TÜRK LOYDU

RULES FOR THE CLASSIFICATION OF NAVAL SHIPS

Part E

Chapter 104 - Propulsion Plants 2015

This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction is on or after 01st of January 2015.

If there is a difference between the rules in English and in Turkish, the rule in English is to be considered as valid. This publication is available in print and electronic pdf version. Once downloaded, this document will become UNCONTROLLED. Please check the website below for the valid version.

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Chapter 104 - Propulsion Plants

Section 1 General Rules and Instructions

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SECTION 1

GENERAL RULES AND INSTRUCTIONS

SECTION 1

GENERAL RULES AND INSTRUCTIONS

A. General

1. These Rules apply to the propulsion plant of seagoing surface ships and craft intended for naval activities.

The following types of propulsion plants are not included in these Rules:

- Nuclear power plants
- Plants with fuel cell technology **(1)**
- Steam boilers for main propulsion
- Steam turbines
- Low speed diesel engines with crossheads
- Reversible two-stroke diesel engines
- Plants for operation with heavy fuel oil and its pretreatment

However, on application, plants of a type listed above may be included in a design review and classification procedure, where relevant for the overall concept of a naval project.

2. Apart from machinery and equipment detailed below, these Rules are also applicable individually to other machinery and equipment where this is necessary for the safety of the ship and its crew.

3. Designs which deviate from these Rules may be approved, provided that such designs have been recognized as equivalent.

4. Machinery installations which have been developed on novel principles and/or which have not yet been sufficiently tested in shipboard service require special TL approval.

In such cases TL is entitled to require additional documentation to be submitted and special trials to be carried out. Such machinery may be marked by the Notation **EXP** affixed to the Character of Classification.

5. In addition to these Rules, TL reserve the right to impose further requirements in respect of all types of machinery where this is unavoidable due to new findings or operational experience, or TL may permit deviations from the Rules where these are specially warranted.

6. Reference to further regulations and standards

6.1 If the requirements for propulsion plants and operating agents are not defined in these Rules, the application of other regulations and standards has to be defined as far as necessary.

6.2 The regulations of the "International Convention for the Safety of Life at Sea 1974/1978" **(SOLAS),** as amended are considered in these Rules as far as they appear to be applicable to naval surface combat ships. The definite scope of application has to be defined in the building specification by the Naval Authority and the shipyard.

These Rules are also in compliance with the provisions of the "International Convention for the Prevention of Pollution from Ships" of 1973 and the relevant Protocol of 1978 **(MARPOL 73/78).**

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(1) *For auxiliary power to be produced with fuel cell technology see TL Rules Guidelines for the Use of Fuel Cell Systems on Board of Ships and Boats.*

6.3 For ships of NATO states the Nato Agreement for Standardisation (STANAG) has to be considered.

6.4 Besides of these Rules national regulations, international standards and special definitions in the building specification respectively in the mission statement of the actual ship have to be considered. The application of such regulations is not affected by the TL Rules.

7. Design

The design of the propulsion plant has to fulfill the following conditions:

7.1 The operation of the naval ship and the habitual conditions foreseen on board as well as the operation of all systems under the operational conditions of combat, wartime cruise, peacetime cruise and peacetime in-port readiness must be ensured at all times.

7.2 The power distribution network shall be designed to ensure operability in case of network failure.

7.3 The operation of certain systems and equipment, which are necessary for safety, is to be guaranteed under defined emergency conditions.

7.4 The risks for crew and ship from operation of the propulsion plant shall be minimized.

7.5 High working reliability shall be achieved by simple and clearly arranged operation processes as well as by application of type-approved products.

7.6 The requirements concerning design, arrangement, installation and operation which are defined in Chapter 101 - Classification and Surveys and Chapters 102 - Hull Structures and Ship Equipment , 105 - Electrical Installations, 106 - Automation and 107 – Ship Operation Installations and Auxiliary Systems, must be fulfilled.

7.7 A high degree of survivability of the ship should be achieved by redundancies in the design and functioning of essential equipment.

7.8 The principles of ergonomic design of machinery and equipment have to be considered.

7.9 Where in a class of naval ships, originally planned to be identical, deviations become necessary, TL shall be duly informed and changes properly documented.

8. Equivalence

8.1 Naval ships deviating from the TL Rules in their type, equipment or in some of their parts may be classed, provided that their structures or equipment are found to be equivalent to the TL requirements for the respective Class.

8.2 In this respect, **TL** can accept alternative design, arrangements and calculation/analyses (FE, FMEA, etc.) which are suitable to satisfy the intent of the respective **TL** requirements and to achieve the equivalent safety level.

B. Definitions

1. Ship speeds

1.1 v_0

Expected maximum, continuous ahead speed v_0 [kn] of the ship in calm water at the draught **T**, when the total available driving power is acting exclusively on the propulsion devices.

1.2 v_{max}

Expected maximum ahead speed v_{max} [kn] of the ship in calm water at the draught **T**, when the total available maximum driving power is acting exclusively on the propulsion devices. This speed is related to an overload condition, permissible only for a defined, relatively short time period.

1.3 v_M

Expected economic, continuous ahead cruising speed v_M [kn] of the ship, which provides the maximum radius of action.

1.4 v_{min}

Expected minimum ahead speed v_{min} [kn] of the ship in calm water at the draught **T**, when the total available driving power is acting at its technically possible minimum power output.

1.5 Draught T

The draught **T** is the vertical distance at the middle of the length **L**, from base line to the deepest design water line, as estimated for the lifetime of the ship.

2. Rated driving power P

The rated driving power [kW] is defined as continuous power to be delivered by the propulsion machinery when running at rated speed and with the total available power acting exclusively on the propulsion devices.

3. Auxiliary electrical power

The auxiliary electrical power [kVA] is defined as the continuous electrical power at continuous speed v_0, which is not directly used for propulsion of the ship, but for driving all kinds of auxiliary devices and equipment. The degree of redundancy shall be defined in the building specification.

4. Essential equipment

4.1 Principal requirements

Essential equipment is required to ensure continuity of the following functions:

- Propulsion, manoeuvrability, navigation and safety of the ship
- Safety of the crew and embarked troops
- Functioning of all equipment, machinery and appliances needed for flooding control, fire fighting, NBC defence, degaussing, etc.
- Functioning of all equipment, machinery and appliances needed to an unrestricted extent for the primary duty of the naval ship

These requirements apply for the mechanical part of the equipment and complete equipment units supplied by subcontractors.

Essential equipment is subdivided into:

- Primary essential equipment according to 4.2
- Secondary essential equipment according to 4.3

4.2 Primary essential equipment

Primary essential equipment is that required to be operative at all times to maintain the manoeuvrability of the ship as regards propulsion and steering and that required directly for the primary duty of the naval ship.

It comprises e.g.:

- Steering gear
- Controllable pitch-propeller installation
- Scavenging air blowers, fuel oil supply pumps, fuel booster pumps, fuel valve cooling pumps, lubricating oil pumps, cooling water pumps for main and auxiliary engines and turbines necessary for propulsion
- Forced draught fans, feed water pumps, water circulating pumps, vacuum pumps and condensate pumps for auxiliary boilers of ships where steam is used for equipment supplying primary essential equipment
- Burner equipment for auxiliary steam boilers of ships where steam is used for equipment supplying primary essential equipment
- Azimuth thrusters which are the sole means for propulsion/steering including lubricating oil pumps, cooling water pumps
- Main propulsion plant with internal combustion engines and gas turbines, gears, main shafting, propellers
- Electric generator units and associated power sources supplying primary essential equipment

- Hydraulic pumps for primary essential equipment
- Weapon systems (effectors)

4.3 Secondary essential equipment

Secondary essential equipment is that required for the safety of ship and crew, and is such equipment which can briefly be taken out of service without the propulsion, steering and equipment needed for the primary duty of the naval ship, being unacceptably impaired.

It comprises e.g.:

- Windlasses and capstans
- Azimuth thrusters, if they are auxiliary equipment
- Fuel oil transfer pumps and fuel oil treatment equipment
- Lubrication oil transfer pumps and lubrication oil treatment equipment
- Starting air and control air compressors
- Turning device for main engines
- Bilge, ballast and heel-compensating installations
- Fire pumps and other fire fighting installations
- Ventilating fans for engine and boiler rooms
- Equipment considered necessary to maintain endangered spaces in a safe condition
- Equipment for watertight closing appliances
- Auxiliary and main engine starting installations
- Generator units supplying secondary essential equipment, if this equipment is not supplied by generators as described in 4.2
- Hydraulic pumps for secondary essential equipment
- Parts of the shipboard aircraft installations
- NBC fans and passage heaters
- Decontamination equipment

5. Non-essential equipment

Non-essential equipment is that which temporary disconnection does not impair the principal requirements defined in 4.1.

C. Documents for Approval

1. All documents have to be submitted for approval to TL in Turkish or English language.

2. The survey of the ship's construction will be carried out on the basis of approved documents. The drawings must contain all data necessary for approval. Where necessary, calculations and descriptions of the ship's elements are to be submitted. Any non-standard symbols used are to be explained in a key list. All documents have to indicate the number of the project and the name of the Naval Authority and/or shipyard.

The drawings and documents have to give sufficient evidence for proving that the requirements set out in this Chapter have been complied with.

3. The supporting calculations shall contain all necessary information concerning reference documents. Literature used for the calculations has to be cited, important but not commonly known sources shall be added in copy.

The choice of computer programs according to the "State of the Art" is free. The programs may be checked by TL through comparative calculations with predefined test examples. A generally valid approval for a computer program is, however, not given by TL.

The calculations have to be compiled in a way which allows to identify and check all steps of the calculation in an easy way. Hand written, easily readable documents are acceptable.

Comprehensive quantities of output data shall be presented in graphic form. A written comment to the main conclusions resulting from the calculations has to be provided.

4. A summary of the required documents is contained in Chapter 101 - Classification and Surveys, Table 4.1. Further details are defined in the following Sections of this Chapter.

5. TL reserve the right to demand additional documentation if that submitted is insufficient for an assessment of the naval ship.

This may especially be the case for plants and equipment related to new developments and/or which are not tested on board to a sufficient extent.

6. The drawings are to be submitted in triplicate, all calculations and supporting documentation in one copy for examination at a sufficiently early date to ensure that they are approved and available to the Surveyor at the beginning of the manufacture of or installation on the naval ship.

7. Once the documents submitted have been approved by TL they are binding for the execution of the work. Subsequent modifications and extensions require the approval of TL before being put into effect.

8. At the commissioning of the naval ship or after considerable changes or extensions of the propulsion plant, the documentation for approval as defined in the different Sections, showing the final condition of the systems, has to be given on board. All documents have to indicate the name of the ship, the newbuilding number of the shipyard and the date of execution.

D. Ambient Conditions

1. General operating conditions

1.1 The selection, layout and arrangement of the ship's structure and all shipboard machinery shall be such as to ensure faultless continuous operation under defined standard ambient conditions.

More stringent requirements must be observed for Class Notation **AC1** (see Chapter 101 - Classification and Surveys, Section 2, C.).

For the Class Notation **ACS** variable requirements for unusual types and/or tasks of naval ships can be discussed case by case, but shall not be less than the standard requirements.

Components in the machinery spaces or in other spaces which comply with the conditions for the Notations **AC1** or **ACS** must be approved by TL.

1.2 Inclinations and movements of the ship

The design conditions for static and dynamic inclinations of a naval ship have to be assumed independently from each other. The standard requirements and the requirements for Class Notation **AC1** are defined in Table 1.1.

The effects of elastic deformation of the ship's hull on the machinery installation have to be considered.

1.3 Environmental conditions

The standard requirements and the requirements for Class Notation **AC 1** are defined in Table 1.2.

2. Vibrations

2.1 General

2.1.1 Machinery, equipment and hull structures are normally subject to vibration stresses. Design, construction and installation must in every case take account of these stresses.

The fault-free long-term service of individual components shall not be endangered by vibration stresses.

2.1.2 Where a machine or a piece of equipment generates vibrations when in operation, the intensity of the vibration shall not exceed defined limits. The purpose is to protect the vibration generators, the connected assemblies, peripheral equipment and hull components from additional, excessive vibration stresses liable to cause premature failures or malfunctions

2.1.3 The following provisions relate to vibrations in the frequency range from 2 to 300 Hz. The underlying assumption is that vibrations with oscillation frequencies below 2 Hz can be regarded as rigid-body vibrations while vibrations with oscillation frequentcies above 300 Hz normally occur only locally and may be interpreted as structure-borne noise. Where, in special cases, these assumptions are not valid (e.g. where the vibration is generated by a gear pump with a tooth meshing frequency in the range above 300 Hz) the following provisions are to be applied in analogous manner.

2.1.4 Attention has to be paid to vibration stresses over the whole relevant operating range of the vibration exciter.

Where the vibration is generated by an engine, consideration must cover the whole available working speed range and, where appropriate, to the whole power range.

2.1.5 The procedure described below is largely standardized. Basically, a substitution quantity is formed for the vibration stress or the intensity of the exciter spectrum (cf. 2.2.1). This quantity is then compared with permissible or guaranteed values to check that it is admissible.

2.1.6 The procedure mentioned in 2.1.5 takes the physical facts into account only incompletely. The aim is to evaluate the true alternating stresses or alternating forces. No simple relationship exists between the actual load and the substitution quantities: vibration amplitude, vibration velocity and vibration acceleration at the external parts of the frame. Nevertheless, this procedure is adopted since at present, it appears to be the only one which can be implemented in a reasonable way. For these reasons it is expressly pointed out that the magnitude of the substitution quantities applied in relation to the relevant limits enables no conclusion to be drawn concerning the reliability or load of components as far as these limits are not exceeded. It is, in particular, inadmissible to compare the load of components of different reciprocating machines by comparing the substitution quantities measured at the engine frame.

2.1.7 For reciprocating machinery, the following statements are only applicable for outputs over 100 kW and speeds below 3 000 min^{-1}.

2.1.8 The special rules concerning torsional vibrations according to Section 8 have to be considered.

2.2 Assessment

2.2.1 In assessing the vibration stresses imposed on machinery, equipment and hull structures, the vibration velocity v is generally used as a criterion for the prevailing vibration stress. The same criterion is used to evaluate the intensity of the vibration spectrum produced by a vibration exciter (cf. 2.1.2).

In the case of a purely sinusoidal oscillation, the effective value of the vibration velocity v_{eff} can be calculated by the formula:

$$v_{eff} = \frac{1}{\sqrt{2}} \cdot \hat{s} \cdot \omega = \frac{1}{\sqrt{2}} \cdot \hat{v} = \frac{1}{\sqrt{2}} \cdot \frac{\hat{a}}{\omega} \qquad (1)$$

in which

$\hat{s}$ = vibration displacement amplitude,

$\hat{v}$ = vibration velocity amplitude,

v_{eff} = effective value of vibration velocity,

$\hat{a}$ = vibration acceleration amplitude,

ω = angular velocity of vibration.

For any periodic oscillation with individual harmonic components 1,2,...n, the effective value of the vibration velocity can be calculated by the formula:

$$v_{effi} = \sqrt{v_{eff1}^2 + v_{eff2}^2 + ... + v_{effn}^2} \qquad (2)$$

in which v_{eff} is the effective value of the vibration velocity of the i-th harmonic component. Using formula (1), the individual values of v_{effi} are to be calculated for each harmonic.

Depending on the prevailing conditions, the effective value of the vibration velocity is given by formula (1) for purely sinusoidal oscillations or by formula (2) for any periodic oscillation.

Table 1.1 Design conditions for ship inclinations and movements

Type of movement	Type of inclination and affected equipment	Design conditions	
		Standard requirements	Notation AC 1
Static condition	**Inclination athwartships (1)** Main and auxiliary machinery	15°	25°
	Other installations **(2)**	22,5°	25°
	No uncontrolled switches or functional changes	45°	45°
	Ship's structure	acc. to stability requirements	acc. to stability requirements
	Inclinations fore and aft: (1) Main and auxiliary machinery	5°	5°
	Other installations **(2)**	10°	10°
	Ship's structure	acc. to stability requirements	acc. to stability requirements
Dynamic condition	**Rolling: (1)** Main and auxiliary machinery	22,5°	30°
	Other installations **(2)**	22,5°	30°
	Pitching: (1) Main and auxiliary machinery	7,5°	10°
	Other installations **(2)**	10°	10°
	Accelerations: Vertical (pitch and heave)	a_z [g] **(3)**	pitch: 32 °/s^2 heave: 1,0 g
	Transverse (roll, yaw and sway)	a_y [g] **(3)**	roll: 48 °/s^2 yaw: 2 °/s^2
	Longitudinal (surge) Combined acceleration	a_x [g] **(3)** acceleration ellipse **(3)**	sway: a_y [g] a_x [g] **(4)** direct calculation

(1) *Athwartships and fore and aft inclinations may occur simultaneously*
(2) *Ship's safety equipment, switch gear and electric/electronic equipment*
(3) *Defined in Chapter 102 - Hull Structures and Ship Equipment, Section 5, B.*
(4) *To be defined by direct calculation*

Table 1.2 Design environmental conditions

Environmental area	Parameters	Design conditions	
		Standard requirements	**Notation AC1**
Outside the ship/air	Temperature For partially open spaces	- 25 °C to + 45 °C **(1)** -	- 30 °C to + 55 °C **(1)** - 10 °C to + 50 °C **(1)**
	Temperatures related to: - atmospheric pressure - max. relative humidity	1000 mbar 60 % **(2)**	900 mbar to 1100 mbar 100 %
	Salt content	1 mg/m³	1 mg/m³
		withstand salt-laden spray	withstand salt-laden spray
	Dust/sand	to be considered	filters to be provided
	Wind velocity (systems in operation)	43 kn **(3)**	90 kn
	Wind velocity (systems out of operation)	86 kn **(3)**	100 kn
Outside the ship/ seawater	Temperature **(4)**	-2°Cto +32°C	-2°C to +35°C
	Density acc. to salt content	1,025 t/m³	1,025 t/m³
	Flooding	withstand temporarily	withstand temporarily
Outside the ship/ icing of surface	Icing on ship's surfaces up to 20 m above waterline	see Chapter 102, Section 2, B.3.4	see Chapter 102, Section 2, B.3.4
Outside the ship/ navigation in ice	Ice class B	drift ice in mouth of rivers and coastal regions	drift ice in mouth of rivers and coastal regions
Entrance to the ship/ for design of heating/ cooling systems	Air temperature	-15°Cto +35 °C	-15°Cto +35 °C
	Max. heat content of the air	100kJ/kg	100 kJ/kg
	Seawater temperature	- 2 °C to + 32 °C	-2°C to +35°C
Inside the ship/ all spaces **(5)**	Air temperature	0 °C to + 45 °C	0 °C to + 45 °C
	Atmospheric pressure	1000 mbar	1000 mbar
	Max. relative humidity	up to 100% (+45 °C)	100 %
	Salt content	1 mg/m³	1 mg/m³
	Oil vapour	withstand	withstand
	Condensation	to be considered	to be considered
Inside the ship/ air-conditioned areas	Air temperature	0 °C to + 40 °C	0 °C to + 40 °C
	Max. relative humidity	80%	100 %
	Recommended ideal climate for manned computer spaces	-	air temperature + 20 °C to + 22 °C at 60 % rel. humidity
Inside the ship/ in electrical devices with higher degree of heat dissipation	Air temperature	0 °C to + 55 °C	0 °C to + 55 °C
	Max. relative humidity	100 %	100 %

(1) *Higher temperatures due to radiation and absorption heat have to be considered*

(2) *100 % for layout of electrical installations*

(3) *For lifting devices according to TL Rules , Guidelines for the Construction and Survey of Lifting Appliances,*

(4) *TL may approve lower limit water temperatures for ships operating only in special geographical areas*

(5) *For recommended climatic conditions in the ship's spaces see also Chapter 107 — Ship Operation Installations and Auxiliary Systems, Section 11, F.*

2.2.2 The assessment of vibration loads is generally based on areas A, B and C, which are enclosed by the boundary curves shown in Fig. 1.1. The boundary curves of areas A, B, and C are indicated in Table 1.3. If the vibration to be assessed comprises several harmonic components, the effective value according to 2.2.1 must be applied. The assessment of this value shall take account of all important harmonic components in the range from 2 to 300 Hz.

2.2.3 Area A can be used for the assessment of all machines, equipment and appliances. Machines, equipment and appliances for use on board a ship shall as a minimum requirement be designed to withstand a vibration load corresponding to the boundary curve of area A.

Otherwise, with TL's consent, steps must be taken (vibration damping etc.) to reduce the actual vibration load to the permissible level.

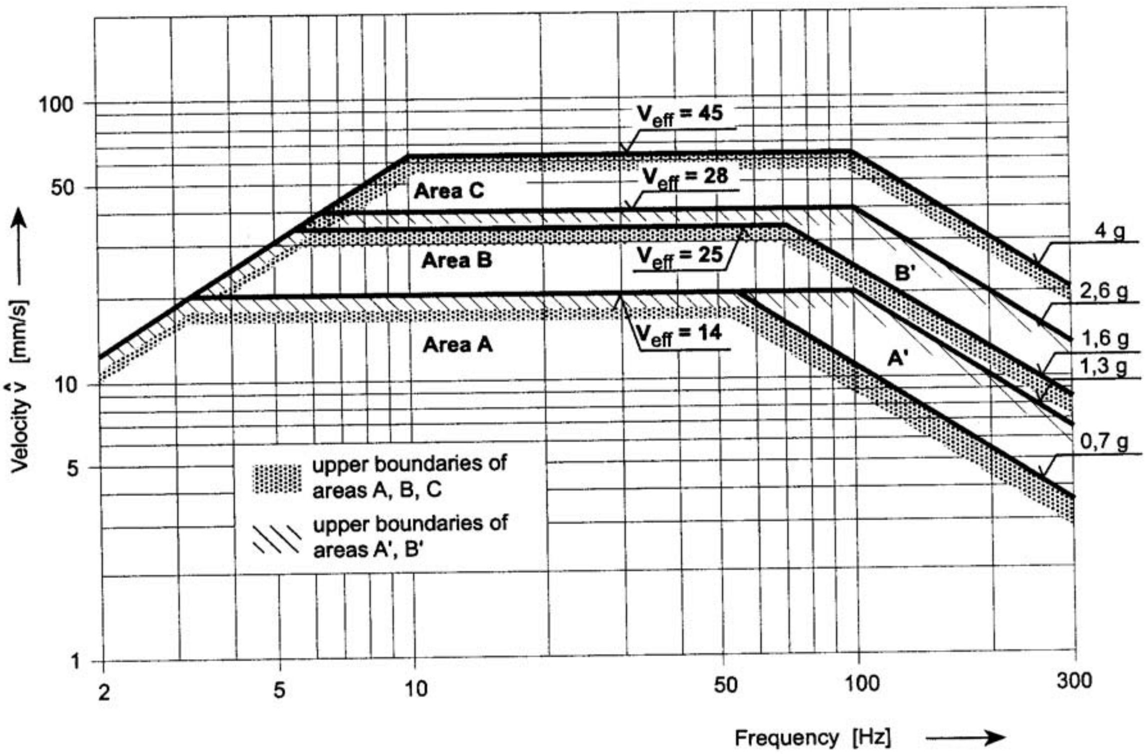

Fig. 1.1 Areas for the assessment of vibration loads

Table 1.5 Numerical definition of the area boundaries shown in Fig. 1.1

Areas		A	B	C	A'	B'
$\hat{s}$	[mm]	< 1	< 1	< 1	< 1	< 1
$\hat{v}$	[mm/s]	<20	< 35	< 63	< 20	< 40
v_{eff}	[mm/s]	< 14	< 25	< 45	< 14	< 28
â	[g]	< 0.7	< 1.6	< 4	< 1.3	< 2.6

2.2.4 Reciprocating machines must be separately considered, because they act as vibration exciters. Both the vibration generated by reciprocating machines and the stresses consequently imparted to directly connected peripheral equipment (e.g. governors, exhaust gas turbochargers and lubricating oil pumps) and adjacent machines or apparatus (e.g. generators, transmission systems and pipes) may, for the purpose of these Rules and with due regard to the limitations stated in 2.1.6, be assessed using the substitution quantities presented in 2.2.

2.2.4.1 In every case the manufacturer of reciprocating machines has to guarantee permissible vibration loads for the important directly connected peripheral equipment. The manufacturer of the reciprocating machine is responsible to TL for proving that the vibration loads are within the permissible limits in accordance with 2.3.

2.2.4.2 Where the vibration loads of reciprocating machines lie within the A' area, separate consideration or verifications relating to the directly connected peripheral equipment (cf. 2.2.4) are not required. The same applies to machines and apparatus located in close proximity to the vibration exciter (2.2.4).

In these circumstances directly connected peripheral appliances shall in every case be designed for at least the limit loads of area B', and machines located nearby for the limit loads of area B.

If the permissible vibration loads of individual directly connected peripheral appliances in accordance with 2.2.4.1 lie below the boundary curve of area B, permissibility must be proved by measurement of the actually occurring vibration load.

2.2.4.3 If the vibration loads of reciprocating machines lie outside area A' but are still within area B', it must be proved by measurement that directly connected peripheral appliances are not loaded above the limits for area C.

In these circumstances directly connected peripheral appliances shall in every case be designed for at least the limit loads of area C, and machines located nearby for the limit loads of area B.

Proof is required that machines and appliances located in close proximity to the main exciter are not subject to higher loads than those defined by the boundary curve of area B.

If the permissible vibration loads of individual, directly connected peripheral appliances or machines in accordance with 2.2.4.1 lie below the stated values, permissibility must be proved by measurement of vibration load which actually occurs.

2.2.4.4 If the vibration loads of reciprocating machines lie outside area B' but are still within area C, it is necessary to ensure that the vibration loads on the directly connected peripheral appliances still remain within area C. If this condition cannot be met, the important peripheral appliances must, in accordance with 2.3, be demonstrably designed for the higher loads.

Suitable measures (vibration damping etc.) are to be taken to ensure reliable prevention of excessive vibration loads on adjacent machines and appliances. The permissible loads stated in 2.2.4.3 (area B or a lower value specified by the manufacturer) continue to apply to these units.

2.2.4.5 For directly connected peripheral appliances, TL may approve higher values than those specified in 2.2.4.2, 2.2.4.3 and 2.2.4.4, if these are guaranteed by the manufacturer of the reciprocating machine in accordance with 2.2.4.1 and are proved in accordance with 2.3.

Analogously, the same applies to adjacent machines and appliances, if the relevant manufacturer guarantees higher values and provides proof of these in accordance with 2.3.

2.2.5 For appliances, equipment and components which, because of their installation in steering gear compartments or bow thruster compartments, are exposed to higher vibration stresses, the permissibility of the vibration load may, notwithstanding 2.2.3, be assessed according to the limits of area B. The design of such equipment shall allow for the above mentioned increased loads.

2.3 Proofs

2.3.1 Where in accordance with 2.2.4.1, 2.2.4.4 and 2.2.4.5 TL is asked to approve higher vibration load values, as a general rule the binding guarantee by the manufacturer or the supplier of the permissible values is required.

2.3.2 TL reserve the right to call for detailed proofs (calculations, design documents, measurements, etc.) in cases where this is justified.

2.3.3 Type testing in accordance with the TL Rules - Test Requirements for Electrical/Electronic Equipment and Systems, are regarded as proof of permissibility of the tested vibration load.

2.3.4 TL may recognize long-term trouble free operation as sufficient proof of the required reliability and safety in operation.

2.3.5 The manufacturer of the reciprocating machine is in every case responsible to TL for any proof which may be required concerning the level of the vibration spectrum generated by the reciprocating machine.

2.4 Measurement

2.4.1 Proof based on measurements is normally required only for reciprocating machines with an output of more than 100 kW, provided that the other conditions set out in 2.2.4.2 - 2.2.4.4 are met. Where circumstances justify this, TL may also require proofs based on measurements for smaller outputs.

2.4.2 Measurements are to be performed in every case under realistic service conditions at the installation location. During verification, the output supplied by the reciprocating machine shall be not less than 80 % of the rated value. The measurement shall cover the entire available speed range in order to facilitate the detection of any resonance phenomena.

2.4.3 TL may accept proofs based on measurements which have not been performed at the installation location (e.g. test bed runs), but under different mounting conditions, provided that the transferability of the results can be proved.

The results are normally regarded as transferable in the case of flexibly mounted reciprocating machines of customary design.

If the reciprocating machine is not flexibly mounted, the transferability of the results may still be acknowledged if the essential conditions for this (similar bed construction, similar installation and pipe routing etc.) are fulfilled.

For assessment of the vibration stresses affecting or affecting or generated by reciprocating machines normally the location with the highest vibration loads comes into consideration. Fig. 1.2 indicates the points of measurement which are normally required for an in-line reciprocating piston engine. The measurement has to be performed in all three directions. In justified cases exceptions can be made from data acquisition at all measuring points.

2.4.5 The measurements may be performed with mechanical manually-operated instruments provided that the instrument setting is appropriate to the measured values bearing in mind the measuring accuracy.

Directionally selective, linear sensors with a frequency range of at least 2 to 300 Hz should normally be used. Non-linear sensors can also be used provided that the measurements take account of the response characteristic

2.4.6 The records of the measurements for the points at which the maximum loads occur are to be submitted to TL together with a tabular evaluation.

3. Shock

Naval ships may also be exposed to shock forces created by air or underwater explosions from conventional or nuclear weapons.

Details for shock requirements are described in Chapter 102 - Hull Structures and Ship Equipment, Section 16, D.

E. Materials

1. Approved Materials

1.1 The materials used for propulsion plants have to fulfill the quality requirements defined in TL Material Rules and Welding Rules. The approved materials for the different systems are defined in the following Sections.

1.2 Materials deviating from the defined quality requirements may only be used with special approval of TL. The suitability of the materials has to be proven.

F. Fuels and Consumables for Operation

1. All fuels and consumables used for the operation of propulsion plants must be in accordance with the requirements of the manufacturers.

2. The flash point **(2)** of liquid fuels for the operation of boilers and diesel engines may not be lower than 60°.

For emergency power generating sets, however, use may be made of fuels with a flash point of ≥ 43 °C. The fuel must enable a starting of the emergency generating set at ambient temperatures of - 15 °C and above.

3. In exceptional cases, for ships intended for operation in limited geographical areas or where special precautions subject to TL approval are taken, fuels with flash points between 43 °C and 60 °C may also be used. This is conditional upon the requirement that the temperatures of the spaces in which fuels are stored or used must invariably be 10 °C below the flash point.

4. The fuel must be filterable.

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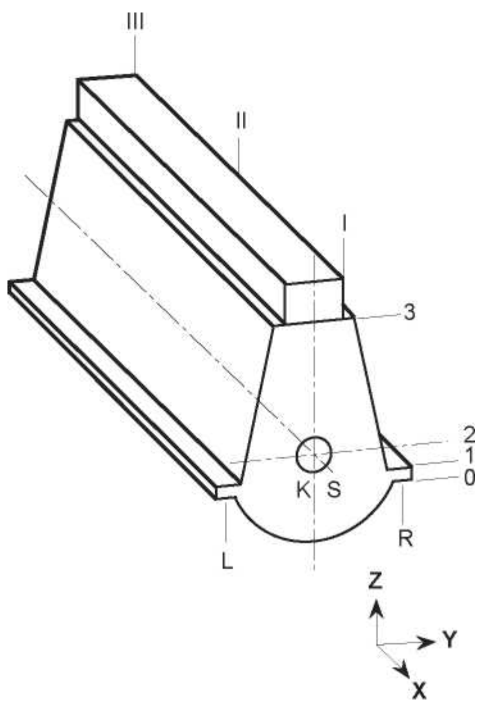
(2) *Based, up to 60 °C, on determination of the flash point in a closed crucible (cup test).*



Sides for measurement

L left side looking towards coupling flange
R right side looking towards coupling flange

Measuring height
0 bed
1 base
2 crankshaft height
3 frame top

Measuring point over engine length
I coupling side (KS)
II engine center
III opposite side to coupling (KGS)

Fig. 1.2 Schematic representation of in-line piston engine

5. The fresh cooling water for internal combustion engines has to be treated from freshwater and corrosion protection agent.

