degree of the crankshaft rotation.

11.6.7 The indicator diagram processing program shall calculate for each cylinder:

mean indicated pressure;

cylinder indicated power; maximum cylinder combustion pressure;

maximum compression pressure;

pressure on compression line at point 12° before the top dead centre (TDC);

pressure on expansion line at point 36° after the TDC;

the crankshaft rotation angle corresponding to the maximum combustion pressure;

ignition advance angle.

11.6.8 The fuel supply parameters processing program shall determine:

fuel injection beginning;

fuel injection time angle;

maximum fuel pressure.

11.6.9 The processing program shall provide for comparison of the loading in cylinders.

Permissible deviations of the working process parameters from the average over the cylinders:

mean indicated pressure - not more than ±2,5 %;

maximum combustion pressure - not more than ±3,5 %;

compression end pressure - ±2,5 %.

The cited values of the combustion pressure in any cylinder shall not be less than 85 % of the value obtained on basic tests.

The results of basic tests are considered to mean the results of the acceptance tests of the diesel engine on board or special tests on operational voyage) (refeer to **11.3.8**).

11.6.10 The measurement data shall be submitted according to **11.2.3**.

11.7 REQUIREMENTS FOR CONTROL OF WEAR PARAMETERS OF THE ENGINE CYLINDER AND PISTON ASSEMBLY

11.7.1 The parameter, which defines the engine cylinder and piston assembly condition (its wear), is the tightness of the combustion chamber.

11.7.2 The tightness of the combustion chamber is measured by a special instrument: pneumoindicator, which is a flow-metering device set at a particular cylinder diameter.

11.7.3 The methods for determination of the cylinder tightness and the standards for the cylinder and piston assembly condition shall be presented by the system developer.

11.7.4 The measurement data shall be submitted according to **11.2.3**.

11.8 REQUIREMENTS FOR CONTROL OF VIBRATION PARAMETERS

11.8.1 The objects of vibration control on the ship are the rotary type machinery listed in 11.2.1, as well as reciprocating compressors.

11.8.2 For the purpose of the machinery vibration condition monitoring, use shall be made of the following equipment, which provides for the measurement and processing of the vibration parameters: root-mean-square values of vibration rate or vibration acceleration in 1/3-octave band and in octave band, and the data analysis in temporal area:

11.8.3 The basic requirements for the equipment used in the vibration condition monitoring system:

the housing of the vibrometer-analyzer shall correspond to the IP54 protection type (refer to **2.4.4.2**, Part XI "Electrical Equipment");

frequency range — not less than 4 to 16,000 Hz;

dynamic range — not less than 70 dB.

Special requirements for the vibration diagnosis systems:

the possibility of operating according to a process chart, which ensures performance of at least one complete measurement of the vibration parameters on all the monitoring system objects;

the possibility of transferring data to computer.

11.8.4 The composition of the vibration condition monitoring equipment and organization of the performance thereof shall be agreed upon with the Register when the PMS and CC based survey system is being implemented on board the ship.

11.8.5 When performing the vibration condition monitoring, consideration shall be given to the provisions of of acting normative docs regarding technical supervision during construction of ships.

11.8.6 The requirements for the installation and attachment of the vibration pickup on the controlled item shall be provided.

The preference shall be given to attachment of the pickup by a pin (screw).

To realize such attachment method, pins shall be fitted beforehand at all measurement points.

The vibration pickups may be installed on a magnet.

Where the vibration pickups cannot be installed using a pin or magnet, manual vibration pickups may be used.

11.8.7 For each machinery, points and directions for measuring vibration parameters shall be indicated. The manufacturers' recommendations shall be used. Where no such recommendations are available, type lay-out diagrams of the machinery vibration measurement points shall be taken as a guide (refer to **9.2.5**).

For the vibration condition monitoring, measurement may be restricted to one or two directions on one most loaded machinery bearing.