Fresh water must comply with the requirements of the engine manufacturer with respect to:

- water hardness [dGH]
- p_H value (at 20 °C)
- chloride content [mg/l]

6. The storage of fuel and consumables for operation has to follow the requirements of Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 7.

G. Safety Equipment and Protective Measures

Machinery is to be installed and safeguarded in such a way that the risk of accidents is largely ruled out. Besides of national regulations particular attention is to be paid to the following:

1. Moving parts, flywheels, chain and belt drives, linkages and other components which could constitute an accident hazard for the operating personnel are to be fitted with guards to prevent contact.

2. The design and installation of all systems and equipment has to guarantee that elements, which have to be used during normal operation of the ship by the crew and where no thermal insulation is provided, are kept within the following restrictions concerning accidental contact of hot surfaces.

2.1 No skin contact is possible with elements warmed up under operating conditions to surface temperature above 70 °C.

2.2 Elements, which may be used without body protection, e.g. protective gloves and with a contact time up to 5 s, are to have no higher surface temperature than 60 °C.

2.3 Elements made of materials with high thermal conductivity, which may be used without body protection and a contact time of more than 5 s are not to achieve a surface temperature above 45 °C.

2.4 Therefore exhaust gas lines and other apparatus and lines transporting hot media have to be insulated effectively. Insulation material must be non combustible. Locations where inflammable liquids or moisture may penetrate into the insulation are to be protected in a suitable way by coverings, etc.

3. When using hand cranks for starting internal combustion engines, steps are to be taken to ensure that the crank disengages automatically when the engine starts.

Dead-Man's circuits are to be provided for rotating equipment.

4. Blowdown and drainage facilities are to be designed in such a way that the discharged medium can be safely drained off.

5. In operating spaces, anti-skid floorplates and floor coverings must be used.

6. Service gangways, operating platforms, stairways and other areas open to access during operation are to be safeguarded by guard rails. The outside edges of platforms and floor areas are to be fitted with coamings unless some other means is adopted to prevent persons and objects from sliding off.

7. Safety valves and shutoffs must be capable of safe operation. Fixed steps, stairs or platforms are to be fitted where necessary.

8. Safety valves are to be installed to prevent the occurrence of excessive operating pressures.

H. Survivability

1. Definition

Survivability of a naval ship is to be regarded as the degree of ability to withstand a defined weapon threat and to maintain at least a basic degree of safety and operability of the ship.

Survivability is threatened by:

- Loss of global strength of the hull structure
- Loss of buoyancy and/or stability
- Loss of manoeuvrability
- Fire in the ship and ineffective fire protection or fire fighting capability
- Direct destruction of machinery, equipment or control systems
- Direct destruction of weapons and sensors
- Threat to the crew

2. Measures for improved survivability

The design of a ship which is classed as naval ship has to consider a series of possible measures to improve survivability. These TL Rules for naval surface ships offer in the different Chapters various measures and Class Notations to achieve improved survivability. The degree of including such measures in an actual project has to be defined by the Naval Authority.

3. Measures for the propulsion plant

In this Chapter the following main measure to improve survivability is included.

3.1 Redundant propulsion

The requirements for the Class Notations **RP1 x%** to **RP3 x%** concerning redundant propulsion and manoeuvrability are defined in Section 2, K.

SECTION 2

DESIGN AND CONSTRUCTION OF THE MACHINERY INSTALLATION

Page

A. General

1. As far as necessary for function and safe operation, the design of the propulsion plant has to consider the size and experience of the crew according to the mission statement of the actual naval ship.

2. Normally it can be assumed, that:

- No personnel is permanently present in machinery rooms
- In machinery rooms inspection patrols will be made in regular time intervals
- The machinery control centre (MCC) is permanently manned

3. The operating and maintenance instructions, warning signs, etc. have to be prepared in English and in the user's language.

B. Dimensions of Components

1. General

1.1 All parts must be capable of withstanding the stresses and loads peculiar to shipboard service, e.g. those due to movements of the ship, vibrations, intensified corrosive attack, temperature changes and wave impact, and must be dimensioned in accordance with the requirements set out in the present Chapter. The ambient conditions acc. to Section 1, D. and Chapter 101 - Classification and Surveys and Chapters 105 - Electrical Installations, 106 - Automation and 107 - Ship Operation Installations and Auxiliary Systems, have to be considered.

In the absence of rules governing the dimensions of parts, the recognized rules of engineering practice are to be applied.

1.2 Where connections exist between systems or plant items which are designed for different forces, pressures and temperatures (stresses), safety devices are to be fitted which prevent the over-stressing of the system or plant item designed for the lower design parameters. To preclude damage, such systems are to be fitted with devices affording protection against excessive pressures and temperatures and/or against overflow.

2. Materials

All components subject to these Rules must comply with TL Material Rules.

3. Welding

The fabrication of welded components, the approval of companies and the testing of welders are subject to TL Welding Rules.

4. Screw connections

4.1 Screws are to be designed according to proven and acknowledged principles.

4.2 The design of screw connections between equipment and foundations has to avoid shear forces or bending moments in the screws, only tensional forces in axial direction are allowed. Therefore, the flanges where the screw forces are acting have to be stiffened with a suitable number of brackets to avoid flange bending, which would create bending moments to the screws.

4.3 Only closed holes in flanges shall be provided for screws, because under shock influence screws might slip out of a hole in form of a half open slot. In addition friction connections are not safe under shock influence.

Note :

If expansion screws are used, the peak stresses at the core of the thread are reduced, because the maximum stress will occur at the location of the reduced shaft section. If such screws are long enough, they will be able to protect the mounted equipment from shock loads to some extent, because the elongation of the shaft reduces acceleration peaks.

It is also recommendable to use cap nuts together with expansion screws for connections. With this form of nut the load on the different turns of the thread is nearly the same, *which helps to avoid excessive local stresses.*

If a normal screw is fitted into a threaded hole, the breaking of the screw because of the severe transverse dynamic shock loads will be evident at the first turn of the thread coming out of the hole. This is the case because of the adding up of the bending stress to the maximum axial stress which occurs at this turn. The problem can be solved by a flat necking of the shaft above the last turn of the thread or by a special form of shaft and hole. The bolt is in the latter case provided with a small collar fitting in the upper part of the hole. Thus the biggest part of the bending stress will be transmitted at the collar and is separated from the axial stress at the thread.

5. Tests

5.1 Machinery and its component parts are subject to constructional and material tests, pressure and leakage tests, and trials. All the tests prescribed in the following Sections are to be conducted under supervision of TL.

In case of parts produced in series, other methods of testing may be agreed with TL instead of the tests prescribed, provided that the former are recognized as equivalent by TL.

5.2 TL reserve the right, where necessary, to increase the scope of tests and also to subject to testing those parts which are not expressly required to be tested according to the Rules.

5.3 Components subject to mandatory testing are to be replaced by tested parts.

5.4 After installation on board of the main and auxiliary machinery, operational functioning of the machinery including associated ancillary equipment is to be verified. All safety equipment is to be tested, unless adequate testing has already been performed at the manufacturer's works in the presence of the TL Representative.

In addition, the entire machinery installation is to be tested during sea trials, as far as possible under the intended service conditions.

6. Corrosion protection

Parts which are exposed to corrosion are to be safeguarded by being manufactured of corrosion-resistant materials or provided with effective corrosion protection.

C. Availability of Machinery

1. Ship's machinery is to be so arranged and equipped that it can be brought into operation from the "dead ship" condition with the means available on board.

The "dead ship" condition means that the entire machinery installation including the electrical power supply is out of operation and auxiliary sources of energy such as starting air, battery-supplied starting current etc. are not available for restoring the ship's electrical system, restarting auxiliary operation and bringing the propulsion installation back into operation.

To overcome the "dead ship" condition use may be made of an emergency generator set provided that it is ensured that the electrical power for emergency services is available at all times. It is assumed that means are available to start the emergency generator at all times.

3. In case of "dead-ship" condition it must be ensured that it will be possible for the propulsion system and all necessary auxiliary machinery to be restarted within a period of 30 minutes, see Chapter 105 - Electrical Installations, Section 3, C. 1.5.

D. Control and Regulating

1. Machinery must be so equipped that it can be controlled in accordance with operating requirements in such a way that the service conditions prescribed by the manufacturer can be met.

1.1 For the control equipment of main engines and systems essential for operation see Chapters 105 - Electrical Installations, 106 - Automation and 107 - Ship Operation Installations and Auxiliary Systems.

2. In the event of failure or fluctuations of the supply of electrical, pneumatic or hydraulic power to regulating and control systems, or in case of a break in a regulating or control circuit, steps must be taken to ensure that:

- the appliances remain at their present operational setting or, if necessary, are changed to a setting which will have the minimum adverse effect on operation (fail-safe conditions)

- the power output or engine speed of the machinery being controlled or governed is not increased

- no unintentional start-up sequences are initiated

3. Each driving machinery has to be provided with an emergency stopping device.

4. Manual operation

Every functionally important, automatically or remote controlled system must also be capable of manual operation, see also the Rules in Chapter 106 - Automation, Sections 7 and 8.

A manual emergency stopping device has to be provided.

E. Propulsion Plant

1. General

1.1 All devices forming a part of the propulsion plant have to be provided with peripheral components which ensure a faultless handling as well as a simple and safe operation and control, even if they are not specified in detail.

1.2 All auxiliary machinery and the control units directly needed for the operation of the propulsion plant are to be located as near as possible to the driving machinery.

1.3 Manoeuvring equipment

Every engine control stand is to be equipped in such a way that:

- the propulsion plant can be adjusted to any setting

- the direction of propulsion can be reversed

- the propulsion unit or the propeller shaft can be stopped

1.4 The driving machinery has to be designed and equipped for operation in a sound protection capsule.

Using sound protection capsules the relative movement between the driving machinery and the shipside piping system has to be compensated by flexible connections. If applicable, the elastic mounting of the driving machinery has to be taken into account.

1.5 For connected pumps no electrically driven stand by pumps are to be provided if the propulsion is ensured by several driving machines.

2. Multiple shaft and multi-engine systems

2.1 Definitions

2.1.1 CODAD

CODAD is the abbreviation for COmbined Diesel engine And Diesel engine. In this configuration a propulsion shaft can be driven alternatively by one diesel engine or several diesel engines, see Fig. 2.1.

2.1.2 CODAG

CODAG is the abbreviation for COmbined Diesel engine And Gas turbine. In this configuration a propulsion shaft can be driven alternatively by a diesel engine or by a gas turbine or by both, see Fig. 2.2.

2.1.3 CODOG

CODOG is the abbreviation for COmbined Diesel engine Or Gas turbine. In this configuration a propulsion shaft can be driven alternatively by a diesel engine or a gas turbine, see Fig. 2.3.

2.1.4 COGAG

COGAG is the abbreviation for COmbined Gas turbine And Gas turbine. In this configuration a propulsion shaft can be driven alternatively by one gas turbine or by several gas turbines, see Fig. 2.4.

2.1.5 COGOG

COGOG is the abbreviation for COmbined Gas turbine Or Gas turbine. In this configuration a propulsion shaft can be driven alternatively by one or the other gas turbine, see Fig. 2.5.

2.2 If a ship is equipped with several propulsion machines, it must be possible to disengage the different propulsion engines from the power transmitting unit. At manual or automatic emergency stops of an engine, the relevant clutch must disconnect automatically.

2.3 Steps are to be taken to ensure that in the event of a failure of a propulsion engine, operation can be maintained with remaining engines, where appropriate by a simple change-over system.

2.4 Multiple shaft systems

A space separation between driving engines and driving gear shall be provided, if possible.

All necessary provisions have to be made, that:

- Only one propulsion shaft can be used and no overloading occurs

- Starting and operation is possible with every driving engine intended to drive a propulsion shaft, independently from the other propulsion shafts

For Class Notation redundant propulsion **(RP)** see K.

For multiple-shaft systems, each shaft is to be provided with a locking device which prevents dragging of the shaft.

F. Turning Appliances

1. Machinery is to be equipped with the necessary turning appliances.

2. The turning appliances are to be of self-locking type. Electric motors are to be fitted with suitable retaining brakes.

3. An automatic interlocking device is to be provided to ensure that the propulsion installation cannot start up while the turning gear is engaged. In case of manual turning installations warning devices may be provided alternatively.

G. Operating and Maintenance Instructions

Manufacturers of machinery, boilers and auxiliary equipment must supply a sufficient number of operating and maintenance notices and manuals together with the equipment.

In addition, an easily legible board is to be mounted on boiler operating platforms giving the most important operating instructions for boilers and oil-firing equipment.

H. Markings, Identification

In order to avoid unnecessary operating and switching errors, all parts of the machinery which function is not immediately apparent are to be adequately marked and labelled.

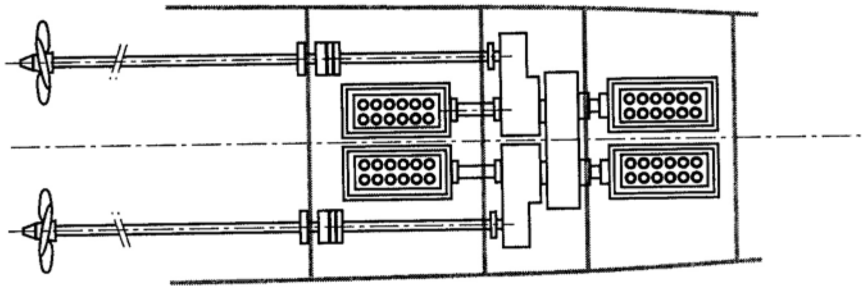


Figure 2.1 Principle arrangement for CODAD propulsion plants

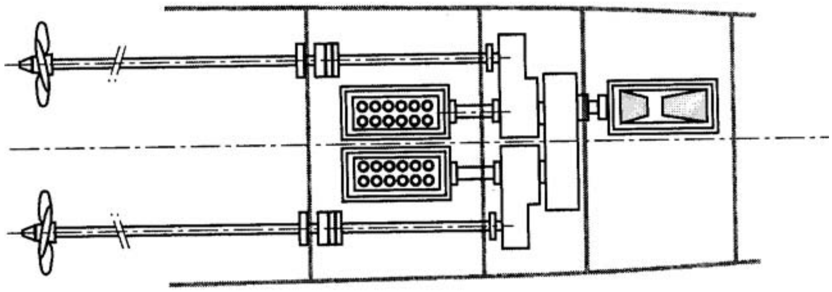


Figure 2.2 Principle arrangement for CODAG propulsion plants

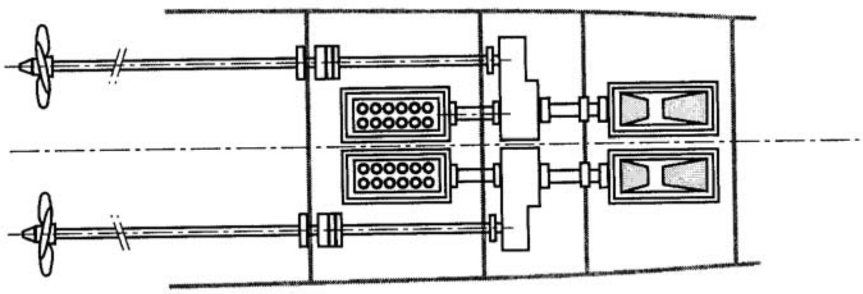


Figure 2.3 Principle arrangement for CODOG propulsion plants

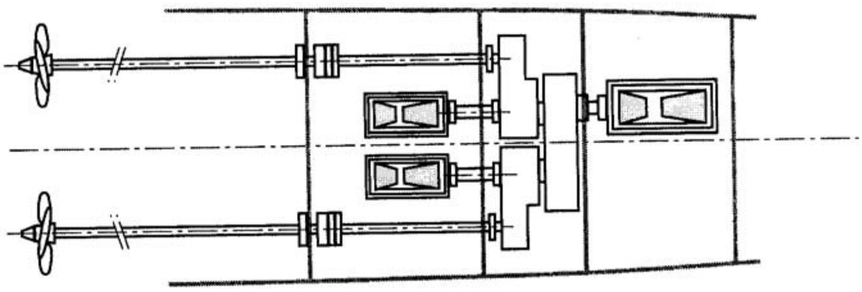


Figure 2.4 Principle arrangement for COGAG propulsion plants

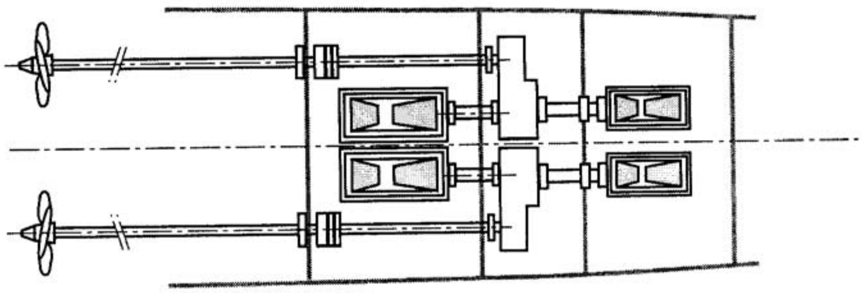


Figure 2.5 Principle arrangement for COGOG propulsion plants

I. Engine Room Equipment

1. Operating and monitoring equipment

1.1 Instruments, warning and indicating systems and operating appliances are to be clearly displayed and conveniently sited. Absence of dazzle, particularly on the bridge, is to be ensured.

Operating and monitoring equipment is to be grouped in such a way as to facilitate easy supervision and control of all important parts of the installation.

The following requirements are to be observed when installing systems and equipment:

- protection against humidity and the effects of dirt
- avoidance of excessive temperature variations
- adequate ventilation

In consoles and cabinets containing electrical or hydraulic equipment or lines carrying steam or water the electrical gear is to be protected from damage due to leakage. Redundant ventilation systems are to be provided for air-conditioned machinery and control rooms.

1.2 Pressure gauges

The scales of pressure gauges are to be dimensioned up to the specified test pressure. The maximum permitted operating pressures are to be marked on the pressure gauges for boilers, pressure vessels and in systems protected by safety valves. Pressure gauges must be installed in such a way that they can be isolated.

Lines leading to pressure gauges must be installed in such a way that the readings cannot be affected by liquid heads and hydraulic hammering.

2. Accessibility of machinery and boilers

2.1 Machinery and boiler installations, apparatuses, control and operating devices must be easily accessible and visible for operation and maintenance. A minimum aisle width of 600 mm and a passage height of 2 050 mm have to be provided, stumbling locations have to be avoided.

2.2 For the layout of machinery spaces (design of foundation structures, laying of pipelines and cable conduits, etc.) and for the design of machinery and equipment (mountings for filters, coolers, etc.) 2.1 is to be complied with.

For the installation and the dismantling of the propulsion machinery, openings of sufficient size have to be provided; for all other parts of the equipment installation and dismantling routes have to be planned.

Fixtures for transport devices have to be provided.

The installation of components within the installation routes has to be avoided or the components must be dismountable.

3. Machinery control centre

Machinery control centres (MCC) are to be provided with at least two exits, one of which can also be used as an escape route.

4. Lighting

All operating spaces must be adequately lit to ensure that control and monitoring instruments can be easily read. In this connection see the rules defined in Chapter 105 - Electrical Installation, Section 11.

5. Bilge wells/ bilges

See rules defined in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

6. Ventilation

The design and construction of ventilation systems are subject to the requirements defined in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 11.

7. Noise abatement

In compliance with the relevant national regulations, care is to be taken to ensure that operation of the ship is not unacceptably impaired by engine noise, e.g. by means of shielding.

J. Communication and Signalling Equipment

1. Oral communication

Means of oral communication are to be provided between the ship's manoeuvring station, the engine room and the steering gear compartment, and these means shall allow fully satisfactory intercommunication independent from the shipboard power supply under all operating conditions (see also Chapter 105 - Electrical Installations, Section 9).

2. Duty alarm system

From the engine room or the machinery control centre a duty alarm system for the engineer officers has to be established for the off-duty period. See also Chapter 106 - Automation, Section 3, C.

3. Engine telegraph

Machinery operated from the engine room must be equipped with a telegraph.

In the case of multiple-shaft installations, a telegraph must be provided for each unit.

Local control stations are to be equipped with an emergency telegraph.

4. Shaft revolution indicator

The speed and direction of rotation of the propeller shafts are to be indicated on the bridge, in the engine room respectively in all control stations. In the case of small propulsion units, the indicator may be dispensed with.

5. Design of communication and signaling equipment

Reversing, command transmission and operating controls etc. are to be grouped together at a convenient point on the control platform.

The current status, "Ahead" or "Astern", of the reversing control is to be clearly indicated on the propulsion plant control platform.

Signalling devices must be clearly perceptible from all parts of the engine room when the machinery is in full operation.

For details of the design of electrically operated command transmission, signalling and alarm systems, see Chapter 105 - Electrical Installations and 106 - Automation.

K. Redundant Systems

1. General

1.1 The Rules relating to redundant propulsion and steering systems apply to ships, which are classified by TL and are to receive the Notation **RP1 x%**, **RP2 x%** or **RP3 x%** affixed to the Character of Classification.

1.2 The Rules for redundant propulsion and steering systems stipulate the level of redundancy for the propulsion and steering systems. It is characterized by the appropriate Notation to be affixed to the Character of Classification as defined in Chapter 101 - Classification and Surveys, Section 2, C.

1.3 The Rules are based on the single-failure concept.

1.4 Documents for approval

1.4.1 Compliance in accordance with the Notation applied for must be demonstrated by block diagrams, schematic drawings, descriptions of system functions and operation, calculations and arrangement plans.

Model tests or calculations shall be used to show the speed and manoeuvring qualities that have to be attained during sea trials in order to demonstrate compliance with the requirements set out in 2.

1.4.2 A failure mode and effects analysis (FMEA) or an equivalent analysis must be conducted for the propulsion and steering systems, and for the auxiliary systems and control systems needed to operate them.

The analysis must demonstrate that a single failure cannot lead to any loss in propulsion and/or in steering ability in accordance with the requirements set out in 2.

The analysis shall further demonstrate that measures are in place for failure detection and control of possible effects and that these measures are adequate to ensure in particular that the propulsion and steering of the ship can be rapidly restored.

In addition, the analysis must deal with the identification of possible failure conditions, which have a common cause. The identification of technical elements and/or operational procedures, which could undermine the redundancy concept, must also be accounted for.

For the Notation **RP1 x%**, the FMEA only has to be performed for the redundant propulsion machines and their requisite auxiliary systems. The events of water ingress or fire in a machinery compartment, and a failure of any of the common elements of the propulsion train related to this Notation do not have to be considered.

For the Notation **RP2 x%**, the FMEA has to be performed for the redundant propulsion and steering systems and their requisite auxiliary systems. The events of water ingress or fire in a machinery compartment and water ingress in a steering gear compartment do not have to be considered.

1.4.3 A programme of tests to be conducted during sea trials must be submitted for approval.

2. General requirements

In accordance with the requirements set out in these Rules, it must be ensured that when a failure in a propulsion or steering system occurs,

2.1 the manoeuvrability of the ship can be maintained so that even under unfavourable weather conditions **(1)** the ship can be manoeuvred into a position of less resistance to the weather and can be maintained in this position,

2.2 a minimum speed can be maintained to keep the ship under control and ensure that it is able to make speed over the ground in waters where there is a strong current. The minimum speed under normal weather conditions **(2)** must be at least 7 knots or half the speed v_0 (the lower value may be applied),

2.3 the requirements stated in 2.1 and 2.2 can be met for a minimum period of 72 hours **(3)** .

(1) *Within the context of these Rules, unfavourable weather conditions are regarded as being a wind speed of up to and including 21 m/s (8 on the Beaufort scale) and a significant wave height of 5,4 m with an average wave period of 8,3 s.*

(2) *Normal weather conditions are regarded as being a wind speed of up to and including 11 m/s (5 on the Beaufort scale) and a significant wave height of 2,8 m with an average wave period of 6,7 s.*

(3) *For ships, which normally spend less than 72 hours cruising at sea, the period specified may be limited to the maximum time of a voyage.*

2.4 the requirements stated in 2.1, 2.2 and 2.3 can be met irrespective of the ship's loading condition,

2.5 the redundant propulsion systems and steering systems are ready for operation at any time and can be activated on demand,

2.6 the redundant propulsion system is capable of taking up operation from a still standing propulsion plant.

Compliance with the above requirements must be demonstrated by calculations and/or model tests and verified in a suitable manner during sea trials.

3. Requirements for auxiliary systems

3.1 Auxiliary systems for redundant propulsion systems which function have a direct effect on the propulsion system, for example fuel, lubrication oil, cooling water, control air and uninterrupted power supply systems, must be provided for each propulsion system independently of each other.

Where standby units are specified for these systems in accordance with TL Rules, these must be provided for each of the systems in question.

3.2 Auxiliary systems for redundant propulsion systems which failure do not have a direct effect on the propulsion system, such as fuel treatment, starting air supply systems etc. are to be designed to be separate from each other. For these systems no additional standby units have to be provided if interconnection lines are provided between the systems and if the units are designed so that the propulsion systems can be supplied with power simultaneously without restriction. In the connection lines shut-off valves are to be provided which must be kept closed during normal operation.

On ships with Class Notation **RP3 x%**, a shut-off valve must be fitted on either side of the partition bulkhead between the machinery compartments.

3.3 In fuel oil systems, the heating facilities for preheating the fuel oil must be designed so that if one propulsion system fails, the required preheating of the fuel oil for the redundant propulsion system can be ensured.

It is not necessary to provide a redundant heating facility if diesel oil storage tanks are provided which allow unrestricted operation for the redundant propulsion system for the period of time specified in 2.3.

3.4 Supply lines from fuel oil service tanks of redundant propulsion systems must be provided with an interconnection fitted between service tank and pump of each system. The interconnection is to be provided with a shut-off device, which must be kept closed during normal operation.

On ships with Class Notation **RP3 x%**, a shut-off valve must be fitted on either side of the partition bulkhead between the machinery compartments.

3.5 The seawater supply of redundant propulsion systems may be achieved via a common sea chest connection by means of a pump assigned to each propulsion system. The systems must be capable of being isolated by means of a shut-off valve in the connection line.

On ships with Class Notation **RP3 x%** the sea chests are to be installed in separate compartments in accordance with 5.1. The shut-off valve in the connection line must be fitted to the partition bulkhead and be capable of being operated either from both machinery compartments or from a position outside the machinery compartments.

3.6 On ships with Class Notation **RP3 x%** it must be possible to operate the redundant propulsion system when one of the seawater cooling systems fails, in accordance with the compartment separation requirements specified in 5.1.

4. Requirements for steering systems

4.1 Rudders

Every redundant steering system must consist of a main and an auxiliary steering gear, each with independent control.

The rudder position must be indicated by means of electrically independent rudder position indicators.

The ship's steering capability must be ensured even when the rudder is blocked at maximum deflection. If the steering ability is impaired to the extent that the requirements set out in 2. cannot be met, it must be possible to move and lock the failed rudder into the midships position.

4.2 Azimuth propulsion units as steering systems

Where ship steering is exclusively performed by azimuth propulsion systems, at least two azimuth propulsion systems must be provided, each with independent controls.

The position of the individual azimuth propulsion systems must be indicated by electrically independent indicators.

If the ship's steering ability is impaired, even when the propulsion of a defective azimuth propulsion system is disconnected, to the extent that the requirements stated in 2. cannot be met, it must be possible to move and to lock the defective azimuth propulsion unit into the midships position.

5. Compartment Separation Requirements for RP3 x%

5.1 Bulkheads and partitions

5.1.1 Redundant propulsion systems and steering systems must be separated from each other by watertight bulkheads.

5.1.2 Partitions between machinery compartments containing redundant propulsion systems must comply with a fire resistance, the level of which depends on the fire potential of the machinery compartments. The partitions must keep their structural integrity in case of fire for at least 60 minutes. Fire insulation shall be provided if the function of essential machinery and equipment could be adversely affected.

5.1.3 Partition walls of machinery compartments, which are isolated from each other by tanks, cofferdams or other void spaces, must keep their structural integrity in case of fire for at least 60 minutes. The length or depths of that spaces shall be at least 500 mm.

5.1.4 Watertight doors may be permitted in accordance with **SOLAS** II-1 / Reg. 18 or Reg. 15 respectively. These have to be equipped with an open/closed status indication and a remote control facility on the bridge.

Watertight doors must not be regarded as emergency exits for machinery compartments.

5.2 Ventilation

Machinery compartments are to be fitted with independent ventilation systems.

6. Tests

Tests are to be performed during sea trials in accordance with an approved sea trial program. The tests are designed to prove that:

- the ship is able to meet the requirements defined
- the propulsion and steering systems have the necessary redundancy in line with the Notation applied for
- the conclusions drawn in the FMEA regarding the effects of failure conditions and measures to detect and control these failure conditions are correct and adequate

7. Further details

Further details concerning redundant systems are defined in Chapter 105, Electrical Installations and in the TL Rules for Classification and Construction, Chapter 23 - Redundant Propulsion and Steering Systems.

SECTION 3

INTERNAL COMBUSTION ENGINES

A. General

1. Scope

The Rules contained in this Section are valid for internal combustion engines as main and auxiliary drives.

Internal combustion engines in the sense of these Rules are four-stroke diesel engines with trunk piston.

2. Ambient conditions

For all engines, which are used on ships with unrestricted range of service, the definition of the performance has to be based on the ambient conditions according to Section 1, D.

3. Rated power

3.1 Diesel engines are to be designed such that their rated power when running at rated speed according to the definitions of the engine manufacturer at ambient conditions as defined in Section 1, D. can be delivered as continuous power. Diesel engines are to be capable of continuous operation within power range ① in Fig. 3.1 and of short period operation in power range ②. The extent of the power ranges are to be stated by the engine manufacturer.

3.2 Continuous power is understood to mean the service standard power which an engine is capable of delivering continuously, provided that the maintenance prescribed by the engine manufacturer is carried out, between the maintenance intervals stated by the engine manufacturer.

3.3 To verify that an engine is rated at its continuous power, it is to be demonstrated that the engine can run at an overload power corresponding to 110 % of its rated power at corresponding speed for an uninterrupted period of 1 hour. Deviations from the overload power value require the agreement of TL.

3.4 Engines, which have to meet the requirements of a permanent low-load operation according to the mission statement of the naval ship, have to be designed with regard to bad combustion and low temperatures. Relevant measures and additional equipment have to be approved by TL.

3.5 After running on the test bed, the fuel delivery system of main engines is normally to be so adjusted that overload power cannot be given in service. The limitation of the fuel delivery system has to be secured permanently.

3.6 Subject to the prescribed conditions, diesel engines driving electric generators must be capable of overload operation even after installation on board.

3.7 Subject to the approval by TL, diesel engines may be designed for a continuous power (fuel stop power) which cannot be exceeded.

3.8 For main engines, a power diagram (Fig. 3.1) is to be prepared showing the power ranges within which the engine is able to operate continuously and for short periods under service conditions.