Note. For units consisting of a machinery and its driving unit (pump and electric motor, fan and electric motor), measurements are made on one machinery bearing and one motor bearing on the coupling side.

When exercising control of the separator vibration condition, measurements shall be made in two radial directions on both motor bearings and in three directions on the separator bowl bearing.

11.8.8 Standardization of the condition on the basis of the controlled parameter vibration levels shall be displayed in the documentation of the technical condition monitoring system submitted to the Register for review (refer to **11.4.1**).

It is necessary to use the recommendations of the control item manufacturer or to be guided by the Register standards (refer to Section **9**).

11.8.9 The results shall be submitted according to **11.2.3**.

11.9 REQUIREMENTS FOR CONTROL OF THE SHOCK PULSE

11.9.1 The condition of the roller bearings is assessed by a shock pulse method.

The controlled machinery manufacturer, developer or supplier of the technical condition monitoring system may propose another method of roller bearing condition assessment. In this case, the proposed method shall be approved by the Register.

11.9.2 For the bearing condition control by shock pulse method, special instruments are used: shock pulse meters and/or roller bearing condition indicators, which shall meet the following basic requirements:

.1 range of controlled bearings:

internal diameter — 50 to 1000 mm;

speed — 10 to 30,000 min^{-1};

dynamic range — not less than 90 dB;

.2 as regards dust- and watertightness, the instrument housing shall correspond to IP54 protection type (refer to **2.4.4.2**, Part XI "Electrical Equipment");

.3 instrument for control of the roller bearing condition may be combined with the vibrometer (refer to **11.8.2**).

11.9.3 The instrument for control of the roller bearing condition shall be fitted with a built-in calibrator to verify precision of readings.

11.9.4 The measurement methods shall make it possible to separate the values of shock pulses arising due to the roller bearing against the background of the signals from other sources.

The methods shall establish positions for other measurements to be made on the bearing housing on the basis of the maximum shock pulse value or contemplate special devices measuring bolts, where there is no direct access to the bearing housing.

11.9.5 The shock pulse standards defining lubrication condition and roller bearing damages shall be presented by the manufacturer of the technical condition monitoring system.

11.9.6 The results shall be submitted according to **11.2.3**.

11.10 REQUIREMENTS FOR THE TREND ANALYSIS OF THE DIAGNOSTIC PARAMETERS AND FOR THE TECHNICAL CONDITION PREDICTION

11.10.1 The processing program for the diagnostic parameters measured by the built-in condition monitoring systems shall contemplate a trend analysis and prediction of the parameter changing. The trend analysis of the diagnostic parameters measured by the portable control facilities shall be made after each last measurement.

11.10.2 The parameter trend is based on the measurements made during the period between special surveys with a frequency not less than 4 to 5 measurements at approximately equal time intervals.

11.10.3 The controlled item condition is predicted for the forthcoming time period between annual surveys.

The prediction is made either on the basis of the past history of the parameters defining condition or on the basis of the known rate of the parameter change.

On completion of the measurement, the prediction shall be adjusted.

11.10.4 Based on the prediction results, the frequency of the condition control may be changed.

If the prediction results indicates that the limiting values of the controlled parameters can be attained, the intervals between the measurements shall be reduced, the causes of the condition degradation established and the maintenance planned.

11.10.5 If the item condition is described by the several independent parameters, prediction shall be made for each parameter. In this case, maintenance becomes necessary when any of the parameters to be predicted reaches the limiting value.

11.10.6 The monitoring system shall be accompanied by the prediction procedure. Along with that, the Register shall be given data confirming reliability of the procedure.

12. REQUIREMENTS FOR BOILER MONITORING SYSTEMS

12.1 GENERAL

12.1.1 This Section specifies technical and organizational requirements for the ships with the distinguishing mark **BMS** (refer to **2.2.28**, Part I «Classification»), which shall be followed to allow the survey carried out by the chief engineer to be credited by the Register as boiler internal survey (refer also to **3.1.5**, Part X «Boilers, Heat Exchangers and Pressure Vessels»).

Documentation on the performed internal survey shall be presented to the attending Register surveyor who shall carry out the remaining scope of the boiler survey.

12.1.2 To assign the distinguishing mark **BMS**, the initial survey shall be performed to confirm that the boiler design and technical condition make it possible for the crew to perform the survey, that the ship is fitted with appropriate boiler condition control and monitoring system, and that the ship's chief engineer is qualified to partially perform the scope of boiler survey.

12.1.3 Distinguishing mark **BMS** may be assigned to auxiliary oil-fired steam boilers and waste-heat boilers with working pressure not exceeding 2,0 MPa.

12.2 DEFINITIONS AND EXPLANATIONS

Definitions and explanations related to the general terminology of this section are given in **1.2**.

Definitions and explanations that are also valid for the parts VIII «Системи і трубопроводи» and Part X "Boilers, Heat Exchangers and Pressure Vessels" have been additionally provided for the purpose of this Section.

In addition to the below mentioned, the definitions specified in Chapter 1.2, Part X "Boilers, Heat Exchangers and Pressure Vessels".

Make-up water means water added to the feed water for replenishing the leaks and condensate losses; it is a mixture of distillate and chemically treated water.

Distillate means water generated in the desalinating plant by evaporation and condensation of sea water.

Feed water means water supplied by feed water pumps to the steam boiler to generate steam; it is a mixture of condensate and make-up water.

Condensate means water generated in the condensate and feed water system upon the waste steam condensation.

Boiler means a ship boiler that heats water or water-based coolant (eg, a solution of ethylene glycol in water) to the appropriate temperature.

Steam boiler means a ship boiler that produces a steam of appropriate parameters.

Boiler water means water inside the boiler and all its components.

Monitoring means continuous process of reading and recording item's parameters under control, which are assumed essential for the life duration, and comparing these parameters with specified values.

12.3 TECHNICAL AND OPERATING DOCUMENTATION

12.3.1 For steam boilers, the ship's Instruction on maintaining boiler water and chemistry quality shall be developed.

This document shall provide recommendations on pre-boiler and in-boiler water treatment and on prevention of scale formation and other factors leading to boiler plant excessive wear. This document shall be developed considering the requirements of instructions developed by boiler firms (manufacturers), standard instructions and applicable industry standards.

The content and availability of this document on board the ship shall be checked by the Register surveyor during the initial survey for assigning the distinguishing mark BMS to the ship.

12.3.2 Instruction on maintaining boiler water and chemistry quality shall contain:

.1 specification and brief description of water preparation process and equipment applied;

.2 schedule, scope and methods of water quality control;

.3 list and diagram of the sampling points;

.4 make-up, feed, boiler water and condensate quality standards;

.5 list of reagents necessary for water treatment and for ship's water laboratory;

.6 data on filter regeneration (if applicable);

.7 recommendations on boiler conservation for the period when they are not in operation.

12.3.3 The ship shall be provided with ship's boiler monitoring log-book.

The following shall be recorded in the log-book:

data on boiler maintenance in accordance with the manufacturer's recommendations and boiler survey results;

results of water chemical analyses;

measures taken to provide the feed and boiler water quality standards;

measures taken for burner units maintenance in accordance with the manufacturer's recommendations;

periodic testing of automatic burner unit interlocking and protecting devices as specified in Chapter 5.3, Part X "Boilers, Heat Exchangers and Pressure Vessels".

12.4 ADDITIONAL REQUIREMENTS FOR THE SHIPS WITH THE DISTINGUISHING MARK BMS

12.4.1 Additional requirements for boiler plants of ships with distinguishing mark BMS.

12.4.1.1 Special devices shall be provided for metering the chemicals and adding them to boiler and feed water.

12.4.1.2 Regular facilities shall be provided for collecting representative samples from boiler and feed water at safe temperature (e.g. by installing a sample cooler).