4. Fuels

4.1 The use of liquid fuels is subject to the Rules contained in Section 1, F.

4.2 For fuel treatment and supply, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 7, B. and Section 8, G.

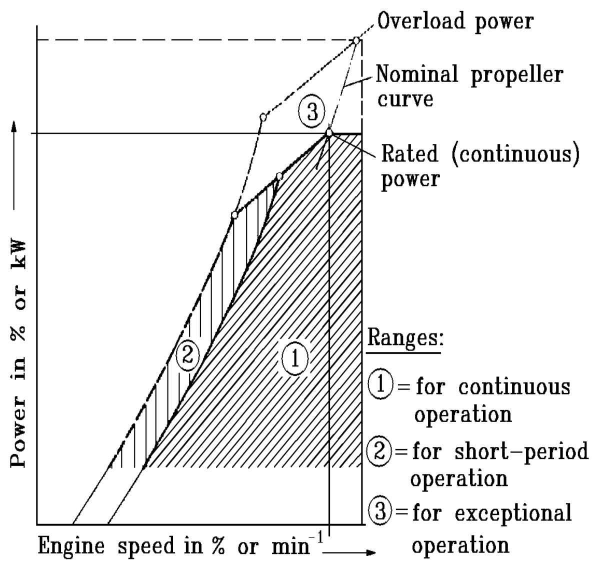


Fig.3.1 Example of a power diagram

5. Accessibility of engines

Engines are to be so arranged in the engine room that all the assembly holes and inspection ports provided by the engine manufacturer for inspections and maintenance are accessible. A change of components, as far as practicable on board, must be possible. Requirements related to space and construction have to be considered for the installation of the engines.

6. Electronic components and systems

6.1 For electronic components and systems which are necessary for the control of internal combustion engines the following items have to be observed:

6.1.1 Electronic components and systems have to be type approved according to the TL Rules - Test Requirements for Electrical/Electronic Equipment and Systems.

6.1.2 For computer system the Rules, Chapter 105 - Electrical Installations, Section 10 have to be observed.

6.1.3 The failure of an electronic control system shall not result in any sudden loss or change of the propulsion power. In individual cases, TL may approve other failure conditions, whereby it is ensured that no increase in ship's speed occur.

6.1.4 The failure probability of an electronic control system has to be proven by a structural analysis (e.g. FMEA), which has to be provided by the system's manufacturer. This shall include the effects on persons, environment and technical condition.

6.1.5 Where the electronic control system incorporates a speed control, F.2.3 of this Section and Chapter 105 - Electrical Installations, Section 9 have to be observed.

6.2 Local control station

6.2.1 For the local control station, H. has to be observed.

The indicators named in H. shall be realized in such a way that one failure can only affect a single indicator. Where these indicators are an integral part of an electronic control system, means shall be taken to maintain these indications in case of failure of such a system.

6.2.2 One failure shall not lead to the loss of more than one indication.

6.2.3 Where these indicators are realized electrically, the power supply of the instruments and of the electronic system has to be realized in such way to ensure the behaviour stated in 6.2.2 and 6.2.3.

B. Documents for Approval

1. For each engine type the drawings and documents listed in Table 3.1 shall, wherever applicable, be submitted by the engine manufacturer to TL for approval (A) or information (R).

2. For each engine type manufactured under licence, the licensee shall submit to TL, as a minimum requirement, the following documents:

- Comparison of all the drawings and documents as per Table 3.1 - where applicable - indicating the relevant drawings used by the licensee and the licensor
- All drawings of modified components, if available, as per Table 3.1 together with the licensor's declaration of consent to the modifications
- Documents concerning measures, respectively additional equipment for low load operation
- A complete set of drawings at the disposal of the local inspection office of TL as a basis for the tests and inspections

Table 3.1 Documents for approval

Serial No.	A/R	Description	Quantity	Remarks (see below)
1	R	Details required on TL forms F 144 and F 144/1 when applying for approval of an internal combustion engine	3	
2	R	Engine transverse cross-section	3	
3	R	Engine longitudinal section	3	
4	 R A	Bedplate or crankcase - cast - welded, with welding details and instructions	 1 3	
5	A	Thrust bearing assembly	3	**(3)**
6	 R A	Thrust bearing baseplate: - cast - welded, with welding details and instructions	1 3	 **(3)** **(3)**
7	 R A	Frame/column: - cast - welded, with welding details and instructions	1 3	 **(1)** **(1)**
8	R	Tie rod	1	
9	R	Cylinder cover, assembly	1	
10	R	Cylinder jacket or engine block	1	**(1) (2)**
11	R	Cylinder liner	1	**(2)**
12	A	Crankshaft for each number of cylinders, with data sheets for calculation of crankshafts	3	
13	A	Crankshaft assembly, for each number of cylinders	*3*	
14	A	Thrust shaft or intermediate shaft (if integral with engine)	3	
15	A	Coupling bolts	3	
16	A	Counterweights including fastening bolts	3	
17	R	Connecting rod, details	3	
18	R	Connecting rod, assembly	3	**(2)**
19	R	Piston assembly	1	
20	R	Camshaft drive, assembly	1	
21	A	Material specifications of main parts with information on non-destructive material tests and pressure tests	3	
22	A	Arrangement of foundation bolts (for main engines only)	*3*	
23	A	Schematic layout or other equivalent documents of starting air system	3	**(6)**
24	A	Schematic layout or other equivalent documents of fuel oil system	*3*	**(6)**
25	A	Schematic layout or other equivalent documents of lubricating oil system	3	**(6)**
26	A	Schematic layout or other equivalent documents of cooling water system	3	**(6)**
27	A	Schematic diagram of engine control and safety system	3	**(6)**
28	A	Schematic diagram of electronic components and systems		
29	R	Shielding and insulation of exhaust pipes, assembly	1	
30	A	Shielding of high-pressure fuel pipes, assembly	3	**(4)**
31	A	Arrangement of crankcase explosion relief valves	3	**(5)**
32	R	Additional equipment for continuous low load operation		
33	R	Operation and service manuals	1	

A for approval
R for reference

(1) *only for one cylinder*
(2) *only necessary if sufficient details are not shown on the transverse cross section and longitudinal section*
(3) *if integral with engine and not integrated in the bedplate*
(4) *for all engines*
(5) *only for engines with a bore > 200 mm, or a crankcase volume ≥ 0,6 m^3*
(6) *and the entire system, if this is part of the goods to be supplied by the engine manufacturer, requirements acc. to the Rules, see Chapter 107 - Ship Operation Installations and Auxiliary Systems*

3. The type specification of an internal combustion engine is defined by the following data:

- Manufacturer's type designation
- Cylinder bore
- Stroke
- Injection system
- Fuels which can be used
- Working cycle
- Scavenging system (naturally aspirated or supercharged)
- Rated power per cylinder at rated speed and maximum continuous brake mean effective pressure
- Supercharging system (pulsating pressure system or constant-pressure system)
- Charge air cooling system
- Cylinder arrangement (in-line, vee)

4. Following initial approval of an engine type by TL, only those documents listed in Table 3.1 require to be resubmitted for examination which em-body important design modifications.

5. Where considered necessary, TL may request further documents to be submitted.

6. The approval of exhaust gas turbochargers, heat exchangers, engine-driven pumps, etc. is to be requested from TL by the respective manufacturer.

7. Torsional vibrations, critical speeds

The rules defined in Section 8 are to be applied.

C. Crankshaft Design

1. Design methods

1.1 Crankshafts shall be designed to withstand the stresses occurring when the engine runs at rated power. Calculations are to be based on the TL Rules Guid- elines for the Calculation of Crankshafts for I.C. Engines, as amended. Other methods of calculation may be used provided that they do not result in crankshaft dimensions smaller than those obtained by applying the aforementioned regulations. The documentation has to be submitted for approval.

1.2 Outside the end bearings, crankshafts designed according to the requirements specified in 1.1 may be adapted to the diameter of the adjoining shaft by a generous fillet ($r \geq 0,06 \cdot d$) or a taper.

1.3 Design methods for application to crankshafts of special construction and to the crankshafts of engines of special type are to be agreed with TL.

2. Shrink joints of built-up crankshafts

The shrink joints of built-up crankshafts are to be designed in accordance with the TL Guidelines as defined in 1.1

3. Screw joints

3.1 Split crankshafts

Only fitted bolts may be used for assembling split crankshafts.

3.2 Power-end flange couplings

The bolts used to connect power-end flange couplings are normally to be designed as fitted bolts in accordance with Section 5, D.4.

If the use of fitted bolts is not feasible, TL may agree to the use of an equivalent frictional resistance transmission.

D. Materials

1. Approved materials

1.1 The mechanical characteristics of materials used for the components of diesel engines must conform to TL Materials Rules. The materials approved for the various components are shown in Table 3.3 together with their minimum required characteristics.

1.2 Materials with properties deviating from those specified may be used only with TL's special approval. Proof of the suitability of such materials has to be given.

1.3 If shock loads gain great importance for the naval ship, cast iron with lamellar graphit (GG) is not recommended for components exposed to such loads. It may only be used if it is proven that the shock loads are sufficiently reduced by adequate mountings.

2. Testing of materials

2.1 In the case of individually produced engines, the following parts are to be subjected to material tests in the presence of the TL representative.

1. Crankshaft

2. Crankshaft coupling flange (non-integral) for main power transmission

3. Crankshaft coupling bolts

4. Pistons or piston crowns made of steel, cast steel or nodular cast iron

5. Cylinder liners made of steel or cast steel

6. Cylinder covers made of steel or cast steel

7. Welded bedplates:
   - plates and bearing transverse girders made of forged or cast steel

8. Welded frames and crankcases

9. Welded entablatures

10. Tie rods

11. Exhaust gas turbocharger:
    - shaft and rotor

12. Bolts and studs for:
    - cylinder covers
    - main bearings
    - connecting rod bearings

13. Camshaft drive gear wheels and chain wheels made of steel or cast steel.

2.1.1 Materials tests are to be performed in accordance with Table 3.2.

Table 3.2 Material tests

Cylinder bore	Parts to be tested (numbered according to the list under D.2.1 above)
≤ 300 mm	1-7-8-9-10
> 300 ≤ 400 mm	1-5-6-7-8-9-10-12-13
> 400 mm	all parts

2.1.2 In addition, material tests are to be carried out on pipes and parts of the starting air system and other pressure systems forming part of the engine, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

2.2 In the case of individually manufactured engines, non-destructive material tests are to be performed on the parts listed below in accordance with Tables 3.4 and 3.5:

Table 3.3 Approved materials and type of test certificate

	TL Material Rules	Components	Test certificate **		
			TL 3.1 C	3.1 B	2.2
Forged steel: $R_m \geq 360$ N/mm^2	Section 5, C.	Crankshafts Connecting rods Pistons and piston crowns Cylinder covers/heads Camshaft drive wheels	X X X **(3)** X X **(3)**	- - X **(4)** - X **(4)**	- - - - -
Rolled or forged steel rounds: $R_m \geq 360$ N/mm^2	Section 5, C	Tie rods Bolts and studs	X X **(1)**	- X **(4)**	- -
Special grade cast steel: $R_m \geq 440$ N/mm^2 Special grade forged steel: $R_m \geq 440$ N/mm^2	Section 6, C. Section 5, C.	Throws and webs of built-up crankshafts	X	-	-
Cast steel	Section 6, C.	Bearing transverse girders (weldable) Pistons and piston crowns Cylinder covers/heads Camshaft drive wheels	X X **(3)** X **(1)** X **(3)**	X X **(4)** X **(2)** X **(4)**	- - - -
Nodular cast iron, preferably ferritic grades: $R_m \geq 370$ N/mm^2	Section 7, B.	Engine blocks Bedplates Cylinder blocks Pistons and piston crowns Cylinder covers/heads Flywheels Valve bodies	- - - X **(3)** - - -	X **(1)** X **(1)** X **(1)** X **(4)** X **(1)** X **(1)** X **(1)**	- - - - - - -
Lamellar cast iron: $R_m \geq 200$ N/mm^2	Section 7, C.	Engine blocks Bedplates Cylinder blocks Cylinder liners Cylinder covers/heads Flywheels	- - - - - -	- - - - - -	X X X X X X
Shipbuilding steel, all TL grades for plates ≤ 35 mm in thickness	Section 3,B.	Welded bedplates Welded frames Welded housings	X X X	- - -	- - -
Shipbuilding steel, TL grade B for plates > 35 mm in thickness					
Structural steel, unalloyed, for welded assemblies	Section 3,C.				

* *All details refer to TL Material Rules*

** *For type of test certificate, see DIN 50049 or EN 1020*

(1) *Only for cylinder bores > 300 mm*

(2) *For cylinder bores ≤ 300 mm*

(3) *Only for cylinder bores > 400 mm*

(4) *For cylinder bores ≤ 400 mm*

1. Steel castings for bedplates, e.g. bearing transverse girders, including their welded joints

2. Solid forged crankshafts

3. Cast, rolled or forged parts of fully built crankshafts

4. Cast or forged parts of semi-built crankshafts

5. Connecting rods

6. Piston crowns of steel or cast steel

7. Tie rods (at each thread over a distance corresponding to twice the threaded length)

8. Bolts which are subjected to alternating loads, e.g.:

   - main bearing bolts
   - connecting rod bolts
   - cylinder cover bolts

9. Cylinder covers made of steel or cast steel

10. Camshaft drive gear wheels made of steel or cast steel

2.2.1 Magnetic particle or dye penetrant tests are to be performed in accordance with Table 3.4 at those points, to be agreed between the TL Surveyor and the manufacturer, where experience shows that defects are liable to occur:

2.2.2 Ultrasonic tests are to be carried out by the manufacturer in accordance with Table 3.5, and the corresponding signed manufacturer's certificates are to be submitted.

2.2.3 Welded seams of important engine components may be required to be subjected to approved methods of testing.

2.2.4 Where there is reason to doubt the soundness of any engine component, non-destructive testing by approved methods may be required in addition to the tests mentioned above.

2.3 Crankshafts welded together from forged or cast parts are subject to TL special approval. Both the manufacturers and the welding process must have been accepted. The materials and the welds are to be tested.

Table 3.4 Magnetic particle tests

Cylinder bore	Parts to be tested (numbered according to the list under D.2.2)
≤ 400 mm	1 - 2 - 3 - 4 - 5
> 400 mm	all parts

Table 3.5 Ultrasonic tests

Cylinder bore	Parts to be tested (numbered according to the list under D.2.2)
≤ 400 mm	1 - 2 - 3 - 4 - 6 - 9
> 400 mm	1 - 2 - 3 - 4 - 5 - 6 - 9 - 1 0

E. Tests and Trials

1. Manufacturing inspections

1.1 The manufacture of all engines is subject to supervision by TL.

1.2 Where engine manufacturers have been approved by TL as "Suppliers of Mass Produced Engines", these engines are to be tested in accordance with TL - Guidelines for Mass Produced Engines, C.

2. Pressure tests

The individual components of internal combustion engines are to be subjected to pressure tests at the pressures specified in Table 3.6.

3. Type approval testing (TAT)

3.1 General

Engines for installation on board ship must have been type tested by TL. For this purpose a type approval test in accordance with 3.1.2 is to be performed.

Table 3.6 Pressure tests (1)

Component		Test pressure, p_p [bar]
Cylinder cover, cooling water space **(3)**		7
Cylinder liner, over whole length of cooling water space **(5)**		7
Cylinder jacket, cooling water space		4, at least 1,5 . p_{eperm} **(2)**
Fuel injection system	Pump body, pressure side	1,5 . p_{eperm} or p_{eperm} + 300 (whichever is less)
	Valves	1,5 . p_{eperm} or p_{eperm} + 300 (whichever is less)
	Pipes	1,5 . p_{eperm} or p_{eperm} + 300 (whichever is less)
Exhaust gas turbocharger, cooling water space		4, at least 1,5 . p_{eperm}
Exhaust gas line, cooling water space		4, at least 1,5 . p_{eperm}
Coolers, both sides **(4)**		4, at least 1,5 . p_{eperm}
Engine-driven pumps (oil, water, fuel and bilge pumps)		4, at least 1,5 . p_{eperm}
Starting and control air system before installation		1,5 . p_{eperm}

(1) *in general, items are to be tested by hydraulic pressure as indicated in the Table. Where design or testing features may require modification of these test requirements, special consideration will be given*

(2) . *p_{eperm} [bar] = maximum working pressure in the part concerned*

(3) *for forged steel cylinder covers test methods other than pressure testing may be accepted, e.g. suitable non-destructive examination and dimensional control properly recorded*

(4) *charge air coolers need only be tested on the water side.*

(5) *for centrifugally cast cylinder liners, the pressure test can be replaced by a crack test*

3.1.1 Preconditions for type approval testing

Preconditions for type approval testing are that:

- The engine to be tested conforms to the specific requirements for the series and has been suitably optimized

- The inspections and measurements necessary for reliable continuous operation have been performed during works tests carried out by the engine manufacturer and TL has been informed of the results of the major inspections

- TL has issued the necessary approval of drawings on the basis of the documents to be submitted in accordance with B.

3.1.2 Scope of type approval testing

The type approval test is subdivided into three stages, namely:

- Stage A - Internal tests

  Functional tests and collection of operating values including test hours during the internal tests, which are to be presented to TL during the type test.

- Stage B - Type test

  This test is to be performed in the presence of the TL Surveyor.

3.2 Stage A - Internal tests

Functional tests and the collection of operating data are to be performed during the internal tests. The engine is to be operated at the load points important for the engine manufacturer and the pertaining operating values are to be recorded. The load points are to be selected according to the range of application of the engine.

3.2.1 Normal case

The normal case includes the load points 25 %, 50 %, 75 %, 100 % and 110 % of the maximum rated power:

- Along the nominal (theoretical) propeller curve and/or at constant speed for propulsion engines
- At rated speed with constant governor setting for generator drive
- Proving of the limit points of the permissible operating range defined by the engine manufacturer

3.2.2 Emergency operation situations

For turbocharged engines the achievable output in case of turbocharger damage is to be determined as follows:

- for engines with one turbocharger, when rotor is blocked or removed
- for engines with two or more turbochargers, when the damaged turbocharger is shut off

Note

The engine manufacturer is to state whether the achievable output is continuous. If there is a time limit, the permissible operating time is to be indicated.

3.3 Stage B - Type test

During the type test all the tests listed under 3.3.1 to 3.3.3 are to be carried out in the presence of the TL Surveyor. The results achieved are to be recorded and signed by TL Surveyor. Deviations from this program, if any, require the agreement of TL.

3.3.1 Load points

Load points at which the engine is to be operated are to conform to the power/speed diagram in Fig. 3.2.

The data to be measured and recorded when testing the engine at various load points must include all the parameters necessary for an assessment.

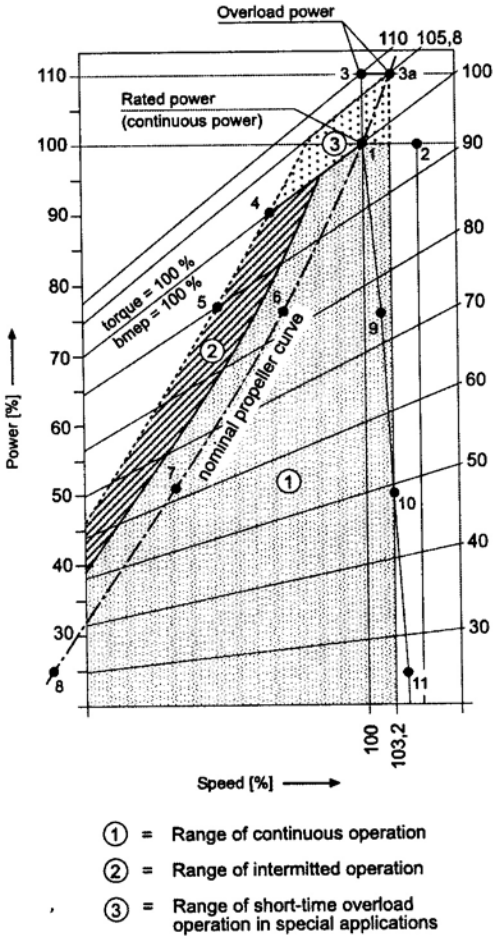


Figure 3.2 Power/speed diagram

The operating time per load point depends on the engine size and on the time for collection of the operating values. The measurements shall in every case only be performed after achievement of steady-state condition.

At 100 % output (rated power) in accordance with 3.3.1.1 an operating time of 2 hours is required. At least two sets of readings are to be taken at an interval of 1 hour in each case.

If an engine can continue to operate without its operational safety being affected in the event of a failure of its independent cylinder lubrication, proof of this shall be included in the type test.

3.3.1.1 Rated power (continuous power)

The rated power is defined as 100 % output at 100 % torque and 100 % speed (rated speed) corresponding to load point 1.

3.3.1.2 100 % power

The operation point 100 % output at maximum allowable speed corresponding to load point 2 has to be performed.

3.3.1.3 Maximum permissible torque

The maximum permissible torque normally results at 110% output at 100% speed corresponding to load point 3 or at maximum permissible power (normally 110 %) at a speed according to the nominal propeller curve corresponding to load point 3 a.

3.3.1.4 Minimum permissible speed for intermittent operation

The minimum permissible speed for intermittent operation has to be adjusted:

- at 100 % torque corresponding to load point 4

- at 90 % torque corresponding to load point 5

3.3.1.5 Part-load operation

For part-load operation the operation points 75 %, 50 %, 25 % of the rated power at speeds according to the nominal propeller curve at load points 6, 7 and 8 and proceeding from the nominal speed at constant governor setting has to be adjusted corresponding to load points 9, 10 and 11. Continuous operation at or below the lower load points (e.g. 50 %, 25 %) has to be released by the engine manufacturer.

3.3.1.6 Continuous low-load operation

It has to be proven that the requirements of A.3.4 are fulfilled. The type and the scope of tests as specified by the manufacturer have to be approved by TL.

3.3.2 Emergency operation

The maximum achievable power when operating in accordance with 3.2.2 has to be performed:

- at speed conforming to nominal propeller curve

- with constant governor setting for rated speed

3.3.3 Functional tests

Functional tests to be carried out as follows:

- Ascertainment of lowest engine speed according to the nominal propeller curve

- Starting tests

- Governor test

- Test of the safety system particularly for over-speed and failure of the lubricating oil pressure

- Test of electronic components and systems according to the test program approved by TL.

3.4 Stage C - Component inspection

Immediately after the test run the components of one cylinder for in-line engines and two cylinders for V-engines are to be presented for inspection as follows:

- Piston, removed and dismantled

- Crank bearing and main bearing, dismantled

- Cylinder liner in the installed condition

- Cylinder head, valves disassembled

- Control gear, camshaft and crankcase with opened covers

Note
If deemed necessary by the TL Surveyor, further dismantling of the engine may be required.

3.5 Test report on stages B and C

The results of the type test are to be incorporated in a report which is to be handed to TL.

3.6 Type test of mass produced engines

3.6.1 For engines with cylinder bores ≤ 300 mm which are to be manufactured in series the type test shall be carried out in accordance with Guidelines for Mass Produced Engines.

3.6.2 For the performance of the type test, the engine is to be fitted with all the prescribed items of equipment. If the engine, when on the test bed, cannot be fully equipped in accordance with the requirements, the equipment may be demonstrated on another engine of the same series.

3.7 Renewal of type test

If the rated power (continuous power) of a type tested and operationally proven engine is increased by more than 10 %, a new type test is required. Approval of the power increase includes examination of the relevant drawings.

4. Works trials

4.1 In general, engines are to be subjected to trials on the test bed at the manufacturer's works and under TL supervision. The scope of these trials shall be as specified below. Exceptions to this require the agreement of TL.

4.2 Scope of works trials

During the trials the operating values corresponding to each load point are to be measured and recorded by the engine manufacturer. All the results are to be compiled in an acceptance protocol to be issued by the engine manufacturer.

In each case all measurements conducted at the various load points shall be carried out under steady operating conditions. The readings for 100 % power (rated power at rated speed) are to be taken twice at an interval of at least 30 minutes.

4.2.1 Main engines for direct propeller drive

The operation points have to be adjusted according to a - e, functional tests have to be performed according to d - f. Other points may be agreed in special cases with TL.

a) 100 % power (rated power):

- at 100 % engine speed (rated engine speed) n_o for:
- at least 60 minutes after reaching the steady-state conditions

b) 110% power:

- at $n = 1,032 \cdot n_o$ for:
- 45 minutes after reaching the steady-state conditions

Note

After the test bed trials the output shall normally be limited to the rated power (100 % power) so that the engine cannot be overloaded in service (see A.3.5).

c) 90 %, 75 %, 50 % and 25 % power in accordance with the nominal propeller curve

d) starting and reversing manoeuvres, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 6, A.2.4

e) test of governor and independent overspeed protection device

f) test of engine shutdown devices

4.2.2 Main engines for electrical propeller drive

The test is to be performed at rated speed with a constant governor setting under conditions of:

a) 100 % power (rated power):

- at least 60 minutes after reaching the steady-state condition

b) 110% power:

- 45 minutes after reaching the steady-state condition

Note

After the test bed trials the output of engines driving generators is to be so adjusted that overload (110 %) power can be supplied in service after installation on board in such a way that the governing characteristics and the requirements of the generator protection devices can be fulfilled at all times (see A.3.6). Special adjustments may be agreed with TL.

c) 75 %, 50 % and 25 % power and idle run

d) start-up tests, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 6, A.2.4

e) test of governor and independent overspeed protection device

f) test of engine shutdown devices

4.2.3 Auxiliary driving engines and engines driving electric generators

The tests have to be performed according to 4.2.2.

For testing of diesel generator sets, see also Chapter 105 - Electrical Installations, Section 16, D.3.2.

4.3 Depending on the type of plant concerned, TL reserve the right to call for a special test schedule.

4.4 In the case of main propulsion engines and engines driving electric generators the rated power is to be verified as minimum power.

4.5 Component inspection

After the test run randomly selected components shall be presented for inspection.

The crankshaft web deflection is to be checked.

5. Shipboard trials (harbour and sea trials)

After the conclusion of the running-in programme prescribed by the engine manufacturer engines are to undergo the trials specified below.

5.1 Scope of sea trials

5.1.1 Main propulsion engines driving fixed propellers

The tests have to be carried out as follows:

a) at rated engine speed n_o:

- for at least 4 hours and

at engine speed corresponding to normal cruise power:

- for at least 2 hours

b) at engine speed n = 1,032 . n_o:

- for at least 30 minutes

where the engine adjustment permits (see A.3.5)

c) determination of the minimum on-load speed.

d) continuous low load operation, if applicable

e) starting and reversing manoeuvres

f) in reverse direction of propeller rotation during the dock or sea trials at a minimum speed of n= 0,7 . n_o:

- for at least 10 minutes

g) testing of the monitoring and safety systems

5.1.2 Main propulsion engines driving controllable pitch propellers or reversing gears

5.1.1 applies as appropriate.

Controllable pitch propellers are to be tested with various propeller pitches. Where provision is made for combiner operation, the combiner curves are to be plotted and verified by measurements.

5.1.3 Main engines driving generators for propulsion

The tests are to be performed at rated speed with a constant governor setting under conditions of

a) 100 % power (rated power):

- for at least 4 hours and

at normal continuous cruise power:

- for at least 2 hours

b) 110% power:

- for at least 30 minutes

c) in reverse direction of propeller rotation during the sea trials at a minimum speed of 70 % of the nominal propeller speed:

- for 10 minutes

d) starting manoeuvres, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 6, A.2.4.

e) testing of the monitoring and safety systems

Note

Tests are to be based on the rated powers of the driven generators.

5.1.4 Engines driving auxiliaries and electrical generators

These engines are to be subjected to an operational test for at least four hours. During the test the set concerned is required to operate at its rated power for an extended period.

It is to be demonstrated that the engine is capable of supplying 110 % of its rated power, and in the case of shipboard generating sets account shall be taken of the times needed to actuate the generator's overload protection system.

5.2 The suitability of main and auxiliary engines to burn special fuels is to be demonstrated if the machinery installation is designed to burn such fuels.

5.3 The scope of the shipboard trials may be extended in consideration of special operating conditions such as low-load operation, towing, etc.

5.4 Earthing

It is necessary to ensure that the limits specified for main engines by the engine manufacturers for the difference in electrical potential (Voltage) between the crankshaft/shafting and the hull are not exceeded in service. Appropriate earthing devices including limit value monitoring of the permitted voltage potential are to be provided.

F. Safety Devices

1. General

The Rules of Chapter 105 - Electrical Installations have to be observed. For automated propulsion plants the Rules of Chapter 106 - Automation have to be considered additionally.

2. Speed control and engine protection against overspeed

2.1 Main and auxiliary engines

2.1.1 Each diesel engine not used to drive an electric generator must be equipped with a speed governor or regulator so adjusted that the engine speed cannot exceed the rated speed by more than 15 %.

2.1.2 In addition to the normal governor, each main engine with a rated power of 220 kW or over which can be declutched in service or which drives a variable-pitch propeller must be fitted with an independent overspeed protection device so adjusted that the engine speed cannot exceed the rated speed by more than 20 %.

Equivalent equipment may be approved by TL.

2.2 Engines driving electric generators

2.2.1 Each diesel engine used to drive an electric main or emergency generator must be fitted with a governor which will prevent transient frequency variations in the electrical network in excess of ± 10 % of the rated frequency with a recovery time to steady state conditions not exceeding 5 seconds when the maximum electrical step load is switched on or off.

In the case when a step load equivalent to the rated output of the generator is switched off, a transient speed variation in excess of 10 % of the rated speed may be acceptable, provided this does not cause the intervention of the overspeed device as required by D.2.1.1.

2.2.2 In addition to the normal governor, each diesel engine with a rated power of 220 kW or over must be equipped with an overspeed protection device independent of the normal governor which prevents the engine speed from exceeding the rated speed by more than 15 %.

2.2.3 The diesel engine must be suitable and designed for the special requirements of the ship's electrical system.

Where connection of loads is envisaged in two stages, the following procedure is to be applied: Sudden loading from no-load to 50 %, followed by the remaining 50 % of the rated generator power, duly observing the requirements of 2.2.1 and 2.2.4.

Connection of the load in more than two steps, see Fig. 3.3, is acceptable on condition that:

- The design of the ship's electrical system enables the use of such generator sets

- Adequate scope for connection of the load in more than two steps is provided in the design of the ship's electrical system and is approved when the drawings are inspected

- Furthermore, the safety of the ship's electrical system in the event of parallel generator operation and failure of a generator is to be demonstrated

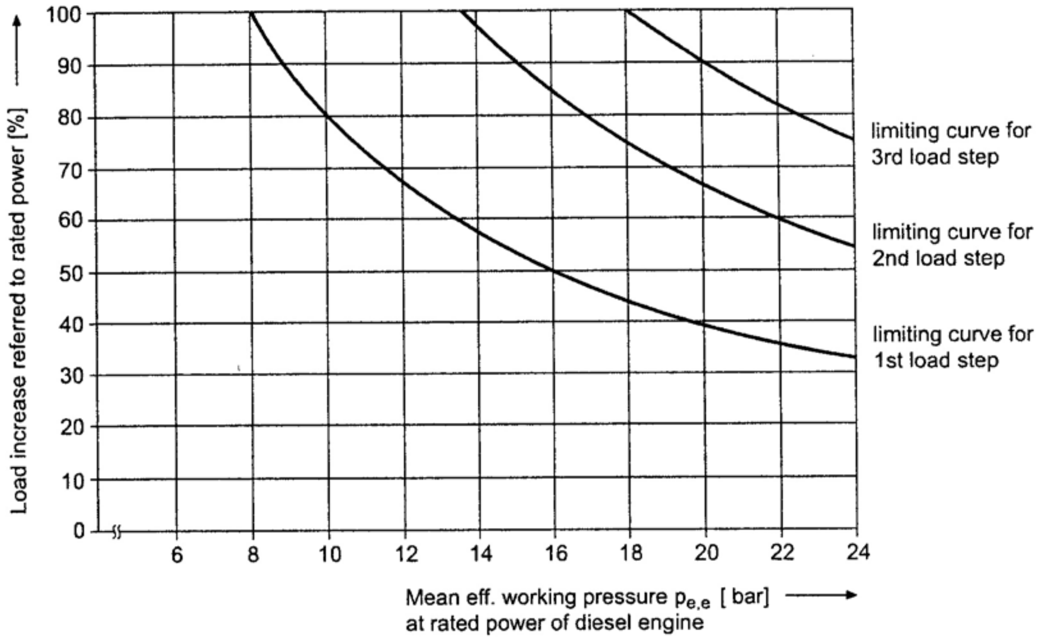


Figure 2.3 Limiting curves for loading diesel engine step by step from no load to rated power as function of the brake mean effective pressure

2.2.4 Speed must be stabilized and in steady-state condition within five seconds, inside the permissible range for the permanent speed variation δ_r.

The steady-state condition is considered to have been reached when the residual speed variation does not exceed ± 1 % of the speed associated with the set power.

2.2.5 The characteristic curves of the governors of diesel engines of generator sets operating in parallel must not exhibit deviations larger than those specified in Chapter 105 - Electrical Installations, Section 1, F.1.

2.2.6 Generator sets which are installed to serve stand-by circuits must satisfy the stand-by function even when the engine is cold. The start-up and loading sequence is to be concluded in about 30 seconds.

2.2.7 Emergency generator sets must satisfy the above governor conditions also unlimited with the start-up and loading sequence having to be concluded in about 45 seconds.

2.2.8 The governors of the engines mentioned in 2.2 must enable the rated speed to be adjusted over the entire power range with a maximum deviation of 5 %.

2.2.9 The rate of speed variation of the adjusting mechanisms must permit satisfactory synchronization in a sufficiently short time. The speed characteristic should be as linear as possible over the whole power range. The permanent deviation from the theoretical linearity of the speed characteristic may, in the case of generating sets intended for parallel operation, in no range exceed 1 % of the rated speed.

Notes relating to 2.1 and 2.2:

a) The rated power and the corresponding rated speed relate to the conditions under which the engines are operated in the system concerned.

b) An independent overspeed protection device means a system all of whose component parts, including the drive, work independently of the normal governor.

2.3 Use of electrical/electronic governors

2.3.1 The governor and the associated actuator must, for controlling the respective engine, be suitable for the operating conditions laid down in the Construction Rules and for the requirements specified by the engine manufacturer. For single propulsion drives it has to be ensured that in case of a failure of the governor or actuator the control of the engine can be taken over by another control device.

The regulating conditions required for each individual application as described in 2.1 and 2.2 are to be satisfied by the governor system.

Electronic governors and the associated actuators are subject to type testing.

For the power supply, see Chapter 105 - Electrical Installations.

2.3.2 Requirements applying to main engines

For propulsion installations, to ensure continuous speed control or immediate resumption of control after a fault, at least one of the following requirements is to be satisfied:

- the governor system has an independent back-up system
- there is a redundant governor assembly for manual change-over with a separately protected power supply
- a complete preset governor assembly is available as a spare
- the engine has a manually operated fuel admission control system suitable for manoeuvring

In the event of a fault in the governor system, the operating condition of the engine must not become dangerous, that is, the engine speed and power must not increase.

Alarms to indicate faults in the governor system are to be fitted.

2.3.3 Requirements applying to auxiliary engines for driving generators

Each auxiliary engine must be equipped with its own governor system.

In the event of a fault in the governor system, the fuel admission in the injection pumps must be set to "0". Alarms to indicate faults in the governor system are to be fitted.

2.3.4 The special conditions necessary to start operation from the dead ship condition are to be observed, see Chapter 105 - Electrical Installations, Section 7, D.

3. Cylinder overpressure warning device

3.1 All the cylinders of engines with a cylinder bore of > 230 mm are to be fitted with cylinder over pressure control valves. The response threshold of these valves shall be set at not more than 40 % above the combustion pressure at the rated power.

3.2 The cylinder overpressure control valves may be replaced by effective combined visual/acoustic cylinder overpressure warning devices. These must have been type-tested by TL.

4. Crankcase airing and venting

4.1 Crankcase airing

The airing of crankcases is not allowed.

4.2 Crankcase venting

4.2.1 Where crankcase venting systems are provided their clear opening is to be dimensioned as small as possible.

4.2.2 Where provision has been made for extracting the lubricating oil vapours, e.g. for monitoring the oil vapour concentration, the negative pressure in the crankcase may not exceed 2,5 mbar.

4.2.3 The vent pipes of two or more engines must not be combined.

5. Crankcase safety devices

5.1 Crankcase safety devices have to be type approved.

5.2 Safety valves to safeguard against overpressure in the crankcase are to be fitted to all engines with a cylinder bore of > 200 mm and/or a crankcase volume of ≥ 0,6 m^3.

All other spaces communicating with the crankcase, e.g. gear or chain casings for camshafts or similar drives, are to be equipped with additional safety devices if the volume of these spaces exceeds 0,6 m^3.

5.3 Engines with a cylinder bore of > 200 mm and ≤ 250 mm must be equipped with at least one safety valve at each end of the crankcase. If the crankshaft has more than 8 throws, an additional safety valve is to be fitted near the middle of the crankcase.

Engines with a cylinder bore of > 250 mm and ≤ 300 mm must have at least one safety valve close to every second crank throw, subject to a minimum number of two.

Engines with a cylinder bore of > 300 mm must have at least one safety valve close to each crank throw.

5.4 Each safety valve must have a free cross-sectional area of at least 45 cm^2.

The total free cross-sectional area of the safety valves fitted to an engine to safeguard against overpressure in the crankcase may not be less than 115 cm^2/m^3 of crankcase volume.

Notes relating to 5.2 and 5.4

a) In estimating the gross volume of the crankcase, the volume of the fixed parts which it contains may be deducted.

b) A space communicating with the crankcase via a total free cross-sectional area of > 115 cm^2/m^3 of volume need not be considered as a separate space. In calculating the total free cross-sectional area, individual sections of < 45 cm^2 are to be disregarded.

c) Each safety valve required may be replaced by not more than two safety valves of smaller cross-sectional area provided that the free cross-sectional area of each safety valve is not less than 45 cm^2.

5.5 The safety devices must take the form of flaps or valves of proven design. In service they must be oiltight when closed and must prevent air from flowing into the crankcase. The gas flow caused by the response of the safety device must be deflected, e. g. by means of a baffle plate, in such a way as not to endanger persons standing nearby.

Safety devices shall respond to as low an overpressure in the crankcase as possible (maximum 0,2 bar).

5.6 Crankcase doors and their fittings must be so dimensioned as not to suffer permanent deformation due to the overpressure occurring during the response of the safety equipment.

5.7 A warning sign is to be mounted on the local engine control platform or, if appropriate, on both sides of the engine drawing attention to the fact that the crankcase doors and/or sight holes may not be opened immediately following stoppage of the engine, but only after a sufficient cooling period has elapsed.

6. Safety devices in the lubricating oil system

Each engine with a rated power of 220 kW or over is to be fitted with devices which automatically shut down the engine in the event of failure of the lubricating oil supply. Exceptions to this rule are engines driving emergency generator sets and emergency fire pumps. For these engines an alarm has to be provided.

G. Auxiliary Systems

1. General

Peripheral piping systems and filter arrangements see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

2. Fuel lines

2.1 General

2.1.1 Only pipe connections with metal sealing surfaces or equivalent pipe connections of approved design may be used for fuel injection lines.

2.1.2 Feed and return lines are to be designed in such a way that no unacceptable pressure surges occur in the fuel supply system. Where necessary, the engines are to be fitted with surge dampers approved by TL.

2.1.3 Oil fuel lines are not to be located immediately above or near units of high temperature steam pipelines, exhaust manifolds, silencers or other equipment required to be insulated according to G.7. As far as practicable, oil fuel lines are to be arranged far apart from hot surfaces, electrical installations or other sources of ignition and are to be screened or otherwise suitably protected to avoid oil spray or oil leakage onto the sources of ignition. The number of joints in such piping system are to be kept to a minimum.

2.2 Shielding

2.2.1 Regardless of the intended use and location of internal combustion engines, all external fuel injection lines (high pressure lines between injection pumps and injection valves) are to be shielded by jacket pipes in such a way that any leaking fuel is:

- Safely collected
- Drained away unpressurized
- Efficiently monitored

2.2.2 If pressure variations of > 20 bar occur in fuel feed and return lines, these lines are also to be shielded.

2.2.3 The high pressure fuel pipe and the outer jacket pipe have to be of permanent assembly.

2.2.4 Where pipe sheaths in the form of hoses are provided as shielding, the hoses must be demonstrably suitable for this purpose and approved by TL.

2.3 Fuel leak drainage

Appropriate design measures are to be introduced to ensure generally that leaking fuel is drained efficiently and cannot enter into the engine lube oil system.

2.4 Heat tracing, thermal insulation, re-circulation

Fuel lines, including fuel injection lines, to engines which are operated with preheated fuel are to be insulated against heat losses and, as far as necessary, provided with heat tracing.

Means of fuel circulation are also to be provided.

3. Filter arrangements

3.1 The requirements for the fuel and lubricating oil filter equipment of motors are defined in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

3.2 Fuel and lubricating oil filters which are to be mounted directly on the engine are not to be located above rotating parts or in the immediate proximity of hot components.

3.3 Where the arrangement stated in 3.1 is not feasible, the rotating parts and the hot components are to be sufficiently shielded.

3.4 Filters have to be so arranged that fluid residues can be collected by adequate means. The same applies to lubricating oil filters if oil can escape when the filter is opened.

3.5 Oil filters fitted parallel for the purpose of enabling cleaning without disturbing oil supply to engines (e.g. duplex filters) are to be provided with arrangements that will minimize the possibility of a filter under pressure being opened by mistake. Filters/filter chambers shall be provided with suitable means for:

- Venting when put into operation
- Depressurizing before being opened

Valves or cocks with drain pipes led to a safe location shall be used for this purpose.

4. Lubricating oil system

4.1 General requirements relating to lubricating oil systems and to the cleaning, cooling etc. of the lubricating oil are contained in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, I. For piping arrangement 2.1.3 is to be applied.

4.1.1 Engines which sumps serve as oil reservoirs must be so equipped that the oil level can be established and, if necessary, topped up during operation. Means must be provided for completely draining the oil sump.

4.1.2 The combination of the oil drainage lines from the crankcases of two or more engines is not allowed.

4.2 The equipment of engines fitted with lubricating oil pumps is subject to Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, I.

4.2.1 Main lubricating oil pumps driven by the engine are to be designed to maintain the supply of lubricating oil over the entire operating range.

4.2.2 Main engines which drive main lubricating oil pumps are to be equipped with independently driven stand-by pumps.

4.2.3 In installations comprising more than one main engine and with separate lubricating oil systems approval may be given for the carriage on board of reserve pumps ready for mounting provided that the arrangement of the main lubricating oil pumps enables the change to be made with the means available on board.

4.2.4 Lubricating oil systems for cylinder lubrication which are necessary for the operation of the engine and which are equipped with electronic dosing units have to be approved by TL.

5. Cooling system

5.1 For the equipment of engines with cooling water pumps and for the design of cooling water systems, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, J. and K.

5.1.1 Main cooling water pumps driven by the engine are to be designed to maintain the supply of cooling water over the entire operating range.

5.1.2 Main engines which drive main cooling water pumps are to be equipped with independently driven stand-by pumps or with means for connecting the cooling water system to independently driven stand-by pumps.

5.1.3 In installations comprising more than one main engine and with separate fresh cooling water systems approval may be given for the carriage on board of reserve pumps ready for mounting provided that the arrangement of the main fresh cooling water pumps enables the change to be made with the means available on board. Shutoff valves must be provided enabling the main pumps to be isolated from the fresh cooling water system.

5.2 If cooling air is drawn from the engine room, the design of the cooling system is to be based on a room temperature of at least 45 °C.

The exhaust air of air-cooled engines may not cause any unacceptable heating of the spaces in which the plant is installed. The exhaust air is normally to be led to the open air through special ducts.

5.3 Where engines are installed in spaces in which oil-firing equipment is operated, Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 17, A.5. is also to be complied with.

6. Charge air system

6.1 Exhaust gas turbochargers

6.1.1 The construction and testing of exhaust gas turbochargers are subject to Section 4.

6.1.2 Exhaust gas turbochargers may exhibit no critical speed ranges over the entire operating range of the engine.

6.1.3 The lubricating oil supply must also be ensured during start-up and run-down of the exhaust gas turbochargers.

6.1.4 Even at low engine speeds, main engines must be supplied with charge air in a manner to ensure reliable operating.

6.1.5 If, in the lower speed range or when used for manoeuvring, an engine can be operated only with a charge air blower driven independently of the engine, a stand-by charge air blower is to be installed or an equivalent device of approved design.

6.1.6 With main engines emergency operation must be possible in the event of a turbocharger failure.

6.2 Charge air cooling

6.2.1 The construction and testing of charge air coolers are subject to Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 16.

6.2.2 Means are to be provided for regulating the temperature of the charge air within the temperature range specified by the engine manufacturer.

6.2.3 The charge air lines of engines with charge air coolers are to be provided with sufficient means of drainage.

7. Equipment for charge air and exhaust gas lines

General rules relating to exhaust gas lines are contained in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, M.

8. Starting Equipment

The relevant equipment is defined in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 6.

H. Control Equipment

1. Main engines

1.1 Local control station

To provide emergency operation of the propulsion plant a local control station is to be installed from which the plant can be operated and monitored.

1.1.1 Indicators for the following parameters are to be clearly sited on the local main engine control station:

- Speed/direction of rotation
- Lube oil pressure
- Fuel pressure
- Cylinder cooling water pressure
- Charge air pressure
- Starting air pressure
- Control air pressure

1.1.2 The following temperature indicators are to be provided on the local control station or directly on the engine:

- Lube oil inlet
- Cylinder cooling water outlet
- Charge air inlet, charge air cooler
- Charge air outlet, charge air cooler
- Fuel at engine inlet (for engines running on heavy fuel only)
- Exhaust gas temperature

  wherever the dimensions permit, at each cylinder outlet and at the turbocharger inlet/outlet

1.1.3 In the case of gear and controllable pitch propeller systems, the local control indicators and control equipment required for emergency operation are to be installed.

1.1.4 Critical speed ranges are to be marked in red on the tachometers.

1.2 Machinery control centre

If the naval ship has a control station for the propulsion system with remote operation or control, the control indicators listed in 1.1.1, 1.1.2 and 1.1.3 are to be installed in this centre.

1.3 Bridge/navigation centre

1.3.1 The essential operating parameters for the propulsion system are to be provided in the control station area.

1.3.2 The following stand-alone control equipment is to be installed:

- Speed/direction of rotation of main engine
- Speed/direction of rotation of shafting
- Propeller pitch (controllable pitch propeller)

Another scope of control equipment may be agreed between Naval Authority, shipyard and TL.

1.3.3 In the case of engine installations up to a total output of 600 kW, simplifications can be agreed with TL.

2. Auxiliary engines

As a minimum requirement the following controls are to be clearly located on the engine:

- Lube oil pressure
- Fuel pressure
- Cylinder cooling water pressure

- Cylinder cooling water temperature (outlet)
- Fuel temperature at engine inlet (for engines running on heavy fuel oil only)

A different scope of controls to be agreed between Naval Authority, shipyard and TL.

I. Alarms

1. General

1.1 The following Rules apply to machinery installations which have been designed for conventional operation without any degree of automation.

1.2 Within the context of these Rules, the word alarm is understood to mean the visual and audible warning of abnormal operating parameters.

2. Scope of alarms

Alarms are to be fitted to signal that the following limiting values are being exceeded:

2.1 Main engines

2.1.1 Lower limiting value

- Lube oil pressure
- Cylinder cooling water pressure
- Piston coolant pressure
- Starting air pressure
- Control air pressure

2.1.2 Upper temperature limit

- Lube oil inlet
- Cylinder cooling water outlet
- Piston coolant outlet
- Charge air outlet, charge air cooler
- Exhaust gas (exhaust-gas turbocharger outlet)

2.2 Auxiliary engines

Lower limit:

- Lube oil pressure
- Cylinder cooling water pressure or flow

J. Engine Alignment/Seating

1. Engines are to be mounted and secured to their foundations in conformity with Guidelines for the Seating of Propulsion Plants.

2. If elastomer bearing elements are used, engines on elastic mountings may only be aligned after settling.

Supply equipment, couplings and compensators have to be adjusted to the respective bearing.

Casting resin bearings have to be built up only in presence of a TL Surveyor by companies approved for this type of work. Only approved casting resins are to be used. The installation guidelines of the resin producer have to be observed.

3. The crankshaft alignment is to be checked every time an engine has been aligned on its foundation by measurement of the crank web deflectionand/or other suitable means.

Note is to be taken of:

- The draught/load condition of the vessel
- The condition of the engine - cold/ preheated/hot

4. Where the engine manufacturer has not specified values for the permissible crank web deflection, assessment is to be based on TL's reference values.

SECTION 4

THERMAL TURBOMACHINERY

Page

A. General

1. Scope

The following Rules apply to main and auxiliary gas turbines and, where appropriate, to exhaust gas turbo-chargers.

TL reserve the right to authorize deviations from the Rules in the case of low-power turbines and exhaust gas turbochargers.

2. Documents for approval

For every gas turbine installation, the documents listed below under a) to f) are to be submitted to TL in triplicate for approval:

a) Assembly and sectional drawings

b) Detail drawings of rotors, casings, blades, combustion chambers and heat exchangers

c) Diagrammatic layout of the fuel system, including control and safety devices, and of the lubricating oil system

d) Start-up equipment with system description

e) Details of operating conditions, including the pressure and temperature curves in the turbine and compressor at the rated power and corresponding rotational speeds, and details of permissible temporary operation beyond the values for the rated power

f) Proof, by calculation or some other method, e.g. in the form of the results of burst tests performed on turbine and compressor wheels, that a sufficient safety margin has been provided for in the components subject to the severest loads. In the case of turbine guide vanes and blades as well as turbine discs, the service life on which the calculations were based is to be specified together with the temperatures occurring in the materials at the rated power.

g) Details of the welding conditions for welded components

h) Testing procedure

A set of operating instructions for each turbine type has to be submitted.

In individual cases, according to the design and purpose of the equipment, TL reserve the right to call for additional documentation.

B. Materials

1. Approved materials

Gas turbine materials must fulfill the requirements imposed by the operating conditions on the individual engine components. In the choice of materials, account is to be taken of such effects as, for example, creep, thermal fatigue, oxidation and corrosion to which parts are subject when in service. Evidence of the suitability of the materials used is to be supplied to TL in the form of details of their chemical and mechanical properties and of the heat treatment applied. Where composite materials are used, their method of manufacture is to be described.

For the combustion air pipes steel or another non-combustible material has to be used. Elastic connections have to be non-flammable.

As material for exhaust gas pipes heat-resistant steel has to be used. The choice of the steel type has to consider the operation temperatures and the corrosion resistance, see also DIN 86009.

Pipes and fittings are to be manufactured from stainless steel.

2. Testing of materials

The materials of shafts, turbine and compressor wheels, guide vanes and blades, turbine and compressor casings, combustion chambers and heat exchangers are to be tested under TL's supervision or according to the manufacturer's test specification accepted by TL in scope of the manufacturer's approval.

For material tests of turbochargers see also the TL Rules Guidelines for the Testing of Exhaust Gas Turbochargers.

C. Design and Construction Principles

1. General data

1.1 Standards

For the design of propulsion plants which are equipped with gas turbines Table 4.1 has to be considered.

Table 4.1 Standards for gas turbines

Standards	Title of standard
DIN 4340	Definitions, designations
DIN 4341	Part 1: Regulations for commissioning of gas turbines
DIN 4342	Standard reference conditions, standard performance

1.2 Data concerning operation parameters have to be defined.

1.3 Operational diagram to be provided.

1.4 The family of gas turbine characteristics has to be defined, with the rated driving power P shown as a function of the speeds of gas generator and the effective power turbine.

1.5 Measures for planned preventive maintenance are to be defined.

1.6 The connection between effective power shaft of the gas turbine and the gear has to be defined together with the manufacturer of the gas turbine. The manufacturer has to provide a guideline for the alignment with a definition of the permissible tolerances.

Note

The theoretical time between two overhauls should be at least 6 000 operating hours for the gas generator and at least 10 000 operating hours for the performance part of the gas turbine. Variations for different operating conditions are to be defined by the manufacturer. Basis of operation is the relation of performance and operating hours of the naval ship defined by the Naval Authority.

2. Foundation

The foundations of geared turbine installations are to be so designed and constructed that only minor relative movements can occur between the turbine and the gearing which can be compensated by suitable couplings.

3. Air supply and exhaust gas installations

3.1 General design requirements

The air intake ducting is to be equipped to prevent extraneous substances from entering the compressor and turbine. In particular, measures are to be taken to reduce sufficiently the salinity of the combustion air. Cleaning equipment is to be provided to remove deposits from compressors and turbines.

The way of cleaning (dry or humid) and the frequency of cleaning as well as the substances to be used have to be agreed with the manufacturer and are to be defined in the building specification.

After the cleaning procedure it must be possible to remove the cleaning substances.

The design and arrangement of the ducts for combustion air and exhaust gas must be in accordance with the guidelines of the turbine manufacturer. These ducts have to be so dimensioned and shaped that the pressure loss permitted by the turbine manufacturer is not exceeded. By using elastic connection pieces the transfer of vibrations and structure-borne sound from the gas turbine to the pipe system shall be avoided. The influence of thermal expansion has to be observed.

Measures are to be taken that the maximum airborne sound level prescribed by the Naval Authority will not be exceeded.

Changes of the sections of combustion air and exhaust gas ducts shall not exceed an angle to the axis of more than 5°.

3.2 Combustion air ducts

The combustion air has to be sucked in from outside considering the following requirements:

- For NBC protected ships the requirements defined by the Naval Authority have to be met.
- If the draught air ducts can be closed, a control device and a start blockage have to be provided.
- Each gas turbine must have its own combustion air duct.
- The openings for sucking in have to be arranged and protected in a way that foreign matters as well as spray and swell water cannot penetrate into the duct system. It has to be avoided that exhaust gases are sucked in. The application of jalousies, air filters, water separators, water traps, etc. is to be defined in the building specification. The requirements of the gas turbine manufacturer for the combustion air have to be met.
- The entrance openings for the combustion air ducts have to be covered by a coarse mesh screen.
- The combustion air ducts have to be of such a stiff design that the pumping of the compressor does not lead to damages.
- The combustion air ducts have to be equipped with dampers controlled by low pressure, which are opening if the air filter devices are blocked, e.g. by icing, impurities. The permissible pressure difference to start with the use of the bypass has to be defined in the building specification.

3.3 Exhaust gas ducts

The exhaust gas duct of each gas turbine has to be led to the open. The outlet nozzle has to be arranged in a way that neither personnel is endangered nor equipment will be harmed.

Exhaust gas ducts and silencers have to be equipped with non-combustible insulation material, which is free of asbestos and with a covering.

Devices for the closing of the exhaust outlet have to be provided. If the covers are removable, possibilities for storage and mounting have to be foreseen. If exhaust gas flaps are remote controlled a control device, starting blockage and an automatic shut down of the gas turbine in case of flap closing have to be provided. The position of the flaps has to be indicated.

If exhaust gas ducts end near the design waterline measures have to be taken that in no case water gets into the gas turbine.

The exhaust gas ducts have to be equipped with drainage and cleaning openings.

4. Combustion chambers

Access to the combustion chambers must be ensured. It shall be possible to inspect the burner cans without having to remove the gas generator.

5. Bearing lubrication

5.1 Bearing lubrication may not be impaired by hot gases or by adjacent hot components.

General requirements for lubrication oil equipment are given in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, I.

Each gas turbine must be equipped with its own, independent lubrication system.

5.2 The lubrication equipment of a gas turbine is to be arranged and protected in a way, that in case of leakage the lubricating oil cannot reach rotating parts or surfaces with a temperature above 220 °C.

The lubricating oil system has to be equipped with a filter device, for which cleaning is possible without stopping the turbine. An exceeding of the maximum permissible pressure difference in the filter has to be indicated. During operation a check of the oil reserves must be possible. At a location which is good accessible a device to take oil samples from the oil circuit has to be provided. Care has to be taken that lubrication oil can be added during operation of the gas turbine.

5.3 The cooling back of lubrication oil has to be performed by oil, possibly from the transmission gear. Otherwise the compatibility of the material of the heat exchanger with the lubricating oil and the cooling liquid has to be proven.

6. Start-up equipment

6.1 Gas turbines are to be fitted with start equipment enabling them to be started up from the "shut down" condition.

The type of the starting equipment has to be defined in the building specification. A preheating of the operation substances (oil, fuel) is permissible.

Up to six subsequent starting procedures must be possible. A start in the hot condition, e.g. after an emergency stop, has to be enabled. If a waiting time is prescribed, the starting blockage must be releasable in an emergency case.

In case of a wrong starting procedure the injected fuel must be drained. A new start may not delayed because of this by more than 60 seconds.

6.2 A starting device with compressed air is to be designed according to Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 6. For hydraulic starting devices the requirements of Chapter 107, Section 14 and for electrical devices the data defined in Chapter 105 - Electrical Installations apply.

Where, in case of several gas turbines, the possibility exists to use bleeding compressed air from an already operating compressor/turbine unit, the connections for bleeding compressed air are to be linked with the compressed air starting system.

6.3 For the cleaning of the gas turbine and the fuel system an operation without ignition must be possible in several cycles. Number and length of the cycles as well as the needed speed have to be defined by the manufacturer.

7. Turning gear

Main propulsion turbines are to be equipped with turning gear.

The rotors of auxiliary turbines must at least be capable of being turned by hand.

8. Connections

Pipes are to be connected in such a way that no unacceptable high forces or moments are transmitted to the gas turbine.

The fuel equipment of a gas turbine is to be arranged and protected in a way, that in case of leakage fuel cannot reach rotating parts or surfaces with a temperature above 220 °C. The installation and mounting of the fuel piping has to be executed in a way that no damage caused by vibrations may occur.

9. Fuel

9.1 TL is to be informed of the fuel grade authorized by the turbine manufacturer and of the equipment needed for treating the fuel.

9.2 The installation of fuel cleaning devices like filters, separators, water traps, etc. has to be defined in the building specification. The requirements of the gas turbine manufacturer concerning the fuel have to be met. Requirements for the fuel system which are not directly related to the gas turbine are given in Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8, G.

9.3 Type and scope of the fuel transfer from the storage tank to the gas turbine have to be arranged according to the requirements of the gas turbine manufacturer and shall be defined in the building specification.

10. Vibrations / acoustic capsule

10.1 The range of service speeds may not give rise to unacceptable bending vibrations or to vibrations affecting the entire installation **(1).**

10.2 If NBC protection of the machinery rooms is demanded, a pressure which is lower than in the machinery room by at least 0,5 hPa (0,5 mbar) has to be established in the sound protection capsule, see also Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 11.

If a separate suction duct is foreseen for the cooling air of the sound protection capsule, such a duct has to be equipped with a water separator. The required degree of cleanliness of the air as well as the needed cooling volume has to be defined in the building specification in accordance with the manufacturer. In case of cooling failure it must be ensured that no overheating of the gas turbine happens. The necessary reduction of performance has to be defined in the building specification.

If a cooling after the operation is required, the cooling system must be able to work independently from the gas turbine. The time period for the cooling and the created quantity of heat have to be defined by the manufacturer of the gas turbine.

10.3 If gas turbines are installed in machinery rooms without sound protection capsules, measures are to be taken that the defined room temperature will not be exceeded. It must be ensured that other aggregates and devices which are installed in the same machinery room are not harmed.

11. Inspection openings

It is recommended that inspection openings be provided which allow the inside of the gas turbine and compressor to be inspected with special equipment, e.g. a borescope or similar, without the need for dismantling.

(1) *The assessment of vibrations may be based on ISO 10816-3 "Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts" or an equivalent standard.*

D. Emergency Operation

1. In multi-shaft installations, the failure of one shaft must not hinder the continued, independent operation of the remaining units.

2. In single-shaft installations with two or more main gas turbines, care is to be taken to ensure that, in the event of one of the gas turbines failing, the others are able to continue operation independently.

3. In the case of single-shaft installations with only one main gas turbine, special agreement is to be reached with TL concerning the emergency operating equipment.

E. Control and Safety Equipment

1. Control equipment

1.1 Gas turbines for main propulsion machinery equipped with controllable pitch propellers, disengaging couplings or an electrical transmission system are to be fitted with a speed governor which, in the event of a sudden loss of load, prevents the revolutions from increasing to the trip speed.

1.2 The speed increase of gas turbines driving electric generators - except those for electrical propeller drive - resulting from a change from full load to no load may not exceed 5 % on the resumption of steady running conditions. The transient speed increase resulting from a sudden change from full load to no-load conditions may not exceed 10 % and must be separated by a sufficient margin from the trip speed.

2. Safety devices

2.1 Gas turbines are to be equipped with a quick-closing device which automatically shuts off the fuel supply to the turbine in case of:

- Overspeed of the power turbine. Speeds exceeding the rated value by more than 15 % are to be prevented.

- An unacceptable drop in the lubricating oil pressure

- Loss of flame during operation

- Excess of temperature limits in compartments

2.2 Start-up must take place automatically in the prescribed sequence. Interlocks must be provided to ensure that this sequence (attainment of ignition speed, ignition, flame monitoring) is followed.

2.3 Equipment is to be provided which will actuate an alarm if:

- The maximum permissible gas temperature at the gas generator outlet is exceeded

- The lubricating oil temperature in the turbine bearings rises excessively

- Excess of permissible temperature in compartments

In case of exceeded gas temperature, the alarm shall actuate a "Reduce output" signal, unless such a reduction is effected automatically.

The provision of an alarm system which responds to excessive vibration velocities is recommended.

2.4 Subject to the agreement of TL the extent of the quick-closing and alarm equipment of low-power gas turbines may be reduced.

2.5 Each gas turbine has to be equipped with a stop mechanism, which shuts off automatically if:

- The maximum speed of gas generator or effective performance turbine is exceeded

- Inadmissible vibrations occur

- The minimum oil pressure falls short

- The maximum entrance temperature of the effective performance turbine is exceeded

- The flame is interrupted during the operation

The stopping shall be possible manually and by remote control. The manual stopping must be possible directly at the gas turbine. Suitable operating devices have to be provided at a good accessible position.

F. Monitoring Equipment

1. Arrangement

The necessary control and monitoring equipment for each main propulsion unit is to be located on the control platform.

2. Scope of the monitoring equipment

2.1 Monitoring equipment is to be provided for those data the reading and/or recording of which is necessary for the reliable control of operations. The following monitoring equipment is to be provided as a minimum:

- Air pressure and temperature at compressor inlet

- Gas pressure and temperature at gas generator outlet

- Lubricating oil pressure and temperature

- Gas generator and power turbine rotor speeds

Equipment is to be provided for periodically recording the temperature at the gas generator outlet.

2.2 For all equipment of control, operating and watch stands and centres the requirements of Chapter 106 - Automation, especially Section 1 have to be applied. The total scope of the operating and control equipment has to be defined in the building specification.

2.3 Automation shall be used to simplify operation and control and exclude operational mistakes by an automatic initiation of operation procedures depending inevitably from each other. In addition automation shall enable a centralised handling and control of the propulsion plant. The equipment for local manual handling and control has to exist to a full extent independently from the degree of automation.

The procedures to prepare the ship for sea shall not be included in the automation.

In case of failure of the energy supply for the automation equipment it must be ensured that the devices remain in the adjusted operational position or, if necessary, are changing into a position not harming the actual operation. For this see also the requirements in Chapter 106 - Automation, Section 1.

2.4 The telemetric transfer of parameters of the machinery plant shall be done only by a separate transfer system.

The equipment for operating and control must ensure a safe operation directly at the gas turbine and also by remote control. All parameters which are important for a regular operation must be indicated directly at the turbine. These indicating instruments shall be put together in an auxiliary control stand, as far as possible.

The safety system must work independently from the gas turbine control. In the case of activation of a safety device, the gas turbine must be blocked against a new start. The devices for deblocking have to be arranged in a way which enables a quick start of the gas turbine again.

G. Maintenance

1. Maintenance schedule

A schedule is to be submitted to TL specifying the maintenance operations to be carried out on gas turbines together with the intervals between such operations.

H. Tests

1. Scope of tests

1.1 Non-destructive testing

The scope of the non-destructive tests to be performed on rotating parts and casings is to be agreed with TL.