12.4.1.3 Facilities shall be provided for continuous early detection of excessive salinity, which shall immediately alarm when salt water is detected in the system.

12.4.1.4 Facilities shall be provided in condensate and feed water system for continuous early detection of oil products or transported goods in the boiler and feed water.

12.4.1.5 To remove oxygen, the feed water shall be kept in an open tank (e.g. in observation tank, hot well or a special deaerator) at temperature of at least 80ºC.

12.4.1.6 Regular facilities shall be provided for monitoring pressure difference before and after exhaust boilers.

12.4.2 Boiler, feed and make-up water quality monitoring.

12.4.2.1 Feed water shall contain minimum dissolved salts, gases, organics and insoluble suspended solids.

The main water quality indicators to be controlled within the monitoring process are total hardness, chloride, oxygen and oil products content.

12.4.2.2 Boiler water quality shall be maintained and documented in accordance with recommended limiting values of boiler and feed water quality indicators as specified by the boiler manufacturer.

Where there are no any special instructions from the boiler manufacturer, the boiler and feed water quality requirements specified in Table **12.4.2.2** for steam boilers with working pressure not exceeding 2 MPa shall be followed.

12.4.2.3 Water quality shall be regularly checked using regular facilities and periodical water analysis in land-based laboratories.

Boiler and feed water shall be monitored with the use of on-board regular facilities at least every 24 h.

Boiler and feed water analysis results shall be recorded in a ship's log book.

12.4.2.4 Boiler water analysis in land-based laboratories shall be carried out at least once a month, and results shall be kept on board the ship.

12.4.2.5 In any cases, deviation of boiler water quality from the prescribed standards shall be immediately corrected.

Acceptable methods of maintaining water quality are maximum condensate return, surface and bottom blowdown, pre-boiler chemical treatment of the feed and make-up water, in-boiler chemical water treatment.

Another method to ensure water quality may be adopted instead of chemical treatment, provided that its equivalence is substantiated.

12.4.2.6 Boiler water quality shall be annually analyzed by the shipowner and corrected, if necessary.

Measures to improve the boiler water quality shall be developed to prevent hard deposit formation and corrosion damages; these measures shall be based on analyses (examinations) of hard deposits found in boiler and corrosion damages.

Table 12.4.2.2.

Water type	Quality indicator	Measurement unit	Gas-tube boilers	Water-tube and composite boilers
Feed water	Total hardness	mg-eq/l	not more than 0,5	not more than 0,3
	Oil and oil products	mg/l	not more than 3	not more than 3
	Oxygen	mg/l	not more than 0,1	not more than 0,1
	Chlorides	mg/l	not more than 50	not more than 15
Condensate	Chlorides	mg/l	not more than 50	not more than 15
Distillate [3]	Total hardness	mg-eq/l	-	not more than 0,05
Make-up water [3]	Total hardness	mg-eq/l	not more than 8	not more than 5
Boiler water	Chlorides	mg/l	not more than 8000	not more than 1200
	Base number	mg/l	150 - 200	150 - 200
	Residual hardness	mg-eq/l	not more than 0,4	not more than 0,2
	Total salinity	mg/l	not more than 13000	not more than 3000
	Phosphate number [1]	mg/l	30 - 60	30 - 60
	Nitrate number [1]	mg/l	75 - 100[2]	75 - 100[2]

Notes:
[1] To be monitored for boilers with phosphate/nitrate water treatment.
[2] The nitrate number shall be 50 % of the actual base number.
[3] To be monitored during make-up water preparation.

12.4.3 Additional requirements for boilers of ships with distinguishimg mark BMS.

12.4.3.1 The boiler comply with the requirements for strength and construction, specified in Part X «Boilers, Heat Exchangers and Pressure Vessels».