1.2 Balancing

Gas turbine and compressor rotors are to be balanced when in the condition ready for assembly.

1.3 Cold overspeed test

Turbine and compressor wheels are to be tested at a speed at least 15 % above the rated speed for not less than three minutes.

Turbine and compressor wheels of exhaust gas turbochargers are to be tested at a speed 20 % above the maximum working speed for at least three minutes.

TL may accept mathematical proof of the stresses in the rotating parts at overspeed as a substitute for the overspeed test itself provided that the design is such that reliable calculations are possible and the rotating parts have been subjected to thorough non-destructive testing to ascertain their freedom from defects.

1.4 Pressure and tightness tests

Finished casing parts and heat exchangers are to be subjected to hydrostatic testing at 1,5 times the maximum permissible working pressure p_{eperm}. If it is demonstrated by other means that the strength of casing parts is sufficient, a tightness test at 1,1 times the maximum permissible working pressure will suffice.

Exhaust gas turbocharger spaces containing cooling water are to be tested at a pressure p_p of 4 bar, subject to a minimum of 1,5 $p_{e,perm}$

p_p = Test pressure [bar]

$p_{e,perm}$ = Maximum permissible working pressure in the part concerned [bar]

I. Trials

1. Factory trials

1.1 Gas turbines are to be subjected at the factory to a trial run carried out, wherever possible, at the service temperature.

The satisfactory operation of the safety and control equipment is to be demonstrated during the trial run.

1.2 Exhaust gas turbochargers are to be tested for 20 minutes at the maximum working speed and at working temperature.

2. Shipboard trials

2.1 Main turbines are to be subjected to a dock trial and thereafter a trial voyage on the basis of test program agreed by TL containing following tests:

- Endurance test at nominal

- Speed start-up manoeuvres

TL reserve the right to call for additional tests in individual cases.

2.2 Turbines driving electric generators or auxiliary machines are to be run for at least 1 hour at their rated power and for 30 minutes at 110 % rated power.

SECTION 5

MAIN SHAFTING

Page

A. General

1. Scope

1.1 The following Rules apply to standard and proven designs of main shafting. Designs deviating from standard and proven type require special approval by TL.

1.2 For difficult or special operating conditions adequate reinforcements have to be provided.

1.3 TL reserve the right to call for propeller shaft dimensions in excess of those specified in this Section if the propeller arrangement results in increased bending stresses.

1.4 In case of ships with ice classes, the strengthening factors given in Section 9 are to be complied with.

2. Documents for approval

2.1 The following drawings are to be submitted in triplicate, all calculations and supporting documentation in one copy for approval:

- Arrangement of the complete propulsion plant

- Detailed drawings and material data for all torque transmitting components, especially shafts and couplings

- Arrangement of the shaft bearings

- Arrangement and detail drawings of the stern tube as well as bush bearings including stern tube sealing and the corresponding lubricating oil system.

- Calculation of the shaft alignment considering all static and dynamic external forces acting on the shaft during operation (e.g. weight of couplings, propeller weight and propeller forces, toothing forces of gears, etc.)

- Calculation of torsional vibrations

- In special cases separate bending vibration calculations may be required

- For cast resin foundation of bearings (thrust, radial including stern tube): arrangement and design of the adapting pieces and bolts

The submitted documentation must contain all required technical data to enable re-calculation of the involved stresses.

B. Materials

1. Approved materials

1.1 Propeller, intermediate and thrust shafts together with flange and clamp connections are to be made of forged steel; as far as applicable, couplings may be made of cast steel.

1.2 If the main shafting is manufactured of non magnetic copper based materials, special approval procedure may be requested.

1.3 For shafts made of fibre reinforced plastics the TL Material Rules - Fibre Reinforced Plastics and Bonding, are applicable.

2. Testing of materials

2.1 All components of the shafting which are transmitting and are therefore exposed to the torque for the ship's propulsion are subject to the TL Material Rules, and must be tested. This requirement is also applicable for metal propeller shaft liners.

2.2 The application technique and the materials used for protection of plastic coatings for propeller shafts running in water must be approved by TL.

C. Shaft Dimensions

1. General

1.1 All parts of the shafting are to be dimensioned in accordance with the following formulae and in compliance with the requirements relating to torsional vibrations set out in Section 8. The dimensioning of the shafting shall be based on the total rated installed power.

1.2 Materials

In general, the nominal tensile strength of steels R_m used for shafting shall be between 400 N/mm^2 and 800 N/mm^2. The value of R_m used for calculation of the material factor C_W, see 3. in accordance with formula (2) shall not be greater than:

- 600 N/mm^2 for carbon and unalloyed steels
- 800 N/mm^2 for liquid quenched and tempered structural steels and stainless austenitic steels, see TL Rules Chapter 103 -Special Materials for Naval Ships, Section 4 or duplex steels

2. Shaft geometry

Where the geometry of a part is such that it cannot be dimensioned in accordance with the following formulae, alternative designs may be approved. For that special evidence of the mechanical strength of the part or parts has to be proven by adequate calculation methods such as to DIN 743 (part 1 - 3): "Shafts and axles, calculation of load capacity". In such cases complete calculations based on the applied standard must be submitted to TL for approval.

3. Minimum diameter

The minimum shaft diameter is to be determined by applying formula (1).

$$d_a \geq d \geq F \cdot k \cdot \sqrt[3]{\frac{P_W}{n \cdot \left[1 - \left(\frac{d_i}{d_a}\right)^4\right]} \cdot C_W} \qquad \textbf{(1)}$$

d = Required outside diameter of shaft, [mm]

d_i = Inner d of shaft [mm], when applicable. If the bore in the shaft is ≤ 0,4 · d, the expression,

$$1 - \left(\frac{d_i}{d_a}\right)^4$$ may be set to 1,0

d_a = Actual outer diameter shaft [mm]

P_w = Rated power of driving motor [kW]

n = Shaft speed, [min^{-1}]

F = Factor for the type of propulsion installation [-]

a) Intermediate and thrust shafts
= 95 for turbine installations, engine installations with slip/hydraulic couplings and electric propulsion installations,

= 100 for all other propulsion installations,

b) Propeller shafts,
= 100 for all types of installations,

C_w = Material factor, [-]

$$= \frac{560}{R_m + 160} \qquad \textbf{(2)}$$

R_m = Tensile strength of the shaft material [N/mm^2]

k = Factor for the type of shaft, [-]

k = 1,0 for intermediate shafts with integral forged flanges or with shrink-fitted (hydraulic) keyless flangeless or flanged coupling

k = 1,1 for intermediate shafts with keyed coupling flanges

At distance of at least 0,2·d from the end of the keyway, such shafts can be reduced to a diameter corresponding to k= 1,0.

k = 1,1 for intermediate shafts with radial holes with a diameter of no more than 0,3·d.

k = 1,1 for thrust shafts in the next vicinity of the plain bearings on either side of the thrust collar, or near the axial bearings where a roller bearing design is applied

k = 1,15 for intermediate shafts designed as multi-splined shafts where d is the outside diameter of the splined shaft. Outside the splined section, the shafts can be reduced to a diameter corresponding to k = 1,0.

k = 1,20 for intermediate shafts with longitudinal slots where the length and width of the slot do not exceed 1,17 · d and 0,25 · d respectively.

k = 1,22 for propeller shafts from in the area of the aft stern tube or shaft bracket bearing, from the end of the propeller cone and up to a least distance 2,5·d,

for keyless, shrink-fitted, propeller as far as a TL approved method is applied.

The same factor may be used for propellers or hubs bolted to an integrally forged flange of the propeller shaft (typical CPP design)

k = 1,26 for propeller shafts in the area specified for k = 1,22,

for keyed propeller in connection with an oil lubricated shaft and

for water lubricated shafts which are protected by adequate means against the influence of sea water

k = 1,4 for propeller shafts in the area specified for k = 1,22,

for grease lubricated stern tube.

k = 1,15 for propeller shafts forward part beyond the area defined as aft stern tube part (k=1,22) but still withing the stern tube.

For the part outside the stern tube the diameter of the propeller shaft may be smoothly reduced to the diameter of the adjacent intermediate shaft.

4. Shafts made of pipes

For pipe shafts with relative thick walls the problem of buckling needs generally not to be investigated. For thin wall and large diameter shafts buckling behaviour must be checked additionally. For isotropic materials the following formula for the critical torque applies:

$$M_{tcrit} = C \cdot \frac{0{,}272 \cdot E \cdot 2 \cdot r_m^{0,5} \cdot t^{2,5} \cdot \pi}{(1-\nu^2)^{0,75}} \quad [\mathrm{Nm}]$$

C = factor for special conditions
 = 1,0 generally

E = modulus of elasticity [N/mm^2]

ν = Poisson's ratio

t = thickness of pipe wall
 = $(d_a - d_i) \cdot 0{,}5$ [mm]

r_m = average radius of the pipe [mm]
 = $0{,}25(d_a + d_i)$

The design criterion is:

$$3{,}5 \cdot M_t = 3{,}5 \frac{P_w/1000}{(2 \cdot \pi \cdot n)/60} \le M_{tcrit}$$

M_t = nominal torque at maximum continuous rating [Nm]

5. An approval of a shaft diameter lower than calculated according to formula (1) is possible under the following conditions:

- the fatigue strength values of the used material in the operating medium have to be submitted

- an advanced calculation method (such as mentioned in 2.) has to be applied

6. Consideration of shock loads

The influence of the additional accelerations caused by shock loads (shock spectra), are to be defined by the Naval Authority. The bending stresses of the shaft have to be checked in relation to the minimum nominal upper yield stress R_{eH}.

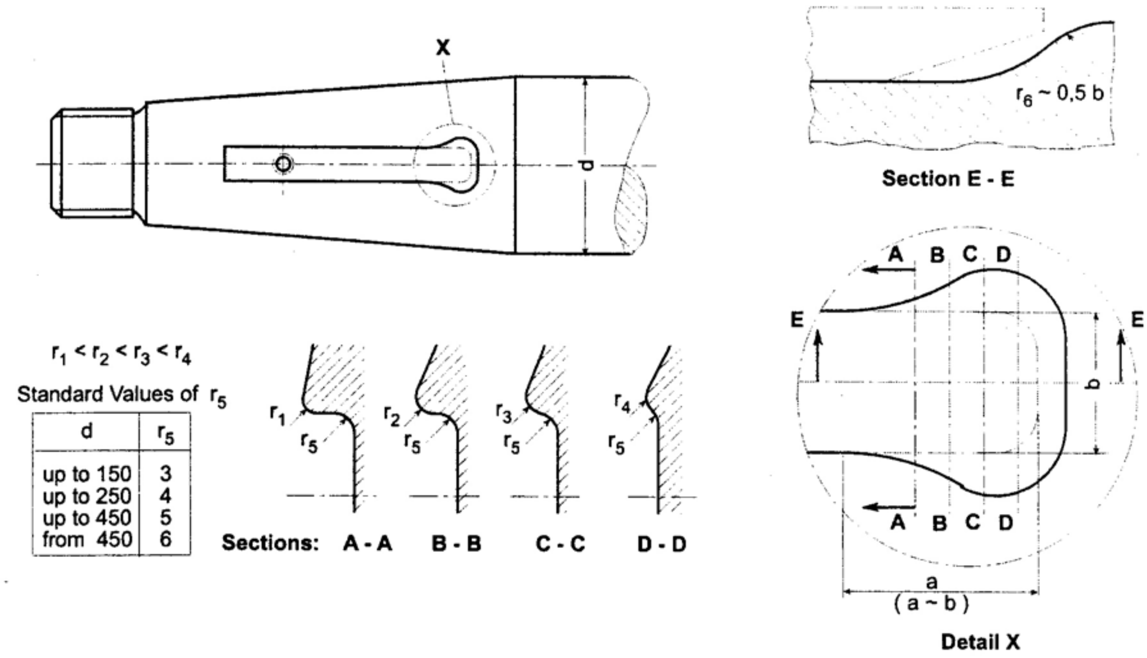


Fig. 4.1 Design of keyway in propeller shaft

D. Design

1. General

The design of the shafts should aim to achieve smooth stress distribution avoiding high stress concentration spots.

Changes in diameter are to be realised by smooth tapering or by providing ample radii.

For intermediate shafts, the radius in the transition between flange and shaft must be at least 0,08 . d, as far as formula (1) is applied for dimensioning of the shafting. The radius at the aft propeller shaft flange shall be at least 0,125 . d.

The imbalance of the shafts, e.g. because of excentric drilling hole of hollow shafts must be within the quality range G 40 according to ISO 1940-1 **(1)**, as far as applicable.

(1) *"Mechanical vibration; Balance quality requirements of rigid rotors; Determination of permissible residual unbalance".*

The surface quality of the shaft has to be chosen according to the type of loads and the notch sensitivity of the material. In the areas between the bearings a minimum quality of the arithmetic mean roughness of R_a= 10 - 16 μm, at bearing running surfaces and transition zones a value of R_a = 1,6 - 2,5 μm will be in general required.

2. Shaft tapers and propeller nut threads

Shafts are in general connected by means of flanged or sleeve couplings.

For flanged couplings a tapering of between 1 : 12 and 1 : 20 should be provided. For the taper of the propeller connection Section 7 applies.

Fixed propellers shall be connected to the propeller shaft by a pressure connection with pre-defined pull up way.

The outside diameter of the threaded end of the propeller securing nut should not be less than 60 % of the calculated bigger taper diameter. The nut has to be secured against the shaft, see Fig. 5.1.

3. Propeller shaft protection

3.1 Sealing

Propeller shafts with oil or grease lubrication are to be provided at both ends with seals of proven effectiveness, approved by TL, see also the requirements applicable to the external sealing of the stern tube in the context of the propeller shaft survey described in Chapter 101 - Classification and Surveys, Section 3.

For protection of the sealing a rope guard should be provided.

The propeller boss seating is to be effectively protected against the ingress of seawater. This seal at the propeller can be dispensed with if the propeller shaft is made of corrosion-resistant material.

3.2 Shaft liners

3.2.1 Propeller shafts which are not made of corrosion-resistant material and which run in seawater are to be protected against contact with seawater by seawater-resistant metal liners or other liners approved by TL and by seals of proven effectiveness on the propeller side.

3.2.2 Metal liners in accordance with 3.2.1, which run in seawater, must be made in a single piece. Only with the expressed consent of TL and in exceptional cases the liner may consist of two or more parts, provided that the abutting edges of the parts are additionally sealed and protected, after fitting, by a method approved by TL to guarantee water-tightness. Such joints will be subject of special tests to prove their effectiveness.

3.2.3 Minimum wall thickness

The minimum wall thickness s [mm] of metal shaft liners in accordance with 3.2.1 is to be determined using the following formula:

$$s = 0{,}03 \cdot d + 7{,}5 \qquad \textbf{(3)}$$

d = shaft diameter under the liner [mm]

In the case of continuous liners, the wall thickness between the bearings may be reduced to 0,75 · s.

4. Couplings

4.1 Definitions

In the formulae (4), (5), (6) and (7), the following symbols are used:

A = Effective area of shrink-fit seating, [mm^2]

c_A = Coefficient for shrink-fitted joints, depending on the kind of driving unit [-]

= 1,0 for geared oil engine and turbine drives,

= 1,2 for direct oil engine drives,

C = Conicity of shaft ends [-]

$$= \frac{\text{difference in taper diameters}}{\text{length of taper}}$$

d = Shaft diameter in area of clamp-type coupling, [mm]

d_s = Diameters of fitted bolts, [mm]

d_k = Root diameter of necked-down bolts, [mm]

D = Diameter of pitch circle of bolts, [mm]

E = Modules of elasticity, [N/mm^2]

f = Coefficient for shrink-fitted joints, [-]

Q = Peripheral force at the mean joint diameter of a shrink fit, [N]

n = Shaft speed, [min^{-1}]

p = Interface pressure of shrink fits, [N/mm^2]

P_w = Rated power of the driving motor(s) [kW]

s_{fl} = Flange thickness in area of bolt pitch circle, [mm]

S = Safety factor against slipping of shrink fits in the shafting, [-]

= 3,0 between motor and gear

= 2,5 for all other applications,

T = Propeller thrust, [N]

z = Number of fitted or necked-down bolts, [-]

R_m = Nominal tensile strength of fitted or necked-down bolt material, [N/mm²]

μ_o = Coefficient of static friction, [-]

= 0,15 for hydraulic shrink fits,

= 0,18 for dry shrink fits,

θ = Half taper of shaft ends, [-]

= C/2

4.2 Coupling flanges

The thickness of coupling flanges of intermediate and thrust shafts as well as of the forward end of the propeller shaft must be not less than 20 % of the Rule diameter of the specific shaft in accordance to formula (1).

Where propellers are connected by means of a forged flange with the propeller shaft, the thickness of this flange must not be less than 25 % of the Rule diameter.

The thickness of mentioned flanges may not be less than the Rule diameter of the fitted bolts, as far as their calculation is based on the same material tensile strength as applied for the shafting.

4.3 Bolts

4.3.1 The bolts used to connect flange couplings are normally to be designed as fitted bolts. The minimum diameter d_s of fitted bolts at the coupling flange faces is to be determined by applying the formula:

$$d_s = 16 \cdot \sqrt{\frac{10^6 \cdot P_W}{n \cdot z \cdot D \cdot R_m}} \qquad \textbf{(4)}$$

The nuts of coupling bolts are to be secured.

4.3.2 Where, in special circumstances, the use of fitted bolts is not feasible, TL may accept application of an equivalent connection with comparable capacity based on frictional force transmission only.

4.3.3 The minimum thread root diameter d_k of the connecting bolts used for clamp-type couplings is to be determined using the formula:

$$d_k = 12 \cdot \sqrt{\frac{10^6 \cdot P_W}{n \cdot d \cdot z \cdot R_m}} \qquad \textbf{(5)}$$

4.3.4 The shaft of necked-down bolts shall not be less than 0,9 times the thread root diameter. If, besides the torque, the bolted connection is also required to transmit considerable additional forces, the size of the bolts must be increased accordingly.

4.4 Shrink-fitted couplings

Where shafts are connected by keyless shrink fitted couplings (flange or sleeve type), the dimensioning of these shrink fits should be chosen in a way that the maximum von Mises equivalent stress in the all parts will not exceed 80 % of the yield strength of the specific materials.

For the calculation of the safety margin of the connection against slippage, the maximal (theoretical) clearance will be applied, derived as the difference between the lowest respectively highest still acceptable limit of the applied nominal tolerance field for the bore and the shaft. The contact pressure p [N/mm²] in the shrunk-on joint to achieve the required safety margin may be determined by applying formulae (6) and (7).

$$p = \frac{\sqrt{\theta^2 \cdot T^2 + f \cdot (c^2 \cdot Q^2 + T^2)} \pm \theta \cdot T}{A \cdot f} \qquad \textbf{(6)}$$

\+ sign following the root applies to conical shrunk joints without an axial stop to absorb astern thrust.

\- sign following the root if the conical shrunk joint has an axial stop to absorb astern thrust.

$$f = \left(\frac{\mu_o}{S}\right)^2 - \Theta^2 \qquad \textbf{(7)}$$

5. Shafting bearings

5.1 Arrangement of shaft bearings

The location of shaft bearings both inside and outside the stern tube should be determined, by means of suitable alignment calculations, in a way that they are subjected to positive reaction forces, irrespective of the condition of the plant (hot/ cold) and the loading condition of the ship.

By appropriate spacing of the bearings and by the alignment of the shafting in relation to the flywheel of the engine or output flange of the gear box, care is to be taken to ensure that no undue shear forces or bending moments are introduced to the crankshaft respectively gear box when the plant is under operational temperature (warm). The number and spacing of the applied bearings should be chosen in a way that the sensitivity of alignment remains low, i.e. no critical loads occur even for the case of hull's deflections or small deviations of nominal alignment due to inaccuracies or wear.

In certain cases it will be recommended to check the reaction forces of the bearing by appropriate alignment calculations of the shafting.

Guide values for the maximum permissible distance between bearings ℓ_{max} [mm] can be determined using formula (8):

$$\ell_{max} = K_1 \cdot \sqrt{d} \qquad \textbf{(8)}$$

d = Diameter of shaft between bearings, [mm]

K_1 = 450 for oil-lubricated white metal bearings,

= 280 for grey cast iron, grease-lubricated stern tube bearings,

= 280–350 for water-lubricated rubber bearings in stern tubes and shaft brackets (upper values for special designs only).

Where the shaft speed exceeds 350 min^{-1} it is recommended that the maximum bearing spacing in accordance with formula (9) be observed in order to avoid excessive loads due to bending vibrations. If the above guide formulae are not fulfilled special considerations based on bending vibration analysis will be applied.

$$\ell_{max} = K_2 \cdot \sqrt{\frac{d}{n}} \qquad \textbf{(9)}$$

n = Shaft speed, [min^{-1}]

K_2 = 8400 for oil-lubricated white metal bearings,

= 5200 for grease-lubricated, grey cast iron bearings and for rubber bearings inside stern tubes and tail shaft brackets.

In specific cases a bending (vibration) stress analysis should be carried out for the shafting system.

5.2 Stern tube bearings

5.2.1 In general two stern tube bearings should be provided. In short stern tubes the forward bearing may be dispensed with. In such cases generally a further free-standing intermediate shaft bearing will be required.

5.2.2 Where the propeller shaft inside the stern tube runs in oil-lubricated white metal bearings or in synthetic rubber or reinforced resin or plastic materials approved for use in oil-lubricated stern tube bearings, the lengths of the after and forward stern tube bearings should be approximately 2 · d_a and 0,8 · d_a respectively.

The length of the after stern tube bearing may be reduced to 1,5 · d_a provided that the contact load, which is calculated from the static load and considering the weight of the propeller, is less than 0,8 Mpa for white metal bearings and less than 0,6 Mpa for bearings made of synthetic materials.

For approved materials higher surface pressure values may be applied.

5.2.3 Where the propeller shaft inside the stern tube runs in bearings made of lignum vitae, rubber or plastic approved for use in water-lubricated stern tube bearings, the length of the after stern tube bearing should be approximately 4 · d_a and that of the forward stern tube bearing approximately 1,5 d_a.

A reduction of the bearing length may be accepted, provided that a superior load capacity of the bearing is proven by adequate shop tests.

5.2.4 Where the propeller shaft runs in grease-lubricated, grey cast iron bushes the lengths of the after and forward stern tube bearings should be approximately 2,5 . d_a and 1,0 . d_a respectively.

The peripheral speed of propeller shafts shall not exceed

- 2,5 to maximal 3 m/s for grease-lubricated grey cast iron bearings
- 6 m/s for water-lubricated rubber bearings
- 3 to maximal 4 m/s for water lubricated lignum vitae bearings

5.2.5 Where propeller shafts are to run in roller bearings inside the stern tube, preferably cylindrical roller bearings with cambered rollers or races and with increased bearing clearance should be used. The camber should be capable to cope with an inclination of the shaft relative to the bearing's centre line of at least 0,1 % for continuous operation without adverse effects.

For application of roller bearings care must be taken that the minimal load requirements as specified by the manufacturer are fulfilled (axial adjustment recommended).

5.3 Bearing lubrication

Roller bearings may be used for the propeller shaft as self-aligning radial bearings only.

5.3.1 The choice of lubrication as well as of the materials for the bearings and their compatibility to each other must take into consideration an anticipated long-life marine application.

5.3.2 Lubricating oil or grease must be introduced into the stern tube in such a way as to ensure a reliable supply of oil or grease to the forward and aft stern tube bearing.

When grease lubrication is applied, a separate grease feeding connection must be provided for each forward and after stern tube bearing.

For oil lubricated stern tube bearings, a header tank is to be fitted at a sufficient height above the ship's load line. Facilities are to be provided for checking the level of oil in the tank at any time.

The temperature of the after stern tube bearing is to be measured and indicated. Alternatively, with propeller shafts less than 400 mm in diameter the stern tube oil temperature may be measured and indicated. In such cases the temperature sensor is to be located in the vicinity of the after stern tube bearing.

In the case of ships with automated machinery, Chapter 106 - Automation has to be complied with.

5.4 Stern tube connections

Oil-lubricated stern tubes are to be fitted with filling, testing and drainage connections as well as with a vent pipe.

Where the propeller shaft runs in seawater, a flushing line is to be fitted in front of the forward stern tube bearing in place of the filling connection.

5.5 Cast resin mounting

The mounting of stern tubes and stern tube bearings made of cast resin and also the seating of intermediate shaft bearings on cast resin parts is to be carried out by TL approved companies in the presence of a TL Surveyor.

Only TL-approved cast resins may be used for stern tube seatings.

The installation instructions issued by the manufacturer of the cast resin must be observed.

E. Pressure Tests

1. Shaft liners

Prior to fitting, but as far as possible in the finish-machined condition, shaft liners are to be subjected to a hydraulic tightness test at 2 bar pressure.

2. Stern tubes

Prior to fitting but as far as possible in their finish-worked condition, cast stern tubes are to be subjected to a hydraulic tightness test at 2 bar pressure. A further tightness test is to be carried out after fitting.

For stern tubes fabricated of welded steel plates, it is sufficient to test for tightness during the pressure tests applied to the hull spaces passed by the stern tube.

F. Special Requirements for Fibre Laminate Shafts

1. Theoretical strength calculation

The strength calculation must at least cover the following failure modi in conjunction with the given corresponding load cases:

- statical failure

  Dimensioning to be performed against nominal torque with a safety of 3.

- failure due to fatigue (high cycle)

  As far as the shaft is not exposed to bending stresses fatigue analysis may be carried out for nominal torque plus 30 % torsional vibration torque.

- buckling failure mode

  Dimensioning may be estimated for a load of 3 times the nominal torque and in accordance to the formulas in 2.

For the strength analysis the nominal strength of the material has to be reduced by the factor 0,7 in order to compensate random influence factors such as geometrical and production inaccuracies as well as environmental factors (moisture, temperature).

The calculation of the stress may be performed on the basis of accepted analytical methods such as CLT (Classical Laminate Theory) or FEM models. With these stresses as input a set of failure modi in relation to fibre and interfibre failure must be checked. This set of failure modi must be coherent, i.e. a complete and accepted theory . **(2)**

2. Buckling failure

For shafts made of anisotropic materials, such as winded shafts of fibre laminate, buckling strength can be checked for the critical torque by the following formula:

$$M_{tcrit} = C_s \cdot \frac{\pi^3}{6000} \cdot \frac{r_m^{5/4} \cdot t^{9/4} \cdot E_x^{3/8}}{0,5} \cdot \left(\frac{E_y}{1 - \nu_{xy} \cdot \nu_{yz}} \right)^{5/8} \; [\text{Nm}]$$

C_s = Factor depending on boundary conditions of support

= 0,800 for free ends

= 0,925 ends simply supported

E_x = Modulus of elasticity in x-direction [N/mm^2]

E_y = Modulus of elasticity in transverse direction [N/mm^2]

ℓ = unsupported length of shaft [mm]

r_m, t = See C.4.

ν_{xy} = Poisson's ratio of the laminate in longitudinal direction

ν_{yx} = Poisson's ratio of the laminate in peripheral direction

The design criteria is:

$$3{,}5 \,.\, M_t \leq M_{tcrit}$$

(2) *VOI calculation scheme under preparation.*

M_t = Nominal torque at maximum continuous rating [Nm]

3. Experimental strength investigation

Experimental strength investigation has to be provided on request. Specifically:

- Testing of samples, if necessary for verification of material data
- Prototype testing/process checking for verification of the theoretical analysis in presence of a TL Surveyor
- After a year or 3000 operating hours, whichever is reached earlier, a visual examination and optionally a crack or delamination check of the fibre laminate components is to be carried out by a TL Surveyor.

4. Final documentation

After finalising manufacturing of the components an updated documentation in the form of a list of all definitive valid analyses and documents is to be submitted to TL. The documentation must refer to the status quo and take into account all alterations or optimisations introduced during designing and manufacturing process as well as the achieved and measured properties.

5. If fire protection requirements are relevant for the composite shafting, specifically in the cases of penetration of fire protection bulkheads and/or redundant propulsion, appropriate provisions shall be taken to ensure the required properties in consent with TL.

SECTION 6

GEARS, COUPLINGS

A. General

1. Scope

1.1 These Rules apply to spur, planetary and bevel gears and to all types of couplings for incorporation in the main propulsion plant or essential auxiliary machinery as specified in Section 1, B.4.

1.2 Documents for approval

Assembly and sectional drawings together with the necessary detail drawings and parts lists are to be submitted to TL in triplicate for approval. They must contain all the data necessary to enable the load calculations to be checked.

B. Materials

1. Approved materials

1.1 Shafts, pinions, wheels and wheel rims of gears in the main propulsion plant should preferably be made of forged steel. Rolled steel bar may also be used for plain, flangeless shafts. Gear wheel bodies may be made of grey cast iron **(1)** or nodular cast iron or may be fabricated from welded steel plate with steel or cast steel hubs.

1.2 Couplings in the main propulsion plant must be made of steel, cast steel or nodular cast iron with a mostly ferritic matrix. Grey cast iron or suitable cast aluminium alloys may also be permitted for lightly stressed external components of couplings and the rotors and casings of hydraulic slip couplings.

1.3 The gears of essential auxiliary machinery according to Section 1, B.4. are subject to the same requirements as those specified in 1.1 as regards the materials used. For gears intended for auxiliary machinery other than that mentioned in Section 1, B.4. other materials may also be permitted.

1.4 Flexible coupling bodies for essential auxiliary machinery according to Section 1, B.4. may generally be made of grey cast iron, and for the outer coupling bodies a suitable aluminium alloy may also be used. However, for generator sets use should only be made of coupling bodies preferably made of nodular cast iron with a mostly ferritic matrix, of steel or of cast steel, to ensure that the couplings are well able to withstand the shock torques occasioned by short circuits. TL reserve the right to impose similar requirements on the couplings of particular auxiliary drive units.

2. Testing of materials

All gear and coupling components which are involved in the transmission of torque and which are intended for the main propulsion plant must be tested in accordance with the TL Material Rules. The same applies to the materials used for gear components with major torque transmission function and couplings in generator drives. Suitable documentation is to be submitted for the materials used for the major components of the couplings and gears of all other functionally essential auxiliary machines in accordance with Section 1, B.4. This documentation may take the form of a TL Material Test Certificate or an acceptance test certificate issued by the steelmaker.

C. Calculation of the Load-Bearing Capacity of Gear Theeth

1. General

1.1 Components of the gearing system are:

- Gear
- Equipment for the gear lubrication and control oil
- Cooling water equipment and switching equipment

1.2 Gears have to be designed to meet the sound

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(1) *The peripheral speed of cast iron gear wheels shall generally not exceed 60 m/s, that of cast iron coupling clamps or bowls, 40 m/s.*

level defined in the building specification. The following design principles for low-noise gears are to be considered:

- Elastic mounting of the gear directly on the ship structure
- Fixed mounting of gear and drive unit on an intermediate framing which is elastically mounted on the ship structure
- Flexible couplings to the drive unit and to the propeller shaft
- Use of low-noise types of toothing, such as double helical gearing
- Installation of low-noise components, e.g. rotary screw pumps, etc. for the gear lubrication. Installation of pumps with small suction height to avoid cavitation noise

2. Calculation of load capacity for spur and bevel gears

2.1 General

2.1.1 The sufficient load capacity of the gear-tooth system of main and auxiliary gears in ship propulsion systems is to be demonstrated by load capacity calculations according to the international standards ISO 6336, ISO 9083 or DIN 3990 for spur gear tooth systems respectively ISO 10300 or DIN 3991 for bevel gears while maintaining the safety margins stated in Table 6.1 for flank and root load.