The boiler shall not have signs of any damage, not documented and agreed with the Register during the last repair.

Plugged piping is not allowed.

Boiler heating surfaces shall not contain soot, sludge, scaling, traces of metal overheating. Boiler elements shall not have visible deformations and malfunctions.

12.4.3.2 The boiler shall provide internal inspections of steam and furnace spaces.

If the boiler has elements that are not available for internal survey, then hydraulic tests with a test pressure equal to 1.25 working shall be provided after the internal survey.

13. QUALITATIVE FAILURE ANALYSIS FOR PROPULSION AND STEERING ON PASSENGER SHIPS

13.1 APPLICATION

13.1.1 The requirements of the present Section refer to the qualitative failure analysis for propulsion and steering for new passenger ships, including those having a length of 120 m or more or having three or more main vertical zones (refer to 2.2.6.1, Part VI "Fire Protection") in compliance with the revised SOLAS Chapter II-2, Regulation 21 (IMO resolution MSC.216(82), Annex 3)..

13.1.2 For ships having at least two independent means of propulsion and steering to comply with SOLAS requirements for a safe return to port, the following shall be provided:

.1 knowledge of the effects of failure in all the equipment and systems due to fire in any space, or flooding of any watertight compartment that could affect the availability of the propulsion and steering;

.2 solutions to ensure the availability of propulsion and steering upon such failures specified in**13.1.2.1**.

13.1.3 Ships not required to satisfy the safe return to port concept will require the analysis of failure in single equipment and fire in any space to provide knowledge and possible solutions for enhancing availability of propulsion and steering.

13.2 SYSTEMS TO BE CONSIDERED

13.2.1 The qualitative failure analysis shall consider the propulsion and steering equipment and all its associated systems which might impair the availability of propulsion and steering.

13.2.2 The qualitative failure analysis shall include:

.1 propulsion and electrical power prime movers (diesel engines, electric motors);

.2 power transmission systems (shafting, bearings, power converters, transformers, slip ring systems);

.3 steering gear (rudder actuator or equivalent for azimuthing propulsor, rudder stock with bearings and seals, rudder, power unit and control gear, local control systems and indicators, remote control systems and indicators, communication equipment);

.4 propulsors (propeller, azimuthing thruster, water jet);

.5 main power supply systems (electrical generators and distribution systems, cable runs, hydraulic, pneumatic);

.6 essential auxiliary systems (compressed air, oil fuel, lubricating oil, cooling water, ventilation, fuel storage and supply systems);

.7 control and monitoring systems (electrical auxiliary circuits, power supplies, protective safety systems, power management systems, automation and control systems);

.8 support systems (lighting, ventilation).

To consider the effects of fire or flooding in a single compartment, the analysis shall address the location and layout of equipment and systems.

13.3 FAILURE CRITERIA

13.3.1 *Failures* are deviations from normal operating conditions such as loss or malfunction of a component or system such that it cannot perform an intended or required function.

13.3.2 The qualitative failure analysis shall be based on single failure criteria (not two independent failures occurring simultaneously).

13.3.3 Where a single failure cause results in failure of more than one component in a system (common cause failure), all the resulting failures shall be considered together.

13.3.4 Where the occurrence of a failure leads directly to further failures, all those failures shall be considered together..

13.4 VERIFICATION OF SOLUTIONS

13.4.1 The shipyard shall submit a report to the Register that identifies how the objectives have been addressed. The report shall include the following information:

.1 the standards used for analysis of the design;

.2 the objectives of the analysis;

.3 any assumptions made in the analysis;

.4 the equipment, system or sub-system, mode of operation of the equipment;

.5 probable failure modes and acceptable deviations from the intended or required function;

.6 evaluation of the local effects (e.g. fuel injection failure) and the effects on the system as a whole (e. g. loss of propulsion power) of each failure mode as applicable;

.7 trials and testing necessary to prove conclusions.

Note. All stakeholders (the Register, shipowners, shipyard and manufacturers) shall as far as possible be involved in the development of the report.

13.4.2 The report shall be submitted prior to approval of detail design plans. The report may be submitted in two parts:

.1 a preliminary analysis as soon as the initial arrangements of different compartments and propulsion plant are known which can form the basis of discussion. This shall include a structured assessment of all essential systems supporting the propulsion plant after a failure in equipment, fire or flooding in any compartment casualty;

.2 a final report detailing the final design with a detailed assessment of any critical system identified in the preliminary report.

13.4.3 Verification of the report findings shall be agreed between the Register and the shipyard.

APPENDIX 1.

SPECIAL APPROVAL OF ALLOY STEEL FOR INTERMEDIATE SHAFT MATERIAL

1. APPLICATION

1.1 General.

1.1.1 The requirements apply to the approval of alloy steel which has a minimum specified tensile strength greater than 800 MPa, but less than 950 MPa intended for use as intermediate shaft material.

1.1.2 The Section contains the main data on the steel fatigue evaluation by means of torsional fatigue testing. The purpose of the torsional fatigue test shall be meeting the requirements to the torsional fatigue to be equal to the intermediate shaft material, specified in the corresponding Sections of the Rules given by the formulae The torsional fatigue strength of said material is to be equal to or greater than the permissible torsional vibration stress τ_l, given by Formulae (8.3.1).

1.1.3 The chemical composition for forgings shall meet the minimum requirements specified in Table 3.7.2.3-2 of **3.7**, Part XIII "Materials", considering the content of sulphur, phosphorus and oxygen. The chemical composition, structures and mechanical properties shall meet the minimum requirements of Part XIII "Materials" and shall be submitted to the Register for consideration.

2. CARRYING OUT OF TESTS

2.1 The tests shall 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 shall be evaluated in consideration of the severest torsional stress concentration in the design criteria. Mean surface roughness shall be 0,2 μm R_a with the absence of localized machining marks verified by visual examination at low magnification (x20) as required by Section 8.4 of ISO 1352..

Test procedures shall be in accordance with Section 10 of ISO 1352.

2.2. Test conditions shall be in accordance with Table 2.2.

Table 2.2

1	Loading type	Torsion
2	Stress ratio	R = 1
3	Load waveform	Constant - amplitude sinusoidal
4	Evaluation	S-N curve
5	Number of cycles for test terminal	1×10^7
6	Specimens	Notched and unnotched

2.3 The steels shall have a degree of cleanliness as shown in Table 2.3 when tested according to ISO 4967 method A.

Representative samples shall be obtained from each heat of forged or rolled products. The samples shall be subject to ultrasonic testing required by **3.7,7.2** Part XIII "Materials" prior to acceptance.

Table 2.3

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

3 ACCEPTANCE CRITERIA

3.1 Total stresses shall be equal to or greater than the values given by the following formulae:

For measured high-cycle torsional fatigue strength:

$$\tau_{l1} \geq \tau_{l\lambda=0} = (\sigma_B + 160) \cdot C_k \cdot C_d / 6 \qquad (3\text{-}1)$$

For low-cycle torsional fatigue strength:

$$\tau_{l2} \geq (1{,}7 \cdot \tau_{l1}) / \sqrt{C_k} \qquad (3\text{-}2)$$

where:

τ_l - permissible amplitude of stress in MPa in the sample due to torsional vibration for continuous operation (refer to 8.3.1);

σ_B – specified minimum tensile strength in MPa of the shaft material;

C_k – = factor for the particular shaft design features; when selecting stress concentration factor, *scf*, (for calculating C_k for unnotched specimen *scf* = 1 (refer to Table 8.3.1);

C_d – size factor (refer to **8.2.1**).

Veritas Register of Shipping LTD

Rules for Classification and Construction of Sea Going Ships

Part VI

Machinery Installations

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