Table 6.1 Minimum safety margins for contact and root bending stress

Case	Boundary conditions	S_H	S_F
1.	Modulus m_n ≤16	1,3	1,8
2.	Modulus m_n >16	0,024 m_n + 0,916	0,02 m_n+1,48
3.	In the case of two mutually independent main propulsion systems up to an input torque of 8 000 Nm	1,2	1,55

2.1.2 For gears in the main propulsion plant proof of the sufficient mechanical strength of the roots and flanks of gear teeth in accordance with the formulae contained in this Section is linked to the requirement that the accuracy of the teeth should ensure sufficiently smooth gear operation combined with satisfactory exploitation of the dynamic loading capacity of the teeth. For this purpose, the magnitude of the individual pitch error f_p and of the total profile error F_f should generally conform to at least quality 5 as defined in DIN 3962 or 4 to ISO 1328, and in the case of higher peripheral speeds generally to at least quality 4 as defined in DIN 3962 or 3 to ISO 1328. The total error of the tooth trace $f_{Hß}$ should conform at least to quality 5 to DIN 3962, while the parallelism of axis should at least meet the requirements of quality 5 or 4 to DIN 3964 or ISO 1328 respectively. The surface roughness R_z of the tooth flanks of gears should generally not exceed 4 μm.

The tooth root radius ρ_{ao} on the tool reference profile should be at least 0,25 · m_n.

TL reserve the right to call for proof of the accuracy of the gear-cutting machines used and for testing of the method used to harden the gear teeth.

3. Symbols, terms and summary of input data

3.1 Indices

1 = pinion
2 = wheel
n = normal plane
t = transverse plane
o = tool

3.2 Parameters

a = Centre distance, [mm]

b = Face width, [mm]

b_{eh} = Effective face width (bevel gears), [mm]

Bz_O = Measure for shift of datum line

d = Standard pitch diameter [mm]

d_a = Tip diameter, [mm]

d_f = Root diameter, [mm]

F_t = Circular force at reference circle, [N]

$F_{\beta x}$ = Initial equivalent misalignment, [μm]

f_{pe} = Normal pitch error, [μm]

f_f = Profile form error, [μm]

h_{a0}^* = Addendum coefficient of tool, [-]

h_{f0}^* = Dedendum coefficient of tool, [-]

h_{FfP0}^* = Utilized dedendum coefficient of tool, [-]

K_A = Application factor, [-]

$K_{F\alpha}$ = Transverse load distribution factor (root stress), [-]

$K_{F\beta}$ = Face load distribution factor (root stress), [-]

$K_{H\alpha}$ = Transverse load distribution factor (contact stress), [-]

$K_{H\beta}$ = Face load distribution factor (contact stress), [-]

$K_{H\beta\text{-}be}$ = Bearing factor (bevel gears), [-]

K_v = Dynamic factor, [-]

K_γ = Load distribution factor. [-]

m_n = Normal modul, [mm]

m_{nm} = Mean normal modul (bevel gear), [mm]

n = Number of revolutions, [min^{-1}]

N_L = Number of load cycles, [min^{-1}]

P = Transmitted power, [kW]

pr = Protuberance at tool, [mm]

Q = Toothing quality, acc. to DIN, [-]

q = Machining allowance, [mm]

R_a = Arithmetic mean roughness, [μm]

R_{zF} = Mean peak to valley roughness of root [μm]

R_{zH} = Mean peak to valley roughness of flank, [μm]

S_F = Safety factor against tooth breakage, [-]

S_{FG} = Tooth root stress limit, [N/mm^2]

S_H = Safety factor against pittings, [-]

T = Torque, [Nm]

u = Gear ratio, [-]

x = Addendum modification coefficient, [-]

x_{hm} = Mean addendum modification coefficient, [-]

x_{sm} = Thickness modification coefficient, [-]

Y_F = Tooth from factor (root), [-]

Y_{NT} = Live factor (root), [-]

$Y_{\delta\ rel\ T}$ = Relative notch sensitivity factor, [-]

$Y_{R\ rel\ T}$ = Relative surface condition factor, [-]

Y_S = Stress correction factor, [-]

Y_{ST} = Stress correction factor for reference test gears, [-]

Y_X = Size factor for tooth root stress, [-]

Y_β = Helix angle factor for tooth root stress, [-]

z = Number of teeth, [-]

Z_E = Elasticity factor, [-]

Z_H = Zone factor (contact stress), [-]

Z_L = Lubricant factor, [-]

Z_{NT} = Live factor (contact stress), [-]

Z_v = Speed factor, [-]

Z_R = Roughness factor, [-]

ZW = Work-hardening factor, [-]

ZX = Size factor (contact stress), [-]

Z_β = Helix angle factor (contact stress), [-]

Z_ε = Contact ratio factor (contact stress), [-]

α_n = Normal pressure angle, [°]

α_{pr} = Protuberance angle, [°]

β = Helix angle, [°]

β_m = Mean helix angle (bevel gears), [-]

υoil = Oil temperature, [°C]

ν_{40} = Kinematic viscosity of the oil at 40°C [mm^2/s]

ν_{100} = kinematic viscosity of the oil at 100°C [mm^2/s]

ρ_{a0}^* = coefficient of tip radius of tool, [-]

Σ = Shaft angle (bevel gears), [°]

σ_F = Root bending stress, [N/mm^2]

σ_{FE} = Root stress, [N/mm^2]

σ_{FG} = Root stress limit, [N/mm^2]

σ_{F0} = Nominal root stress, [N/mm^2]

σ_{Flim} = Endurance limit for bending stress, [N/mm^2]

σ_{FP} = Permissible root stress, [N/mm^2]

σ_H = Calculated contact stress, [N/mm^2]

σ_{HG} = Modified contact stress limit, [N/mm^2]

σ_{Hlim} = Endurance limit for contact stress, [N/mm^2]

σ_{HP} = Permissible contact stress, [N/mm^2]

σ_{H0} = Nominal contact stress, [N/mm^2]

3.3 The input data required to carry out load-bearing capacity calculations are summarized in Table 6.2.

4. Influence factors for load calculations

4.1 Rated torque

The calculation of the rated torque has to be based on the planned maximum continuous rating.

4.2 Application factor K_A

The application factor K_A takes into account the increase in rated torque caused by external increases in dynamic and transient load. K_A is determined for main and auxiliary systems in accordance with Table 6.3.

4.3 Load distribution factor K_γ

The load distribution factor K_γ takes into account deviations in load distribution, e.g. in gears with dual or multiple load distribution or planetary gearing with more than three planet wheels.

The following values apply in respect of planetary gearing:

Gear with:

- up to 3 planet wheels $K_\gamma = 1,0$
- 4 planet wheels $K_\gamma = 1,2$
- 5 planet wheels $K_\gamma = 1,3$
- planet wheels $K_\gamma = 1,6$

In gears which have no load distribution $K_\gamma = 1,0$ is applied.

For all other cases K_γ is to be agreed with TL.

Table 6.2 List of input data for evaluating load-bearing capacity

Yard./Newb. No.						Reg. No.			
Manufacturer					Type				
Application					Cylindrical gear ☐		Bevel gear **(1)** ☐		
Nominal rated power	P			kW	Ice class				-
No. of revolutions	n_1			1/min	No. of planets				-
Application factor	K_A			-	Dynamic factor	K_v			-
Face load distribution factors	$K_{H\beta}$				Load distribution factor	K_γ			
	$K_{H\beta\text{-}be}$**(1)**			-	Transversal load distribution factors	$K_{H\alpha}$			
	$K_{F\beta}$			-		$K_{F\alpha}$			
Geometry Data		Pinion	Wheel		**Tool Data**		Pinion	Wheel	
Number of teeth	z		-	-	Addendum modification coefficient	x			-
Normal modul	m_n			mm	Mean addendum modification coeff.	x_{hm}**(1)**			-
Mean normal modul	m_{nm}**(1)**			mm	Thickness modification coeff.	x_{sm}**(1)**			-
Normal pres. angle	α_n			°	Coefficient of tool tip radius	ρ_{a0}^*			-
Centre distance	a			mm	Addendum coefficient of tool	h_{a0}^*			-
Shaft angle	Σ**(1)**			°	Dedendum coefficient of tool	h_{f0}^*			-
Relative effective face width	b_{eh}/b**(1)**			-	Utiliz. ded. coeff. of tool	h_{FfPO}^*			
Helix angle	β			°	Protuberance	pr			mm
Mean helix angle	β_m**(1)**			°	Protuberance angle	α_{pr}			°
Face width	b			mm	Machining allowance	q			mm
Tip diameter	d_a			mm	Measure at tool	Bz_O			mm
Root diameter	d_{fe}			mm	Backlass allowance/tolerance				-
Lubrication Data					**Quality**				
Kin.viskosity 40°C	ν_{40}			mm²/s	Quality acc. to DIN	Q			-
Kin.viskosity 100°C	ν_{100}			mm²/s	Mean peak to valley roughness of flank	R_{zH}			μm
Oil temperature	ν_{Oil}			°C	Mean peak to valley roughness of coot	R_{zF}			μm
FZG class				-	Initial equivalent misalignment	$F_{\beta x}$			μm
Material Data					Normal pitch error	f_{pe}			μm
Material type					Profile form error	f_f			μm
Endurance limit for contact stress	σ_{Hlim}			N/mm²	Date :				
Endurance limit for bending stress	σ_{Flim}			N/mm²					
Surface hardness				HV					
Core hardness				HV	Signature :				
Heat treatment method				-					

(1) *Declaration for bevel gear.*

Table 6.3 Application factor K_A

System type	K_A
Turbines and electric drive systems	1,1
Diesel engine drive systems with fluid clutch between engine and gears	1,1
Diesel engine drive systems with highly flexible coupling between engine and gears	1,3
Diesel engine drive systems with no flexible coupling between engine and gears	1,5
Generator drives	1,5
Auxiliary machinery under static load	0,6-1,0
Note *For other types of system K_A is to be stipulated separately.*	

4.4 Face load distribution factors $K_{Hß}$ and $K_{Fß}$

The face load distribution factors take into account the effects of uneven load distribution over the tooth flank on the contact stress ($K_{Hß}$) and on the root stress ($K_{Fß}$).

In the case of flank corrections which have been determined by recognized calculation methods, the $K_{Hß}$ and $K_{Fß}$ values can be preset. These factors take account of special influence of ship operation on the load distribution.

4.5 Transverse load distribution factors $K_{H\alpha}$ and $K_{F\alpha}$

The transverse load distribution factors $K_{H\alpha}$ and $K_{F\alpha}$ take into account the effects of an uneven distribution of force of several tooth pairs engaging at the same time.

In the case of gears in main propulsion systems with a gear tooth system of a quality described in 2.1.2.

$$K_{H\alpha} = K_{F\alpha} = 1,0$$

can be applied. For other gears the face factors are to be calculated in accordance with DIN/ISO explicitly quoted under 2.1.1 and 2.1.2

5. Contact stress

5.1 The calculated contact stress σ_H shall not exceed the permitted flank stress σ_{HP} (Hertzian flank stress). The calculation of the permissible flank stress is based on the ultimate strength, which follows from the material depending fatigue contact stress σ_{Hlim} according to Table 6.4 under consideration of the stress correction factors Z_{NT}, Z_L, Z_V, Z_R, Z_W, Z_X and the safety factor S_H according to Table 6.2.

$$\sigma_H = \sigma_{Ho} \cdot \sqrt{K_A \cdot K_\gamma \cdot K_v \cdot K_{H\beta} \cdot K_{H\alpha}} \le \sigma_{HP} \qquad (1)$$

$$\sigma_{Ho} = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_i}{d_1 \cdot b} \cdot \frac{u+1}{u}}$$

5.2 The permissible contact stress σ_{HP} shall include a safety margin S_H as given in Table 6.1 against the contact stress limit σ_{HG} which is determined from the material-dependent fatigue strength σ_{Hlim} as shown in Table 6.4 **(2)** allowing for the stress correction factors Z_{NT}, Z_L, Z_V, Z_R, Z_W, Z_X.

$$\sigma_{HP} = \frac{\sigma_{HG}}{S_H} \qquad (2)$$

$$\sigma_{HG} = \sigma_{Hlim} \cdot Z_{NT} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_W \cdot Z_X$$

Table 6.4 Endurance limits (3) for contact stress σ_{Hlim}

Material	$\sigma_{H\,lim}$ [N/mm²]
Case-hardening steels, case-hardened	1500
Nitriding steels, gas nitrided	1250
Alloyed heat treatable steels, bath or gas nitrided	850-1000
Alloyed heat treatable steels, induction hardened	0,7HV10 + 800
Alloyed heat treatable steel	1,3HV10 + 350
Unalloyed heat treatable steel	0,9HV10 + 370
Structural steel	1,0 HB + 200
Cast steel, cast iron and nodular cast graphite	1,0 HB + 150

(2) *With consent of TL for case hardened steel with proven quality higher endurance limits may be accepted.*

(3) *With consent of TL for case hardened steel with or over proven quality application of higher values for fatigue strength may be accepted.*

Table 6.5 Endurance limit for tooth root bending stress $\sigma_{FE} = \sigma_{Flim} \cdot Y_{ST}$, with Y_{ST} =2

Material	$\sigma_{FE}=\sigma_{Flim}^{*} \cdot Y_{ST}$ [N/mm²]
Case-hardened steels, case-hardened	860 - 920
Nitriding steels, gas nitrided	850
Alloyed heat treatable steel, bath or gas nitrided	740
Alloyed heat treatable steel, induction hardened	700
Alloyed heat treatable steels, heat treated	0,8HV10 + 400
Unalloyed heat treatable steels	0,6 HV10 + 320
Structural steel	0,8HB+180
Cast steel, cast iron with nodular graphite	0,8HB+140
Note *For alternating stressed toothing only 70 % of these values are permissible.*	

6. Tooth root bending stress

6.1 The calculated maximum root bending stress σ_F of the teeth shall not exceed the permissible root stress σ_{FP} of the teeth. The calculation of the permissible root bending stress is based on the ultimate strength σ_{FG}, which follows from the material depending fatigue root stress $\sigma_{F\,lim}$ according to Table 6.5 under consideration of the stress correction factors Y_{ST}, Y_{NT}, $Y_{\delta\,rel\,T}$, $Y_{R\,rel\,T}$, Y_X and the safety factor S_F according to Table 6.1.

The tooth root stress is to be calculated separately for pinion and wheel.

$$\sigma_F = \sigma_{F0} \cdot K_A \cdot K_V \cdot K_\gamma \cdot K_{F\beta} \cdot K_{F\alpha} \leq \sigma_{FP} \qquad (3)$$

$$\sigma_{F0} = \frac{F_t}{b \cdot m_n} \cdot Y_F \cdot Y_S \cdot Y_\beta$$

6.2 The permissible root bending stress σ_{FP} shall have a safety margin S_F as indicated in Table 6.1 against the root stress limit σ_{FG} which is determined from the material-dependent fatigue strength σ_{FE} or σ_{Flim} accordance with Table 6.5 **(2),** allowing for the stress correction factors Y_{ST}, Y_{NT}, $Y_{\delta\,rel\,T}$, $Y_{R\,rel\,T}$, Y_X.

$$\sigma_{FP} = \frac{\sigma_{FG}}{S_F} \qquad (4)$$

$$\sigma_{FG} = \sigma_{F\,lim} \cdot Y_{ST} \cdot Y_{NT} \cdot Y_{\delta\,rel\,T} \cdot Y_{R\,rel\,T} \cdot Y_X$$

D. Gear Shafts

1. Minimum diameter

The dimensions of shafts of reversing and reduction gears are to be calculated by applying the following formula:

$$d \geq F \cdot k \cdot \sqrt[3]{\frac{P}{n \cdot \left[1 - \left(\frac{d_i}{d_a}\right)^4\right]} \cdot C_W} \qquad (3)$$

for $\frac{d_i}{d_a} \leq 0{,}4$ the expression

$\left[1 - \left(\frac{d_i}{d_a}\right)^4\right]$ may be set to 1,0

d = Required outside diameter of shaft, [mm]

d_i = Diameter of shaft bore, if applicable, [mm]

d_a = Actual shaft diameter, [mm]

P = Driving power of shaft, [kW]

n = Shaft speed, [min^{-1}]

F = Factor for the type of drive, [-]

= 95 for turbine plants, electrical drives and engines with slip couplings,

= 100 for all other types of drive. TL reserve the right to specify higher F values if this appears necessary in view of the loading of the plant.

C_W = material factor

$$= \frac{500}{R_m + 160}$$

R_m = tensile strength of the shaft material

For whell shafts no higher than 800 N/mm^2.shall be used. For pinion shafts the actual tensile strength may be used.

k = 1,10 for gear shafts

= 1,15 in the area of the pinion or wheel body is this is keyed to the shaft and for multiple-spline shafts.

Higher values of k may be specified by TL where increased bending stresses in the shaft are expected because of the bearing arrangement, the casing design, the tooth pressure, etc.

E. Equipment

1. Gear lubrication

1.1 General

The gear system has to be designed to enable a start with a lubrication oil temperature from 0°C upwards without restrictions.

For engageable couplings the guidelines according to G.5. are valid.

Suitable equipment has to be provided, which limits the water content in the gear lubricant and the humidity within the gear in a way to exclude corrosion in the gear.

1.2 Oil level indicator

For monitoring the lubricating oil level in main and auxiliary gears, equipment must be fitted to enable the oil level to be determined.

1.3 Pressure and temperature control

Temperature and pressure gauges are to be fitted to monitor the lubricating oil pressure and the lubricating oil temperature at the oil-cooler outlet before it enters the gears.

Plain journal bearings are also to be fitted with temperature indicators.

Where gears are fitted with plane bearings, a temperature indicator is to be mounted at a suitable point. For gears rated up to 2 000 kW, special arrangements may be agreed with TL.

Where ships are equipped with automated machinery, the requirements of Chapter 106 - Automation are to be complied with.

1.4 Lubricating oil pumps

Lubricating oil pumps driven by the gearing must be mounted in such a way that they are accessible and can be replaced easily by using common board available tools.

The supply of lubricating oil has to be ensured by a main pump and an independent stand by pump. If a reduction gear is approved for sufficient self lubrication at 75 % of the driving torque, the stand by pump may be abolished up to a performance relation P/n_1 [kW/min^{-1}]≤ 3,0.

2. Equipment for operation, control and safety

Equipment for operation and control has to enable a safe operation of the gear by remote control as well as directly at the gear. All parameters which are important for a regular operation must be indicated directly at the gear. These indicating instruments shall be put together in an auxiliary control stand, as far as possible.

3. Gear casings

The casings of gears belonging to the main propulsion plant and to important auxiliaries must be fitted with removable inspection covers to enable the gears to be inspected, the thrust bearing clearance to be measured and the oil sump to be cleaned.

4. Seating of gears

It has to be taken care that no inadmissible forces caused by deformation of the foundation as part of the hull structure are transfered to the toothing.

The seating of gears on steel or cast resin chocks is to conform to the TL Rules , Guidelines for the Seating of Propulsion Plants.

For the seating of gears on casting resin chocks the thrust must be absorbed by stoppers. The same applies for casting resin foundations of separate thrust bearings.

F. Balancing and Testing

1. Balancing quality

1.1 Gear wheels, pinions, shafts, gear couplings and, where applicable, high-speed flexible couplings must be assembled in a properly balanced condition.

1.2 The following balancing quality ranges according to DIN/ISO 1940, Part 1 have to be met:

- 6,3 for gear shafts, pinion and coupling members for engine gears
- 2,5 for torsion shafts and gear couplings, pinions and gear wheels belonging to turbine transmissions

2. Testing

2.1 Testing in the manufacturer's works

When the testing of materials and component tests have been carried out, gearing systems for the main propulsion plant are to be presented to TL for final inspection and operational testing in the manufacturer's works. The final inspection is to be combined with a trial run lasting several hours under part or full-load conditions, on which occasion the tooth clearance and contact pattern are to be checked. In the case of a trial at full-load, any necessary running-in of the gears must have been completed beforehand.

Where no test facilities are available for the operational and on-load testing of large gear trains, these tests may also be performed on board ship on the occasion of the dock trials.

Tightness tests are to be performed on those components to which such testing is appropriate.

Reductions in the scope of the tests require the consent of TL.

2.2 Tests during sea trials

2.2.1 Prior to the start of sea trials, the teeth of the gears belonging to the main propulsion plant are to be coloured with suitable dye to enable the contact pattern to be established. During the sea trials, the gears are to be checked at all forward and reverse speeds to establish their operational efficiency and smooth running as well as the bearing temperatures and the freedom from contamination of the lubricating oil. At the latest on conclusion of the sea trials, the gearing is to be examined via the inspection openings and the contact pattern checked. If possible the contact pattern has to be checked after conclusion of every load step. Assessment of the contact pattern is to be based on the guide values for the proportional area of contact in the axial and radial directions of the teeth given in Table 6.6 and shall take account of the running time and loading of the gears during the sea trial.

2.2.2 In the case of multistage gear trains and planetary gears manufactured to a proven high degree of accuracy and if the check has been satisfying after a load test of several hours in the workshop of the manufacturer or if the bearing face of all tooth meshings has been proven at a type test under full load, checking of the contact pattern may, with the consent of TL, be reduced in scope.

2.3 Acoustic properties to be proven in compliance with Chapter 102 - Hull Structures and Ship Equipment, Section 16, B.3.

Table 5.6 Percentage area of contact

Material, shaping of teeth	Working depth (without tip relief)	Width of tooth (without end relief)
heat-treated, hobbed, formed by generating method	33% average values	70%
surface-hardened, ground, shaved	40% average values	80%

G. Design and Construction of Couplings

1. It must be possible to disengage respectively to install and dismantle all couplings outside of gears using the tooling on board without displacing of major system's components such as gear, thrust bearing, engine etc.

2. Flange and clamp-type couplings

In the dimensional design of the coupling bodies, flanges and bolts of flange and clamp-type couplings, the Rules specified in Section 5 are to be complied with.

3. Tooth couplings

3.1 Torsionally stiff couplings, such as multi-tooth couplings may be used to compensate deviations in radial and axial direction.

3.2 Adequate loading capacity of the tooth flanks of straight-flanked tooth couplings requires that the following conditions are satisfied:

$$p = \frac{9{,}9 \cdot 10^8 \cdot P \cdot K_A}{b \cdot h \cdot d \cdot z \cdot n} \le p_{perm} \quad (4)$$

$$\frac{P \cdot 10^{15}}{n^3 \cdot d_m^2 \cdot G} \ge 4{,}5 \quad (5)$$

Values close to 4,5 are allowed only with high manufacturing accuracy and little residual imbalance.

Where methods of calculation recognized by TL are used for determining the Hertzian stress on the flanks of tooth couplings with convex tooth flanks, the permissible Hertzian stresses are equal to 75 % of the values of σ_{HP} with stress correction factors set to 1.0:

P = Driving power at coupling, [kW]

d = Standard pitch diameter, [mm]

K_A = Application factor in accordance with C.4.2, [-]

z = Number of teeth, [-]

n = Speed in rev/min, [min^{-1}]

h = Working depth of toothing, [mm]

b = Load-bearing tooth width, [mm]

d_m = Diameter of gyration, [mm]

G = Mass of coupling sleeve, [kg]

σ_{HP} = Permissible Hertzian stress, [N/mm^2]

p = Loading capacity of the tooth flanks, [N/mm^2]

p_{perm} =400 - 600 N/mm^2 for tooth systems of quenched and tempered steel; the higher values apply to higher-strength steels, higher quality toothing and superior surface finishes.

=800 - 1000 N/mm^2 for hardened and possibly ground tooth systems; the higher values apply primarily to nitrided tooth systems of superior surface finish manufactured to close tolerances.

3.3 The coupling teeth are to be effectively lubricated. For this purpose a permanent oil or grease lubrication in the coupling may generally be regarded as adequate where

$$d \cdot n^2 < 6 \cdot 10^9 \ [mm/min^2] \quad (6)$$

For higher values of $d \cdot n^2$, couplings in main propulsion plants are to be provided with a circulating lubrication oil system.

3.4 For the dimensional design of the sleeves, flanges and bolts of gear couplings the formulae given in Section 5 are to be applied.

4. Flexible couplings

4.1 Flexible couplings must be approved for the loads specified by the manufacturer and for use in main propulsion plants and essential auxiliary machinery.

It must be ensured that no damage occurs from oil or fuel on flexible components.

The radial and axial deviations as well as the angle deviations which have to be compensated by the flexible coupling are to be defined in the building specification, both in the way of peak and steady (operational) values.

4.2 Flexible couplings in the main drive have to be so dimensioned that they withstand an operation with intermittent ignition at an arbitrary cylinder during a reasonable time. Additional dynamic loads due to torsional vibration must be considered in this respect. Reference is made to Section 8.

4.3 With regard to the casings, flanges and bolts of flexible couplings, the requirements specified in Section 5, D. are to be complied with.

4.4 The couplings must be able to compensate all relative displacements occuring during operation without initiating further inadmissible forces for the adjacent elements of the plant. If a flexible coupling is causing - according to its type - during operation thrust to the coupled elements, care must be taken to absorb these forces by bearings.

5. Clutches

Clutches have to be designed under consideration of the defined operation characteristics. It has to be en sured that in the open condition the driven secondary parts of the clutch are exposed to residual, negligible torque only. A limitation of speed and time for the operation of the disengaged clutch within the operational speed range is inadmissible. It must be ensured, that:

- the heat created during clutch in/out procedure is controlled sufficiently i.e. does not lead to overheating

- in case of a drop of the control clutch pressure the stand by pump will be activated automatically

- for air controlled clutches a redundancy is established in case of a compressed air failure

- for electrically activated clutches an automatic switching to a second feeding is provided

- the actual position (in/out) is indicated (for this see also Section 2)

6. Hydraulic couplings/Torque converters

The torque characteristic of the hydraulic coupling has to be adjusted to the operating conditions. As hydraulic oil the lubricating oil required for the diesel engines or the gears shall be used.

A timely unlimited operation of the drive machines with empty coupling must be guaranteed for the whole speed range. The actual operation condition has to be indicated (for this see also Section 2).

7. Mechanical clutches for multi-engine synchronization

7.1 Basic description

For propulsion plants driven by multiple power sources of different type (such as diesel engines and turbines) generally a switching over to alternative operational modes without intermediate shut-down or reduction of the speed of the driving engine may be required. For such purposes a synchronisation of the speed of the engines in duty and the idling engine should take place before introduction of mechanical clutch in procedure.

The synchronisation aims to minimise the clutch in shock and induced peak torques, but also to enable an undisturbed and smooth continuous operation while changing the operational mode. The speed difference before introduction of clutch in procedure should not be more than 10%, or depending on the moment of inertias of the driving and driven parts the transient speed drop or increase after clutch in should be less than 5%.

7.2 Design requirements

The mechanical part of the clutch may be of multiple disc or mechanical teeth type. All components must be designed for the nominal transmitted torque with a safety factor of 2,5. In case that the speed is not synchronised in accordance to 7.1 a safety factor of 3,5 must be reckoned with. In case that multiple disc plates or other frictional devices are applied, they should be set in a way that the slip point is reached for torque values between 150 % and 250 % of the nominal torque, depending on the requirements of the manufacturer.

Additional functions, like lock-in/lock-out control or position indication may be required depending on the overall design of the propulsion plant.

8. Testing

Couplings for ship propulsion plants and couplings for generator sets and transverse thrusters are to be presented to TL for final inspection and, where appropriate, for the performance of functional and tightness tests.

SECTION 7

PROPELLER

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SECTION 7

PROPELLER

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A. General

1. Scope

These Rules apply to screw propellers as well as miscellaneous propulsion systems. See Section 9 for information on propeller sizes and materials for ships navigating in ice.

2. Documents for approval

2.1 Design drawings of propellers in main propulsion systems having an engine output in excess of 300 kW and in transverse thrust systems of over 500 kW, are to be submitted to **TL** in triplicate for examination. The drawings are required to contain all the details necessary to carry out an examination in accordance with the following requirements.

2.2 In the case of controllable pitch propeller systems, general drawings and sectional drawings are to be submitted in triplicate in addition to the design drawings for blade, boss and pitch control mechanisms. Control and hydraulic diagrams are to be attached to a description of the functional characteristics. In the case of new designs or controllable pitch propeller systems which are being installed for the first time on a vessel with **TL** Class, a description of the controllable pitch propeller system has also to be provided.

3. Design

3.1 Propellers are to be designed in a way that their power consumption lies within the family of characteristics of the driving machinery.

- The propeller of controllable pitch plants shall absorb the continuous rating of the driving machinery at nominal speed.

- A fixed pitch propeller shall reach the absorbed power/speed relation defined in the building specification at nominal speed.

Note:
The maximum ahead pitch of CPP's should be 8 % greater than the design pitch.

3.2 The construction of controllable pitch plants has to be flood safe.

3.3 For determination of the propeller parameters well known and established methods may be used. The lay out of the propeller has to consider the noise requirements in the building specification, e.g. minimum circumferential speed, etc. Nominal speed ahead and propeller diameter are to be selected for a maximum ship speed without cavitation. The limit curve for cavitation noise in the Sigma n - C_{Th} diagram in L. may be used. The noise emission from the propeller shall be estimated already in the concept phase.

4. Designation

Each propeller and the essential components for torque transmission and for blade adjustment of controllable pitch propellers respectively have to be definitely marked with the appropriate steel-stamp. The markings have to be executed by steel-stamp numbers with rounded edges to avoid notch effects.

B. Materials

1. Propellers and propeller hubs

The material for the propulsion device has to be selected according to the actual functional requirements. Special materials are not prescribed

Materials and their parameters may be taken from the **TL** Material Rules.

Metallic propellers are to be made of sea-water-resistant copper cast alloys or steel cast alloys with a minimum tensile strength R_m of 440 N/mm^2 and with sufficient bending fatigue strength.

For the purpose of the following design Rules governing the thickness of the propeller blades, the requisite resistance to seawater of a cast copper alloy or cast steel alloy is considered to be achieved if the alloy can withstand a fatigue test under alternating bending stresses comprising 10^8 load cycles amounting to about 20 % of the minimum tensile strength and carried out in a 3 % NaCl solution, and if it can be proven that the fatigue strength under alternating bending stresses in natural seawater is not less than about 65 % of the values established in 3 % NaCl solution. Sufficient fatigue strength under alternating bending stresses must be proven by a method recognized by TL.

2. Components for controllable pitch propellers and built-up propellers

The materials of the major components of the pitch control mechanism and also the blade and boss retaining bolts must comply with the requirement pertaining to metallic materials.

The blade retaining bolts of assembled propellers or controllable pitch propellers are to be manufactured of seawater-resistant materials if they are not protected against contact with seawater.

3. Material parameters

The material has to be documented according to the TL Material Rules, Sections 12.

For the definition of the final material the manufacturer has to deliver the following data:

- Designation of the material (acronym)

- Chemical composition

- Tensile strength, yield stress and elongation of a material sample (serves especially for the identification of the material)

- Bending fatigue strength in sea water spray fog (serves as limit value for the strength calculations)

- Density of material, modulus of elasticity, thermal expansion coefficient

- Magnetic characteristics, if applicable

- Information concerning repairing ability (weldability, heat treatment)

- Information concerning resistance against corrosion and erosion

4. Novel materials

Where it is proposed to use propeller materials which serviceability is not attested by a sufficient period of practical experience, TL must be provided with special proof of the suitability of such materials.

5. Material testing

The material of propellers, propeller bosses and all other major components involved in the transmission of torque and pitch setting is to be tested in accordance with the TL Material Rules. This also applies to components which are used to control the blades and also to propellers in main propulsion systems smaller than 300 kW and transverse thrust systems of less than 500 kW.

C. Design and Dimensioning of Propellers

1. Noise behaviour

1.1 Cavitation noise

The propeller has to be designed to develop low noise, especially at the nominal acoustic operation point. Cavitation noise has to be avoided.

Note

Guiding values for cavitation avoidance are contained in L.

1.2 Singing behaviour

By calculating the natural frequencies of the propeller and by a comparison with the hydrodynamic excitation at the trailing edges the risk of singing of the propeller has to be estimated and minimized. If singing is observed during trials, relevant counter measures have to be applied.

Note:

The singing of a propeller is a strong peak tone in the noise spectrum. It is created by the excitation of natural frequencies as a consequence of vortex shedding at the trailing edge.

1.3 Air blow-out device

1.3.1 Blow-out devices for air may be considered for

1.3.2 naval ships for which low-noise operation is required in velocity ranges with cavitating propeller. If an air blow-out device is required in the building specification, the system has to be agreed with the Naval Authority and TL. The details of the design have to be included in the building specification.

1.3.3 The exits of the blown-out air have to be arranged in a way that a compact air veil covers the blade surface. The feed of the air into the propulsion system should be done at the front end of the propeller shaft. The air temperature at the shaft entrance should not be higher than 40°C. By special measures in the construction it has to be secured that no air penetrates into the hydraulic system. On the other hand no oil or water shall get into the air system.

1.3.4 For the creation of an effective air veil at the propeller blade the required air volume is depending on the propeller speed. Therefore speed regulated air compressors have to be provided.

1.3.5 All components and pipes of the air system have to be made of stainless steel.

1.3.5 For ships with NBC protection the air should be sucked from outside of the citadel. Ventilation and drainage pipes shall be conducted in closed form to the outside.

1.4 Measurements of water-borne noise

1.4.1 The measurements of water-borne noise have to be executed in deep and shallow water according to the building specification.

1.4.2 For the assessment of cavitation noise the following test criteria will be applied simultaneously:

- Recording audible noise in the frequency range 30 Hz - 20 kHz

- Comparative evaluation of the relevant third filter analyses. Checking if a clear increase of noise level in the complete frequency range above 1 kHz is to be observed or if with increased speed a transfer of the noise peak to the range of 100 Hz is happening

- Creation of a DEMON ("Demolition of Envelop Modulation on Noise") spectrum

- Measurement of the target level with a linear antenna

1.4.3 The execution of the measurements and the documentation of results has to be coordinated with TL.

2. Symbols and terms

A = Effective area of a shrink fit, [mm^2]

A_D = Propeller plane area [m^2]

B = Developed blade width of cylindrical sections at radii 0,25R, 0,35R and 0,6R, [mm]

c_A = Coefficient for shrunk joints, [-]

= 1,0 for engine and turbine gear transmissions,
= 1,2 for direct drives,

C_G = Size factor in accordance with formula (2), [-]

C_{Dyn} = Dynamic load factor in accordance with formula (3), [-]

C_w = Characteristic value for propeller material as shown in Table 7.1 (corresponds to the minimum tensile strength R_m of the propeller material). [-]

C = Conicity of shaft ends, [-]

$$= \frac{\text{difference in taper diameter}}{\text{length of taper}}$$

Table 7.1 Characteristic values C_w

Material	Description (1)	C_w
Cu 1	Cast manganese brass	440
Cu 2	Cast manganese nickel brass	440
Cu 3	Cast nickel aluminium bronze	590
Cu 4	Cast manganese aluminium bronze	630
Fe 3	Martensitic cast chrome steel 13/1-6	660
Fe 4	Martensitic-austenitic cast steel 17/4	600
Fe 5	Ferritic-austenitic cast steel	600
Fe 6	Austenitic cast steel 17/8-11	500
(1) *For the chemical composition of the alloys, see TL Rules - Materials and Welding*		

C_{Th} = Thrust load coefficient

$$= \frac{T}{0{,}5 \cdot \rho \cdot v_A^2 \cdot A_D}$$

d = Pitch circle diameter of blade or propeller-fastening bolts, [mm]

d_k = Root diameter of blade or propeller-fastening bolts, [mm]

D = Diameter of propeller, [mm]

= 2 · R

d_m = Mean taper diameter, [mm]

e = Blade rake acc. Fig. 7.1 [mm]

= R · tanε

E_T = Thrust stimulating factor in accordance with formula (5). [-]

f, f_1, f_2, f_3 = Factors in formulae (2), (3), (4) and (7), [-]

F_M = Bolt load, [N]

H = Propeller blade face pitch at radii 0,25R, 0,35R and 0,6R [mm]

H_m = Mean effective propeller pitch on blade for pitch varying with the radius, [mm]

$$= \frac{\Sigma(R \cdot B \cdot H)}{\Sigma(R \cdot B)}$$

R, B and H are to be substituted by values corresponding to the pitch at the various radii.

k = Coefficient for various profile shapes for some examples, see Table 7.2, [-]

Table 7.2 Values of k for examples of various profile shapes

Profile shape	k		
	0,25 R	0,35 R	0,6 R
Segmental profiles with circular arced back, β_x = 0,12	73	62	44
Segmental profiles with parabolic back, β_x = 0,11	77	66	47
Blade profiles as for Wageningen B series propellers $\beta_{x0,25}$ = 0,10 $\beta_{x0,35}$ = 0,11 $\beta_{x0,60}$ = 0,12	80	66	44

L_M = 2/3 of the leading-edge component of the blade width at 0,9R, but at least 1/4 of the total blade width at 0,9R for propellers with heavily raked blades. [mm]

L = Pull-up length when mounting propeller on taper, [mm]

L_{mech} = Pull-up length at t = 35°C [mm]

L_{temp} = Temperature-related portion of pull-up length at t < 35°C [mm]

M = Torque, [Nm]

n_2 = Propeller speed, [min^{-1}]

P_w = Maximum rated engine power, [kW]

p = Specific surface pressure in shrunk joint,

[N/mm^2]

p_L = Local pressure at the propeller blade surface [N/mm^2]

p_S = Static pressure at the propeller axis of rotation, [N/mm^2]

p_V = Vapour pressure, [N/mm^2]

Q = Peripheral force at mean taper diameter, [N]

$R_{p0,2}$ = 0,2% proof stress of propeller material, [N/mm^2]

R_{eH} = Minimum nominal upper yield strength, [N/mm^2]

R_m = Tensile strength, [N/mm^2]

r_D = Filet radius, pressure side, [mm]

r_S = Fillet radius, suction side [mm]

S = Margin of safety against propeller slipping on taper = 2,8, [-]

$SIGMA_n$ = Cavitation inception number

$$\frac{p_S - p_V}{0{,}5 \cdot \rho \left(\pi \cdot D \cdot \frac{n_2}{60} \right)^2}$$

D has to be inserted in metres

t = Maximum blade thickness of developed cylindrical section at radii 0,25R, 0,35R and 0,6R, [mm]

T = Propeller thrust, [N]

T_M = Impact moment, [Nm]

v_A = Average water velocity to the propeller [m/s]

v_S = Speed of ship, [kn]

w = Wake fraction, [-]

$W_{0,35R}$ $W_{0,6R}$ = Section modulus of cylindrical section at radii 0,35R and 0,6R, [mm^3]

W_x = Section modulus of cylindrical section at the radius x [mm^3]

Z = Total number of bolts used to retain one blade or propeller, [-]

z = Number of blades, [-]

α = Pitch angle of profile at radii 0,25R, 0,35R and 0,6R, [-]

$$\alpha_{0,25} = \arctan \frac{1{,}27 \cdot H}{D}$$

$$\alpha_{0,35} = \arctan \frac{0{,}91 \cdot H}{D}$$

$$\alpha_{0,6} = \arctan \frac{0{,}53 \cdot H}{D}$$

α_A Tightening factor for retaining bolts and studs, [-]

= 1,2 - 1,6
depending on the method of tightening used (see VDI 2230 or equivalent standards).

ε = Rake angle enclosed by face generatrix and normal, [-]

θ = Half-conicity of shaft ends, [-]

= C / 2

μ_o = Coefficient of static friction, [-]

= 0,13 for hydraulic oil shrunk joints – steel/bronze

= 0,18 for dry shrunk joints - steel/bronze

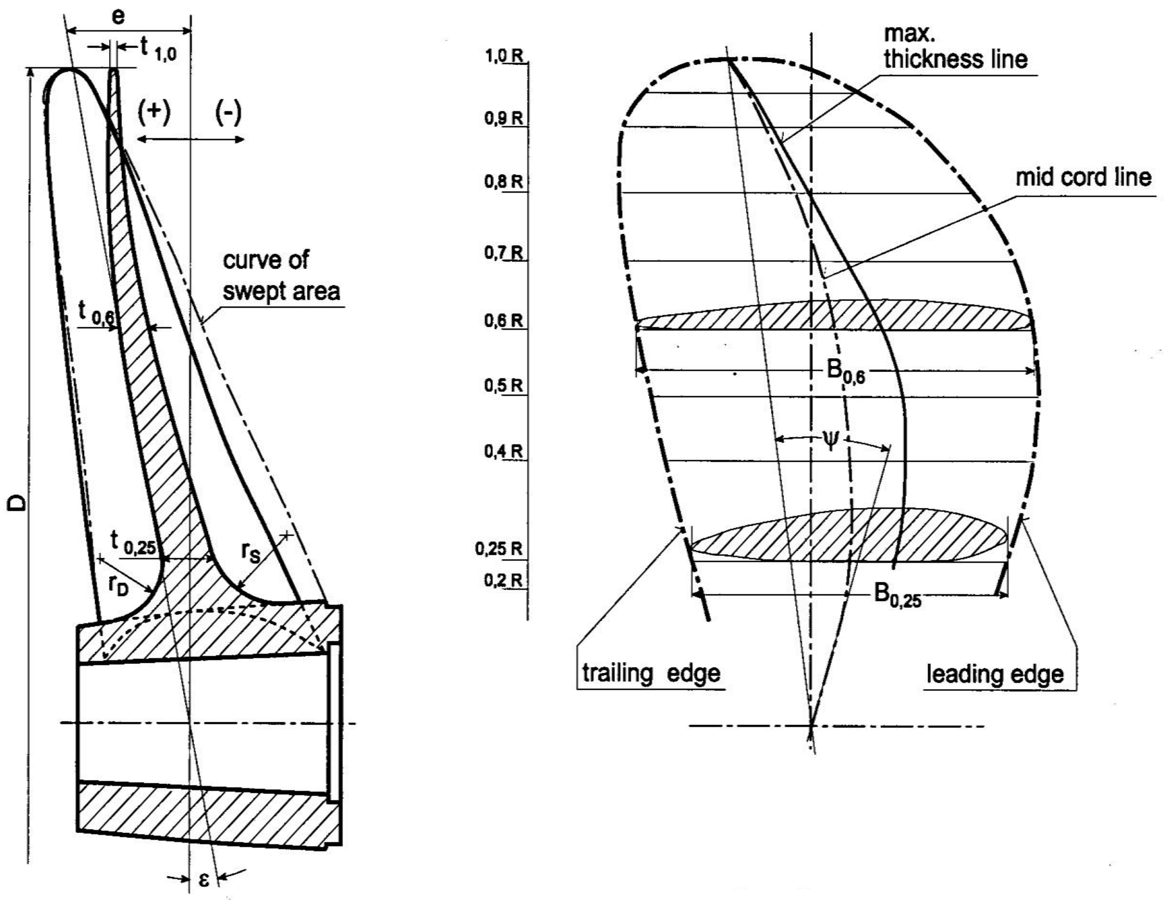


Figure 7.1 Illustration of blade geometry

Ψ = Skew angle acc. to Fig. 7.1, [°]

ρ = Density of water, [kg/m^3]

σ_{max}/σ_m = Ratio of maximum to mean stress at pressure side of blades [-]

3. Calculation of blade thickness

3.1 At radii 0,25 R and 0,6 R, the blade thicknesses of fixed pitch propellers must, as a minimum requirement, comply with the formula (1):

$$t = K_o \cdot k \cdot K_1 \cdot C_G \cdot C_{Dyn} \qquad (1)$$

$$K_o = 1 + \frac{e \cdot \cos\alpha}{H} + \frac{n_2}{15000}$$

k = as in Table 7.2

= k' for other profiles as defined in Table 7.2.

$$k' = k \cdot \sqrt{\frac{\beta_x}{\beta_x'}}$$

β_x = factor for the section modulus of the cylindrical section related to the pitch line of the blade for profile shapes defined in Table 7.2

β_x' = factor for the section modulus of the cylindrical section related to the pitch line of the blade for profile shapes other than defined in Table 7.2

$$= \frac{W_x}{t^2 \cdot B}$$

$$K_1 = \sqrt{\frac{P_W \cdot 10^5 \cdot [2 \cdot (D/H_m) \cdot \cos\alpha + \sin\alpha]}{n_2 \cdot B \cdot z \cdot C_W \cdot \cos^2 \varepsilon}}$$

C_G = Size factor, [-]

$$1{,}1 \geq \sqrt{\frac{f_1 + D}{12{,}2}} \geq 0{,}85 \qquad (2)$$

D has to be inserted in [m],

f_1 = 7,2 for monobloc propellers,

= 6,2 for separately casted blades of variable-pitch or built-up propellers,

C_{Dyn} = Dynamic factor, [-]

$$= \sqrt{\frac{(\sigma_{max}/\sigma_m - 1) + f_3}{0{,}5 + f_3}} \geq 1{,}0 \qquad (3)$$

for $\frac{\sigma_{max}}{\sigma_m} > 1{,}5$ otherwise

= 1,0

σ_{max}/σ_m can be roughly calculated from the thrust-stimulating factor E_T according to formula (5). For a more accurate calculation proceed according to 3.5.

$$\frac{\sigma_{max}}{\sigma_m} = f_2 \cdot E_T + 1 \quad \text{with} \qquad (4)$$

$$E_T \approx \frac{4{,}3 \cdot 10^{-9} \cdot \nu_s \cdot n_2 \cdot (1-w) \cdot D^3}{T}$$

f_2 = 0,4 - 0,6 for single-screw ships, the lower value applies to stern shapes with a wide propeller tip clearance and no rudder heel, and the larger value to sterns with little clearance and with rudder heel. Intermediate values are to be selected accordingly.

= 0,2 for twin-screw ships

f_3 = 0,2 for propeller materials which satisfy the requirements of B.1.

3.2 The blade thicknesses of controllable pitch propellers are to be determined at radii 0,35 · R and 0,6 · R by applying formula (1).

For ships with more than one design point, the lower diameter/pitch ratio D/H_m applicable to open-water navigation can be used in formula (1).

3.3 The blade thicknesses calculated by applying formula (1) are minima for the finish-machined propellers.

3.4 The fillet radii at the transition from the face and the back of the blades to the propeller boss should correspond, in the case of three and four-bladed propellers, to about 3,5 % of the propeller diameter. For propellers with a larger number of blades the maximum fillet radii allowed by the propeller design should be aimed at, and the radii shall not in any case be made smaller than 0,4 · $t_{0,25R}$.

3.5 For special designs such as propellers with skew angle Ψ ≥ 25°, end plate propellers, tip fin propellers, special profiles etc, special mechanical strength calculations are to be submitted to TL.

A geometry data file and details on the measured make are to be submitted to TL by data carrier or e-mail, together with the design documents to enable the evaluation of the blade stress special designs to be carried out.

D. Propeller Mounting

1. Tapered mountings for fixed propellers

1.1 Where the tapered joint between the shaft and the propeller is fitted with a key, the propeller is to be mounted on the tapered shaft in such a way that approximately the mean torque can be transmitted from the shaft to the propeller by the frictional bond. The propeller nut is to be secured in a suitable manner.

1.2 Where the tapered fit is performed by the hydraulic oil technique without the use of a key, the necessary pull-up distance on the tapered shaft is given by the expression

$$L = L_{mech} + L_{temp} \;\textbf{(1)} \qquad (6)$$

---

(1) *Where appropriate, allowance is also to be made for surface smoothing when calculating L.*

where L_{mech} is determined according to the formulae of elasticity theory applied to shrunk joints for a specific pressure p [N/mm^2] at the mean taper diameter found by applying formula (7) and for an ambient temperature of 35 °C .

$$p = \frac{\sqrt{\theta^2 \cdot T^2 + f \cdot (c_A^2 \cdot Q^2 + T^2)} \pm \theta \cdot T}{A \cdot f} \qquad (7)$$

"+" sign following the root applies to shrunk joints of tractor propeller

"-" sign following the root applies to shrunk joints of pusher propeller

$$f = (\mu_o / S)^2 - \theta^2$$

$$L_{temp} = (d_m / C) \cdot 6 \cdot 10^{-6} \cdot (35 - t) \qquad (8)$$

t = The temperature at which the propeller is mounted. [°C]

L_{temp} applies only to propellers made of bronze and austenitic steel.

1.3 The von Mises' equivalent stress based on the maximum specific pressure p and the tangential stress in the bore of the propeller hub may not exceed 75 % of the 0,2 % proof stress or yield strength of the propeller material.

1.4 The tapers of propellers which are mounted on the propeller shaft with the aid of the hydraulic oil technique should not be more than 1 : 15 or less than 1 :25.

1.5 The propeller nut must be strongly secured to the propeller shaft.

2. Flange connections for controllable pitch propellers

2.1 Flanged propellers and the bosses of controllable pitch propellers are to be attached using fitted pins and bolts.

2.2 The diameter of the fitted pins is to be calculated by applying formula (4) given in Section 5, D.4.3.

3. Blade retaining bolts

3.1 The blade retaining bolts shall be designed in such a way as to withstand the forces induced in the event of plastic deformation of the blade at 0,35 R caused by a force acting on the blade at 0,9 R. The bolt material shall have a safety margin of 1,5 against its minimum nominal upper yield stress.

The thread core diameter shall not be less than

$$d_k = b \cdot \sqrt{\frac{M0{,}35R \cdot \alpha A}{d \cdot Z \cdot R_{eH}}} \qquad (9)$$

$M_{0,35R}$ = $W_{0,35R} \cdot R_{p0,2}$

b = 4,4 propeller fastening bolts
= 2,6 for blade retaining bolts

3.2 The blade retaining bolts are to be tightened in a controlled manner in such a way that the tension on the bolts is about 60 - 70 % of their minimum nominal upper yield stress.

The shank of blade retaining bolts may be designed with a minimum diameter equal to 0,9 times the root diameter of the thread.

3.3 Blade retaining bolts must be secured against unintentional loosening.

E. Controllable Pitch Propellers

1. General

For multi-shaft propulsion plants separated hydraulic systems have to be provided for each controllable pitch propeller.

2. Design

For the design of the components, the following aspects have to be considered.

2.1 The adjustment of the controllable pitch propeller has to be done in a way that at a position "zero" of the operating lever and minimum operation speed, zero thrust is developed. If deviations because of adjustment tolerances are occurring, only thrust ahead shall be created.

Note

The maximum adjustable pitch ahead shall be at least 108 % of the design pitch [mm], the maximum pitch astern shall be at least 70 % of the design pitch [mm].

2.2 The installation and the dismantling of the controllable pitch propellers shall be possible without axial displacement of the shafts. The leading edge of the blade shall lead without overhang to the blade root disc.

2.3 The hub shall be tightened reliably. The space before the blade gaskets shall stay under constant pressure to avoid pressure and volume variations at the gaskets during pitch variation. A device has to be provided which allows flushing of the hub content at the floating ship. The blade position for this procedure has to be marked at a flange of the propeller shaft in the hull with "P" (purging).

2.4 The following blade positions of each blade have to be marked permanently at the hub:

- Maximum pitch ahead
- Design pitch
- Zero thrust position
- Maximum pitch ahead and astern

3. Emergency control

3.1 Controllable pitch propeller plants are to be equipped with means for emergency control to maintain the function of the controllable pitch propeller in case of failure of the remote control system. It is recommended to provide a device enabling the propeller blades to be locked in the "ahead" setting position.

This pitch has to be selected in a way that a start of the propulsion system is possible with the weakest driving machinery and at a standstill of the ship. Afterwards it shall be possible to operate the system like a fixed pitch propeller.

3.2 Suitable devices have to prevent that an alteration of the blade pitch setting can lead to an overload or stall of the propulsion engine.

It has to be ensured that, in the event of failure of the control system, the setting of the blades

– does not change, or
– drifts to a final position slowly enough to allow the emergency control system to be put into operation

4. Hydraulic control equipment

4.1 Where the pitch-control mechanism is operated hydraulically, two mutually independent, power driven pump sets are to be fitted. For propulsion plants up to 200 kW, one power-driven pump set is sufficient provided that, in addition, a hand-operated pump is fitted for controlling the blade pitch and that this enables the blades to be moved from ahead to the astern position in a short enough time.

For all operating conditions the adjusting time between design pitch and maximum astern pitch shall be defined in building specification. Guidance values are:

- 22 s maximum for propellers with a diameter D≤3,0 m
- 30 s maximum for propellers with a diameter D>3,0 m

4.2 The lay-out of the hydraulic system shall ensure that the electrically driven pumps are activated in case that:

- the mechanically driven pump fails
- parallel operation with the mechanically driven pump in the lower speed range is required
- short adjustment times are necessary, e.g. at

manoeuvring operation

4.3 Each pump for the control oil has to be designed for an angle velocity for blade adjustment of 2,5° per second. This velocity is valid for:

- operation with the electrically driven pump for the complete speed range

- operation with the mechanically driven pump at nominal speed of the propeller

4.4 For hydraulic pipes and pumps Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8 has to be applied.

5. Pitch control mechanism

For the pitch control mechanism proof is to be furnished that when subjected to impact moments T_M as defined by formula (10) the individual components still have a safety factor of 1,5 relative to the minimum nominal upper yield stress of the materials used.

$$T_M = 1{,}5 \frac{R_{P0,2} \cdot W_{0,6R}}{\sqrt{\left(\frac{0{,}15\,D}{L_M}\right)^2 + 0{,}75}} \qquad (10)$$

$W_{0,6R}$ can be calculated by applying the formula (11).

$$W_{0,6R} = 0{,}11\,(B \cdot t^2)_{0,6R} \qquad (11)$$

The components have to be designed fatigue-resistant for the maximum pressure.

An indication of the blade position must be connected mechanically in a form-fitting way with the propeller blades. The adjustment of the blades shall be realized with a total accuracy from the adjusting device to the blades of ± 0,25°.

6. Indicators

Controllable pitch propeller systems are to be provided with an engine room indicator showing the actual setting of the blades. Further blade position indicators are to be mounted on the bridge and in the machinery control centre (see also Chapter 106 - Automation, Section 4 and Chapter 105 - Electrical Installations, Section 9, B.).

F. Balancing and Testing

1. Balancing

The finished propeller and the blades of controllable pitch propellers are required to undergo static balancing. The mass difference between blades of controllable - or built-up fixed pitch propellers - has to be not more than 1,5 %.

Note

Wherever dynamic balancing is required or seems to be appropriate (e.g. n_2 > 500 rpm, circumferential tip speed > 60 m/s) the standard ISO DIN 1940-1 could be applied analogously.

2. Testing

Fixed pitch propellers and controllable pitch propeller systems are to be presented to TL for final inspection and verification of the dimensions.

TL reserve the right to require non-destructive tests to be conducted to detect surface cracks or casting defects.

With regard to the assessment and removal of imperfections at propellers the TL Rules Material, Section 12 shall be observed.

In addition it is required for controllable pitch propeller systems to undergo pressure, tightness and operational tests.

3. Quality classes of propellers

3.1 The quality of manufacturing and the accuracy of the dimensions of propellers must be adequate to their use. The classes "S" and "I" have to be distinguished.

Propellers have to be manufactured within quality class "S", if requirements concerning water-borne noise are specified in the building specification or if v_0 > 28 kn.

All other propellers have to be manufactured according to class "I", if not otherwise specified in the building specification.

3.2 The requirements for the quality classes used in 3.1 are given in the international standards ISO 484/1 and 484/2.

G. Rudder Propeller Units

The rated power is transmitted to the propeller via a rotating shaft, vertically to the propeller shaft and a gear situated in an underwater housing. This housing is turnable and therefore the steering effect is achieved by changing the direction of the propeller thrust.

1. General

1.1 Scope

The requirements of G. apply to the rudder propeller as main drive, the ship's manoeuvring station and all transmission elements from the manoeuvring station to the rudder propeller.

1.2 Documents for approval

Assembly and sectional drawings as well as component drawings of the gears and propellers giving all the data necessary for the examination are to be submitted in triplicate to TL for approval.

2. Materials

2.1 Approved materials

The selection of materials is subject, as and where applicable, to the provisions of B. and to those of Section 5, B.1. and Section 6, B.1.

2.2 Testing of materials

All important components of the rudder propeller involved in the transmission of torque and bending moments must be tested under the supervision of TL in accordance with the TL Material Rules.

3. Design and equipment

3.1 Number of rudder propellers

For main propulsion duties by means of rudder propellers at least two units have to be provided. Both units shall be capable of being operated independently of the other. For the design of propellers see C.

3.2 Support pipe and locking devices

The dimensional design of the support pipe and its attachment to the ship's hull shall take account of the loads due to the propeller and nozzle thrust including the dynamic components.

Each rudder propeller is to be provided with a locking device for cases where it is necessary to prevent the unintentional rotation of the propeller or the turning mechanism of the unit which is out of service at any time.

3.3 Control

3.3.1 Both the drive and the turning mechanism of each rudder propeller must be controlled from a manoeuvring station on the navigating bridge.

The controls must be mutually independent and so designed that the rudder propeller cannot be shifted unintentionally.

An additional combined control for all rudder propellers is permitted.

3.3.2 The failure of a single element within the control and hydraulic system of one unit shall not lead to the failure of the other units.

3.3.3 Where the hydraulic systems of more than one rudder propeller are combined, it must be possible in case of a loss of hydraulic oil to isolate the damaged system in such a way that the other control systems remain fully operational.

3.4 Position indicators

3.4.1 The position of each rudder propeller must be displayed on the navigating bridge and at each manoeuvring station.

3.4.2 The actual position must also be indicated at the rudder propeller itself.

3.5 Piping, hydraulic control systems

The pipes of hydraulic control systems are subject to the following provisions:

3.5.1 The pipes are to be made of seamless or longitudinally welded steel tubes. The use of cold-drawn, unannealed tubes is not permitted.

3.5.2 High-pressure hose assemblies may be used for short pipe connections if this is necessary due to vibrations or flexibly mounted units.

3.5.3 The pipes are to be installed in such a way as to ensure maximum protection while remaining readily accessible.

Copper pipes for control lines are to be safeguarded against hardening due to vibration by the use of suitable fastenings.

Pipes are to be installed at a sufficient distance from the ship's shell.

Connections to other hydraulic systems are not permitted.

3.5.4 For arrangement and design of pipes, valves, fittings and pressure vessels, see Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 16 and Section 8, A., B., C., D., U.

3.6 Oil level indicators, filters

3.6.1 Tanks forming part of the hydraulic system are to be fitted with oil level indicators.

3.6.2 The lowest permissible oil level is to be monitored. Audible and visual alarms shall be given on the navigating bridge and in the machinery space. The alarms on the navigating bridge shall be individual alarms.

3.6.3 Filters for cleaning the operating fluid are to be located in the piping system.

3.7 Lubrication

The lubricating oil supply is to be ensured by a main pump and an independent standby pump.

3.7.2 In the case of a separate lubricating system in which the main lubricating oil pumps can be replaced with the means available on board, complete standby pumps ready for mounting may be carried on board.

3.8 Gears

For the design of gears see Section 6. The turning gears are in general to take the form of spur gears or bevel gears.

4. Tests in the manufacturer's works

4.1 Testing of power units

4.1.1 The power units are required to undergo tests on a test stand in the manufacturer's works.

For diesel engines see Section 3.

For electric motors see Chapter 105 - Electrical Installations, Section 14.

4.1.2 For hydraulic pumps and motors, the TL Guidelines for the Design, Construction and Testing of Pumps, are to be applied analogously. Where the drive power is 50 kW or more, this testing is to be carried out in the presence of a TL Surveyor.

4.2 Pressure and tightness tests

Pressure components are to undergo a pressure test. The test pressure is

$$p_c = 1{,}5 \cdot p \qquad (13)$$

p = is the maximum allowable working pressure [bar] = the pressure at which the relief valves open. However, for working pressures above 200 bar the test pressure need not exceed p + 100 bar

For pressure testing of pipes, their valves and fittings, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

Tightness tests are to be performed on components to which this is appropriate.

4.3 Final inspection and operational test

4.3.1 After inspection of the individual components and completion of assembly, rudder propellers are to undergo a final inspection and operational test. The final inspection shall be combined with a trial run lasting several hours under part or full-load conditions. The tooth clearance and contact pattern have to be checked.

4.3.2 When no suitable test bed is available for the operational and load testing of large rudder propellers, the tests mentioned in 4.3.1 can be carried out on the occasion of the dock test.

4.3.3 Limitations on the scope of the test require TL's consent.

5. Shipboard trials

5.1 The faultless operation, smooth running and bearing temperatures of the gears and control system are to be checked during the sea trials under all operating conditions.

After the conclusion of the sea trials, the toothing is to be examined through the inspection openings and the contact pattern is to be checked. The tooth contact pattern is to be assessed on the basis of the reference values for the percentage area of contact given in Section 6, Table 6.6.

5.2 The scope of the check on contact pattern following the sea trials may be limited with the Surveyor's agreement provided that the checks on contact pattern called for in 4.3.1 have proved satisfactory.

H. Lateral Thrust Units

1. General

1.1 Scope

The requirements contained in H. apply to the lateral thrust unit, the control station and all the transmission elements from the control station to the lateral thrust unit.

1.2 Documents for approval

Assembly and sectional drawings for lateral thrust units with an input power of 100 kW and more together with detail drawings of the gear mechanism and propellers containing all the data necessary for checking are each to be submitted to TL in triplicate for approval. In the case of propellers, this only applies to propulsive power levels above 500 kW.

2. Materials

Materials are subject, as appropriate, to the provisions of Section 6, B. H. applies analogously to the materials and the material testing of propellers.

3. Dimensioning and design

The dimensional design of the driving mechanisms of lateral thrust units is governed by Section 6, that of the propellers by C.

The pipe connections of hydraulic drive systems are subject to the applicable requirements contained in G.3.5.

Lateral thrust units must be capable of being operated independently of other connected systems.

For the electrical equipment of lateral thrust units, see Chapter 105 - Electrical Installations, Section 7, B.

4. Tests in the manufacturer's works

G.4. is applicable as appropriate.

For hydraulic pumps and motors with a drive power of 100 kW or more, the tests are to be conducted in the presence of a TL Surveyor.

For lateral thrust units with an input power of less than 100 kW final inspection and function tests may be carried out by the manufacturer, who will then issue the relevant test protocol.

5. Shipboard trials

Testing is to be carried out during sea trials during which the operating times are to be established.

6. Casting defects

Propellers shall be free of cracks. The correction of defects has to be executed for copper cast alloys according to the TL Material Rules, Section 12.

I. Water Jet Propulsion Systems

1. Scope

These requirements apply to all devices producing a thrust by jet. This includes pump jets as well as water jets and comparable drives.

2. Design

2.1 The lay-out data have to be coordinated with the manufacturer of the water jet propulsion aggregate. At all operating conditions no cavitation shall occur in the pump which can lead to damage of the components. To achieve this already in the design phase, the manufacturer has to indicate the areas of erosive cavitation danger.

2.2 Requirements for the manoeuvring abilities have to be specified in the building specification.

2.3 If it is not planned to equip all propulsion units of a multi-shaft ship with manoeuvring devices, it has to be ensured in the building specification that all requirements concerning rudder effect, stopping time, survivability and redundancy are defined and can be met.

3. Arrangement

Pump shaft and entrance duct have to be arranged parallel to the longitudinal midship plane of the ship. The pump shaft must be parallel to the waterline in the trimmed condition of the ship. The pump is to be arranged in a height that a quick start of the system is ensured for the minimum draught of the ship

4. Construction requirements

4.1 The pump has to be integrated in the hull structure in a way that the maximum longitudinal and transverse forces occurring during acceleration or crash-stop operation and during manoeuvres with the jet in the maximum steering position are safely withstood.

Detachable connections to the ship's hull shall enable an easy installation and dismounting of the pump unit.

4.2 The form of the entrance duct has to be coordinated with the manufacturer of the water jet unit. The stream towards the pump has to be continuous and cavitation shall be avoided in the complete inlet area. The entrance duct has to be arranged to exclude the possibility of air ingress.

4.3 To protect the pump from flotsam a protection grid has to be arranged at a suitable location of the entrance duct. Before this grid an inspection port has to be provided. It must be possible to open this port and have access to it at floating ship. It shall be possible to clean the intake protection grid by reversing the flow direction.

5. Manoeuvring facilities

5.1 Steering nozzle

The adjusting angle of the steering nozzle shall reach 30° to each side. If no time for adjusting is defined in the building specification a value less than 8 s has to be assumed for the complete range of 60°.

5.2 Thrust reversing device

If no time for adjusting is defined in the building specification a value of not more than 10 s has to be assumed for the adjusting from "full ahead" to "full astern". The neutral position of the thrust reversing system (zero thrust position) has to be marked at the control device.

6. Hydraulic system

6.1 In case of multi-shaft propulsion each propulsion unit has to be equipped with its own, independently working hydraulic system.

6.2 Control oil pumps

The lay-out of the control oil pumps shall follow E.4.

J. Special Forms of Propulsion Systems

1. General

1.1 The investigation for a propulsion system most suitable for an actual naval ship should include special forms of propulsion. Lay-out and arrangement of these propulsion systems have to be coordinated closely with the manufacturer of the system.

1.2 Requirements for design and manufacturing have to be specified in the building specification. Concerning strength and model tests the rules for propellers have to be applied accordingly. Model tests have to be performed in order to proof the reliability and check special performance characteristics.

1.3 In the following the design characteristics of several propulsion systems are defined. The scope does not fulfill the demand for entirety.

2. Cycloidal propellers

2.1 Cycloidal propellers are propulsion devices with blades rotating around a vertical axis and are able to change the thrust in size and direction.

2.2 If low noise emission is required, the following principles should be observed:

- the size of the device with a minimum circumferential speed of the wheel body at the nominal acoustic layout point has to be chosen
- an operation mode has to be used where the adjustment of the thrust is achieved by adjusting the number of revolutions
- the arrangement in the hull shall enable a distance to the sonar system which is as big as possible (stern arrangement)
- for the reduction of the intake speed a low-noise gear has to be provided
- the connection of the housing to the ship foundation shall be established by an elastic mounting. The foundation as part of the hull structure shall be of appropriate stiffness
- the surface of the wheel body at the same level as the ship's bottom has to be coated with antidrumming material

2.3 If a low magnetic signature is required, a high content of non-magnetizable materials has to be provided, for reference see Chapter 103 - Special Materials for Naval Ships.

3. Supercavitating propellers

The blades of supercavitating propellers are to be designed to achieve a stable cavitation layer over the complete blade surface at the nominal layout point. Lay-out and design have to observe the foreseen operation characteristics and the demanded reversing and steering ability.

4. Partially submerged propellers

Partially submerged propellers are designed for an arrangement at the ship where the propeller blades break through the water surface.

Because of the high transverse forces this type of propulsion is only applicable for multi-shaft propulsion systems. The degree of submerging has to be chosen to achieve a stable ventilation at the suction side.

5. Podded Drives

5.1 Scope

The propulsion power for this type of drive will be created by an electric motor in the underwater gondola of the drive and directly transmitted to one or two propellers at the gondola ends. The underwater part of the system is turnable in a similar way as foreseen for rudder propellers and therefore a steering effect with full propulsion power can be achieved.

5.2 Structural measures

The space where the podded drive is connected to the ship's hull has to be surrounded by longitudinal and transverse watertight bulkheads. The thickness of the shell has to be increased locally.

As podded drives are of novel design direct calculations of the scantlings have to be submitted to TL.

5.3 Requirements for the components

If the podded drives shall be subject to classification its components must fulfil the requirements of the already existing TL Rules, such as:

- Electrical installation: see Chapter 105 Electrical Installations, Section 13
- Gears, couplings: see Section 6
- Shafting: see Section 5
- Propeller: see A., B., C., D.
- Turning mechanism: analogous to rudder propeller units, see G.
- Hydraulics: see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 14.
- Sensor and control system, including excess temperatures, oil levels, leakage indications, unpermissible vibrations, etc., see Chapter 106 -Automation, Section 11
- Any other relevant requirement

K. Dynamic Positioning Systems (DK Systems)

1. General

1.1 Scope

The complete installation necessary for positioning a ship dynamically comprises the sub-systems:

- Power system
- Thruster system and
- Control system

1.2 Position keeping

Position keeping means maintaining a desired position within the normal excursions of the control system and under the defined environmental conditions.

2. Requirements for Class Notations

2.1 Reliability

A DK system consists of components and systems acting together to achieve sufficient reliable position keeping capability. The necessary reliability is determined by the consequence of a loss of position keeping capability. The larger the consequence, the more reliable the DK system shall be.

Consequently the requirements have been grouped into three Class Notations. For each Class Notation the associated single failure criteria shall be defined.

The Class Notation of the ship required for a particular operation is based on a risk analysis of the consequence of a loss of position.

2.2 Class Notations

2.2.1 For Class Notation **DK 1**, loss of position may occur in the event of a single fault.

2.2.2 For Class Notation **DK 2**, a loss of position may not occur in the event of a single fault in any active component or system. Static components will not be considered to fail where adequate protection from damage is demonstrated and reliability is to the satisfaction of TL. Single failure criteria apply to:

- any active component or system, e.g. generators, thrusters, switchboards, remote controlled valves, etc.
- any static component, e.g. cables, pipes, manual valves, etc. which is not properly documented

with respect to protection and reliability

2.2.3 For Class Notation **DK 3**, a single failure applies to:

- items listed above for Class Notation **DK 2**, additionally any normally static component is assumed to fail
- all components in any one watertight compartment, caused by fire or flooding
- all components in any one fire sub-division, caused by fire or flooding

2.2.4 For Class Notations **DK 2** and **DK 3**, a single inadvertent action shall be considered as a single fault, if such an action is reasonably probable.

2.2.5 The requirements for the DK system arrangement for the different Class Notations are shown in Table 7.3.

2.3 Worst case failure

Based on the single failure definitions the worst case failure shall be determined and used as criterion for the consequence analysis.

2.4 Documents for approval

The documents and drawings specified below are to be submitted for approval at least in triplicate. Operation and maintenance manuals may be submitted in a single set:

- General description of the system
- Documentation for control, safety and alarm systems including test program
- Thruster documentation
- Electric power system documentation

2.5 Failure Mode and Effect Analysis (FMEA) / Redundancy test

Documentation concerning reliability and availability of the DK system shall be provided for the Class Notations **DK 2** and **DK 3** by means of a Failure Mode and Effect Analysis (FMEA). As an alternative to a FMEA the redundancy may be documented in a redundancy test procedure which is to be verified during sea trials.

3. Functional requirements

3.1 All components in a DK system shall be designed, constructed and tested in accordance with TL accepted rules and standards.

3.2 In order to meet the single failure criteria redundancy of components will normally be necessary as follows:

- for Class Notation **DK 2**, redundancy of all active components
- for Class Notation **DK 3**, redundancy of all components and physical separation of the components

3.3 For Class Notation **DK 3**, full redundancy may not always be possible (e.g., there may be a need for a single change-over system from the main computer system to the back-up computer system). Non-redundant connections between usually redundant and separated systems may be accepted, provided that it is shown to give clear safety advantages, and that their reliability can be demonstrated and documented to the satisfaction of **TL**. Such connections shall be kept to a minimum and made to fail to the safest condition. Failure in one system shall in no case be transferred to the other redundant system.

3.4 Redundant components and systems shall be immediately available and with such capacity that the DK operation can be continued for such a period that the work in progress can be terminated safely. The transfer to the redundant component or system shall be automatic as far as possible, and operator intervention shall be kept to a minimum. The transfer shall be smooth and within acceptable limitations of the operation.

4. Tests

4.1 Factory acceptance test (FAT)

Before a new installation is surveyed and tested as specified in B. factory acceptance tests shall be carried out at the manufacturer's work. These tests are to be based on the approved program.

4.2 Initial survey

The initial survey shall include a complete survey of the DK system to ensure full compliance with the applicable parts of the Rules:

- verification of redundancy and independence (Class Notations **DK 2** and **DK 3**)
- testing of the alarm system and switching logic of the measuring system (sensor, peripheral equipment and reference system)
- functional tests of control and alarm systems of each thruster
- tests of the electrical installations according to the requirements of Rules
- tests of the remote thrust control
- tests of the complete DK system (all operational modes, back-up system, alarm system and manual override)

The initial survey includes a complete test of all systems and components and of the ability of the ship to keep position after single failures associated with the assigned Class Notation.

5. Further details

Further details concerning dynamic positioning are defined in the **TL** Rules for Classification and Construction, Chapter 22 - Dynamic Positioning Systems.

L. Cavitation Noise of Propellers

Fig. 7.2 shows the probable and unprobable ranges for cavitation depending on the thrust load coefficient.

Cavitation inception number:

$$SIGMA_n = \frac{p_S - p_V}{0{,}5 \cdot \rho \cdot (\pi \cdot D \cdot n_2/60)^2}$$

D has to be inserted in metres

Thrust load coefficient:

$$C_{Th} = \frac{T}{0{,}5 \cdot \rho \cdot v_A^2 \cdot A_D}$$

Table 7.3 DK system arrangement

<table>
<tr><td colspan="3" rowspan="2">Subsystem or component</td><td colspan="5">Minimum requirements for Class Notation</td></tr>
<tr><td>DK0</td><td>DK1</td><td>DK 2</td><td colspan="2">DK 3</td></tr>
<tr><td rowspan="6">Power system</td><td colspan="2">Generators and prime mover</td><td colspan="2">---</td><td>redundant</td><td colspan="2">redundant, separate compartments</td></tr>
<tr><td colspan="2">Main switchboard</td><td colspan="2">1</td><td>2</td><td colspan="2">2 in separate compartments</td></tr>
<tr><td colspan="2">Bus-tie breaker</td><td colspan="2">---</td><td>2 NO(1)</td><td colspan="2">2 NO</td></tr>
<tr><td colspan="2">Distribution system</td><td colspan="2">---</td><td>redundant</td><td colspan="2">redundant, through separate compartments</td></tr>
<tr><td colspan="2">Power management</td><td colspan="2">---</td><td>redundant</td><td colspan="2">redundant, separate compartments</td></tr>
<tr><td colspan="2">UPS for DP control system</td><td>---</td><td>1</td><td>2</td><td colspan="2">2 + 1 in separate compartments</td></tr>
<tr><td>Thruster system</td><td colspan="2">Arrangement of thrusters</td><td colspan="2">---</td><td>redundant</td><td colspan="2">redundant, separate compartments, provided WFC is not exceeded</td></tr>
<tr><td colspan="3">DP relevant auxiliary systems</td><td colspan="2">---</td><td>Redundant (2)</td><td colspan="2">redundant, separate compartments</td></tr>
<tr><td rowspan="2">DK-Control system</td><td colspan="2">no. of computer systems</td><td colspan="2">1</td><td>2</td><td colspan="2">2+1 in separate compartments</td></tr>
<tr><td colspan="2">independent joystick with auto heading</td><td>---</td><td>1</td><td>1</td><td colspan="2">1</td></tr>
<tr><td rowspan="4">Sensors</td><td colspan="2">Position reference systems</td><td>1</td><td>2</td><td>3</td><td colspan="2">3 whereof 1 connected to back-up control system</td></tr>
<tr><td rowspan="3">Vessel's sensors</td><td>Wind</td><td colspan="2">1</td><td>2</td><td>2</td><td rowspan="3">one of each connected to back-up control system</td></tr>
<tr><td>VRS</td><td colspan="2">1</td><td>2</td><td>2</td></tr>
<tr><td>Gyro</td><td colspan="2">1</td><td>3</td><td>3</td></tr>
<tr><td colspan="3">Essential non-DK systems (3)</td><td colspan="2">---</td><td>redundant</td><td colspan="2">redundant, separate compartments</td></tr>
<tr><td colspan="3">Printer</td><td colspan="2">yes</td><td>yes</td><td colspan="2">yes</td></tr>
</table>

(1) *NC bus-tie breakers may be accepted depending on the findings of the FMEA and additional testing (NO = nominally open, NC = nominally closed)*

(2) *When active components are used*

(3) *See TL Rules Chapter 22 – Dynamic Positioning Systems, Section 2, B.6. for essential non-DP systems*

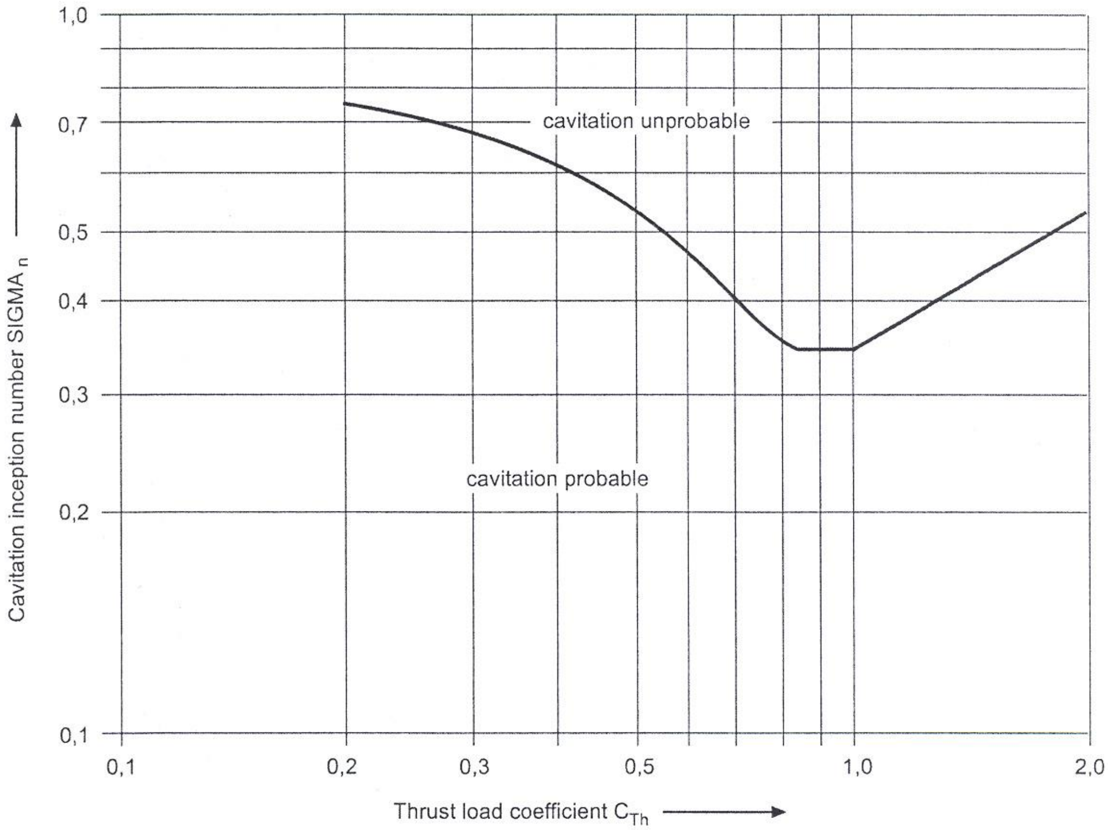


Fig. 7.2 SIGMA$_n$ - C$_{Th}$ - diagram for cavitation noise of propellers

A. General

1. Scope

These Rules apply to screw propellers as well as miscellaneous propulsion systems. See Section 9 for information on propeller sizes and materials for ships navigating in ice.

2. Documents for approval

2.1 Design drawings of propellers in main propulsion systems having an engine output in excess of 300 kW and in transverse thrust systems of over 500 kW, are to be submitted to TL in triplicate for examination. The drawings are required to contain all the details necessary to carry out an examination in accordance with the following requirements.

2.2 In the case of controllable pitch propeller systems, general drawings and sectional drawings are to be submitted in triplicate in addition to the design drawings for blade, boss and pitch control mechanisms. Control and hydraulic diagrams are to be attached to a description of the functional characteristics. In the case of new designs or controllable pitch propeller systems which are being installed for the first time on a vessel with TL Class, a description of the controllable pitch propeller system has also to be provided.

3. Design

3.1 Propellers are to be designed in a way that their power consumption lies within the family of characteristics of the driving machinery.

- The propeller of controllable pitch plants shall absorb the continuous rating of the driving machinery at nominal speed.

- A fixed pitch propeller shall reach the absorbed power/speed relation defined in the building specification at nominal speed.

Note:
The maximum ahead pitch of CPP's should be 8 % greater than the design pitch.

3.2 The construction of controllable pitch plants has to be flood safe.

3.3 For determination of the propeller parameters well known and established methods may be used. The lay out of the propeller has to consider the noise requirements in the building specification, e.g. minimum circumferential speed, etc. Nominal speed ahead and propeller diameter are to be selected for a maximum ship speed without cavitation. The limit curve for cavitation noise in the Sigma n - C_{Th} diagram in L. may be used. The noise emission from the propeller shall be estimated already in the concept phase.

4. Designation

Each propeller and the essential components for torque transmission and for blade adjustment of controllable pitch propellers respectively have to be definitely marked with the appropriate steel-stamp. The markings have to be executed by steel-stamp numbers with rounded edges to avoid notch effects.

B. Materials

1. Propellers and propeller hubs

The material for the propulsion device has to be selected according to the actual functional requirements. Special materials are not prescribed

Materials and their parameters may be taken from the TL Material Rules.

Metallic propellers are to be made of sea-water-resistant copper cast alloys or steel cast alloys with a minimum tensile strength R_m of 440 N/mm^2 and with sufficient bending fatigue strength.

For the purpose of the following design Rules governing the thickness of the propeller blades, the requisite resistance to seawater of a cast copper alloy or cast steel alloy is considered to be achieved if the alloy can withstand a fatigue test under alternating bending stresses comprising 10^8 load cycles amounting to about 20 % of the minimum tensile strength and carried out in a 3 % NaCl solution, and if it can be proven that the fatigue strength under alternating bending stresses in natural seawater is not less than about 65 % of the values established in 3 % NaCl solution. Sufficient fatigue strength under alternating bending stresses must be proven by a method recognized by TL.

2. Components for controllable pitch propellers and built-up propellers

The materials of the major components of the pitch control mechanism and also the blade and boss retaining bolts must comply with the requirement pertaining to metallic materials.

The blade retaining bolts of assembled propellers or controllable pitch propellers are to be manufactured of seawater-resistant materials if they are not protected against contact with seawater.

3. Material parameters

The material has to be documented according to the TL Material Rules, Sections 12.

For the definition of the final material the manufacturer has to deliver the following data:

- Designation of the material (acronym)
- Chemical composition
- Tensile strength, yield stress and elongation of a material sample (serves especially for the identification of the material)
- Bending fatigue strength in sea water spray fog (serves as limit value for the strength calculations)
- Density of material, modulus of elasticity, thermal expansion coefficient
- Magnetic characteristics, if applicable
- Information concerning repairing ability (weldability, heat treatment)
- Information concerning resistance against corrosion and erosion

4. Novel materials

Where it is proposed to use propeller materials which serviceability is not attested by a sufficient period of practical experience, TL must be provided with special proof of the suitability of such materials.

5. Material testing

The material of propellers, propeller bosses and all other major components involved in the transmission of torque and pitch setting is to be tested in accordance with the TL Material Rules. This also applies to components which are used to control the blades and also to propellers in main propulsion systems smaller than 300 kW and transverse thrust systems of less than 500 kW.

C. Design and Dimensioning of Propellers

1. Noise behaviour

1.1 Cavitation noise

The propeller has to be designed to develop low noise, especially at the nominal acoustic operation point. Cavitation noise has to be avoided.

Note
Guiding values for cavitation avoidance are contained in L.

1.2 Singing behaviour

By calculating the natural frequencies of the propeller and by a comparison with the hydrodynamic excitation at the trailing edges the risk of singing of the propeller has to be estimated and minimized. If singing is observed during trials, relevant counter measures have to be applied.

Note:
The singing of a propeller is a strong peak tone in the noise spectrum. It is created by the excitation of natural frequencies as a consequence of vortex shedding at the trailing edge.

1.3 Air blow-out device

1.3.1 Blow-out devices for air may be considered for

1.3.2 naval ships for which low-noise operation is required in velocity ranges with cavitating propeller. If an air blow-out device is required in the building specification, the system has to be agreed with the Naval Authority and TL. The details of the design have to be included in the building specification.

1.3.3 The exits of the blown-out air have to be arranged in a way that a compact air veil covers the blade surface. The feed of the air into the propulsion system should be done at the front end of the propeller shaft. The air temperature at the shaft entrance should not be higher than 40°C. By special measures in the construction it has to be secured that no air penetrates into the hydraulic system. On the other hand no oil or water shall get into the air system.

1.3.4 For the creation of an effective air veil at the propeller blade the required air volume is depending on the propeller speed. Therefore speed regulated air compressors have to be provided.

1.3.5 All components and pipes of the air system have to be made of stainless steel.

1.3.5 For ships with NBC protection the air should be sucked from outside of the citadel. Ventilation and drainage pipes shall be conducted in closed form to the outside.

1.4 Measurements of water-borne noise

1.4.1 The measurements of water-borne noise have to be executed in deep and shallow water according to the building specification.

1.4.2 For the assessment of cavitation noise the following test criteria will be applied simultaneously:

- Recording audible noise in the frequency range 30 Hz - 20 kHz
- Comparative evaluation of the relevant third filter analyses. Checking if a clear increase of noise level in the complete frequency range above 1 kHz is to be observed or if with increased speed a transfer of the noise peak to the range of 100 Hz is happening
- Creation of a DEMON ("Demolition of Envelop Modulation on Noise") spectrum
- Measurement of the target level with a linear antenna

1.4.3 The execution of the measurements and the documentation of results has to be coordinated with TL.

2. Symbols and terms

A = Effective area of a shrink fit, [mm^2]

A_D = Propeller plane area [m^2]

B = Developed blade width of cylindrical sections at radii 0,25R, 0,35R and 0,6R, [mm]

c_A = Coefficient for shrunk joints, [-]

= 1,0 for engine and turbine gear transmissions,

= 1,2 for direct drives,

C_G = Size factor in accordance with formula (2), [-]

C_{Dyn} = Dynamic load factor in accordance with formula (3), [-]

C_w = Characteristic value for propeller material as shown in Table 7.1 (corresponds to the minimum tensile strength R_m of the propeller material). [-]

C = Conicity of shaft ends, [-]

$$= \frac{\text{difference in taper diameter}}{\text{length of taper}}$$

Table 7.1 Characteristic values C_w

Material	Description (1)	C_w
Cu 1	Cast manganese brass	440
Cu 2	Cast manganese nickel brass	440
Cu 3	Cast nickel aluminium bronze	590
Cu 4	Cast manganese aluminium bronze	630
Fe 3	Martensitic cast chrome steel 13/1-6	660
Fe 4	Martensitic-austenitic cast steel 17/4	600
Fe 5	Ferritic-austenitic cast steel	600
Fe 6	Austenitic cast steel 17/8-11	500
(1) *For the chemical composition of the alloys, see TL Rules - Materials and Welding*		

C_{Th} = Thrust load coefficient

$$= \frac{T}{0{,}5 \cdot \rho \cdot v_A^2 \cdot A_D}$$

d = Pitch circle diameter of blade or propeller-fastening bolts, [mm]

d_k = Root diameter of blade or propeller-fastening bolts, [mm]

D = Diameter of propeller, [mm]

= 2 · R

d_m = Mean taper diameter, [mm]

e = Blade rake acc. Fig. 7.1 [mm]

= R · tanε

E_T = Thrust stimulating factor in accordance with formula (5). [-]

f, f_1, f_2, f_3 = Factors in formulae (2), (3), (4) and (7), [-]

F_M = Bolt load, [N]

H = Propeller blade face pitch at radii 0,25R, 0,35R and 0,6R [mm]

H_m = Mean effective propeller pitch on blade for pitch varying with the radius, [mm]

$$= \frac{\Sigma(R \cdot B \cdot H)}{\Sigma(R \cdot B)}$$

R, B and H are to be substituted by values corresponding to the pitch at the various radii.

k = Coefficient for various profile shapes for some examples, see Table 7.2, [-]

Table 7.2 Values of k for examples of various profile shapes

Profile shape	k		
	0,25 R	0,35 R	0,6 R
Segmental profiles with circular arced back, β_x = 0,12	73	62	44
Segmental profiles with parabolic back, β_x = 0,11	77	66	47
Blade profiles as for Wageningen B series propellers $\beta_{x0,25}$ = 0,10 $\beta_{x0,35}$ = 0,11 $\beta_{x0,60}$ = 0,12	80	66	44

L_M = 2/3 of the leading-edge component of the blade width at 0,9R, but at least 1/4 of the total blade width at 0,9R for propellers with heavily raked blades. [mm]

L = Pull-up length when mounting propeller on taper, [mm]

L_{mech} = Pull-up length at t = 35°C [mm]

L_{temp} = Temperature-related portion of pull-up length at t < 35°C [mm]

M = Torque, [Nm]

n_2 = Propeller speed, [min^{-1}]

P_w = Maximum rated engine power, [kW]

p = Specific surface pressure in shrunk joint,

[N/mm²]

p_L = Local pressure at the propeller blade surface [N/mm²]

p_S = Static pressure at the propeller axis of rotation, [N/mm²]

p_V = Vapour pressure, [N/mm²]

Q = Peripheral force at mean taper diameter, [N]

$R_{p0,2}$ = 0,2% proof stress of propeller material, [N/mm²]

R_{eH} = Minimum nominal upper yield strength, [N/mm²]

R_m = Tensile strength, [N/mm²]

r_D = Filet radius, pressure side, [mm]

r_S = Fillet radius, suction side [mm]

S = Margin of safety against propeller slipping on taper = 2,8, [-]

$SIGMA_n$ = Cavitation inception number

$$\frac{p_S - p_V}{0,5 \cdot \rho \left(\pi \cdot D \cdot \frac{n_2}{60} \right)^2}$$

D has to be inserted in metres

t = Maximum blade thickness of developed cylindrical section at radii 0,25R, 0,35R and 0,6R, [mm]

T = Propeller thrust, [N]

T_M = Impact moment, [Nm]

v_A = Average water velocity to the propeller [m/s]

v_S = Speed of ship, [kn]

w = Wake fraction, [-]

$W_{0,35R}$, $W_{0,6R}$ = Section modulus of cylindrical section at radii 0,35R and 0,6R, [mm³]

W_x = Section modulus of cylindrical section at the radius x [mm³]

Z = Total number of bolts used to retain one blade or propeller, [-]

z = Number of blades, [-]

α = Pitch angle of profile at radii 0,25R, 0,35R and 0,6R, [-]

$$\alpha_{0,25} = \arctan \frac{1,27 \cdot H}{D}$$

$$\alpha_{0,35} = \arctan \frac{0,91 \cdot H}{D}$$

$$\alpha_{0,6} = \arctan \frac{0,53 \cdot H}{D}$$

α_A Tightening factor for retaining bolts and studs, [-]

= 1,2 - 1,6
depending on the method of tightening used (see VDI 2230 or equivalent standards).

ε = Rake angle enclosed by face generatrix and normal, [-]

θ = Half-conicity of shaft ends, [-]

= C / 2

μ_o = Coefficient of static friction, [-]

= 0,13 for hydraulic oil shrunk joints – steel/bronze

= 0,18 for dry shrunk joints - steel/bronze

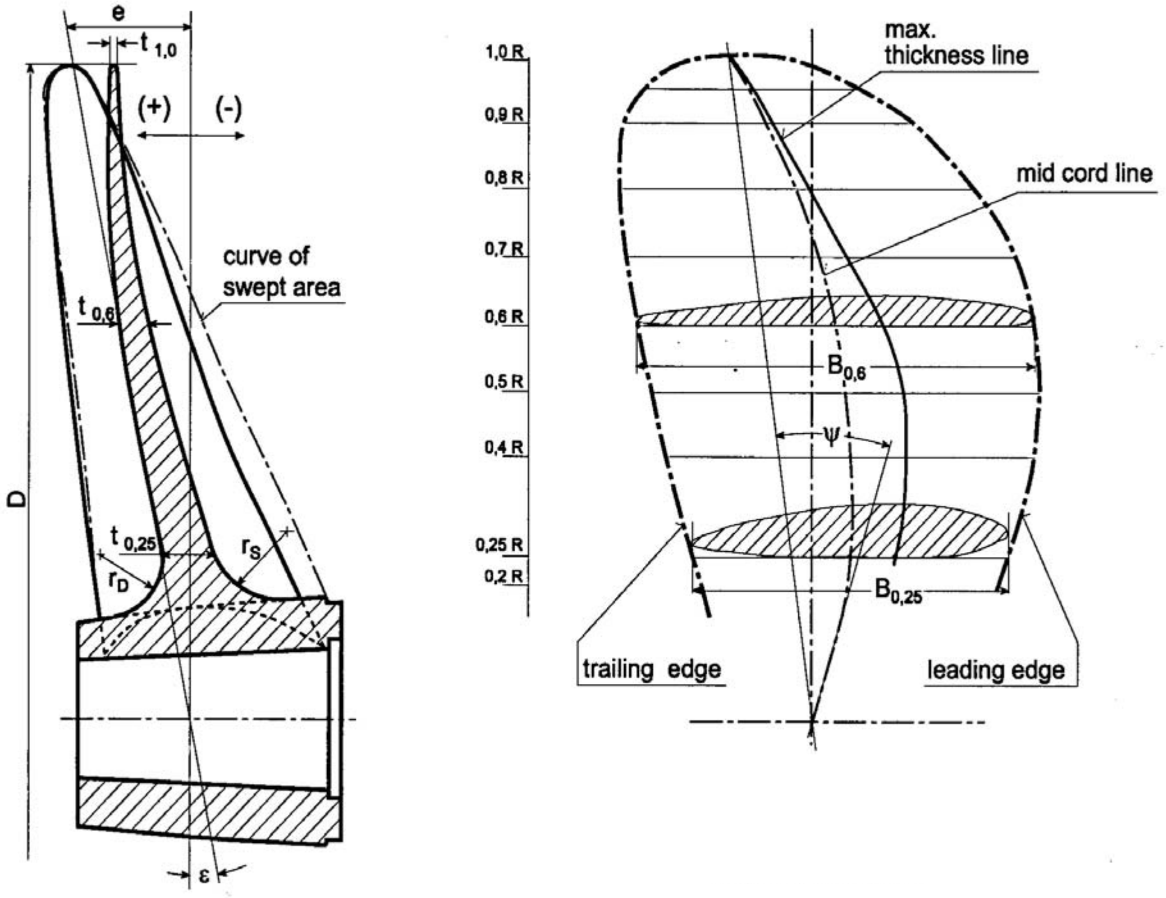


Figure 7.1 Illustration of blade geometry

Ψ = Skew angle acc. to Fig. 7.1, [°]

ρ = Density of water, [kg/m^3]

σ_{max}/σ_m = Ratio of maximum to mean stress at pressure side of blades [-]

3. Calculation of blade thickness

3.1 At radii 0,25 R and 0,6 R, the blade thicknesses of fixed pitch propellers must, as a minimum requirement, comply with the formula (1):

$$t = K_o \cdot k \cdot K_1 \cdot C_G \cdot C_{Dyn} \qquad (1)$$

$$K_o = 1 + \frac{e \cdot \cos\alpha}{H} + \frac{n_2}{15000}$$

k = as in Table 7.2

= k' for other profiles as defined in Table 7.2.

$$k' = k \cdot \sqrt{\frac{\beta_x}{\beta_x'}}$$

β_x = factor for the section modulus of the cylindrical section related to the pitch line of the blade for profile shapes defined in Table 7.2

β_x' = factor for the section modulus of the cylindrical section related to the pitch line of the blade for profile shapes other than defined in Table 7.2

$$= \frac{W_x}{t^2 \cdot B}$$

$$K_1 = \sqrt{\frac{P_W \cdot 10^5 \cdot [2 \cdot (D/H_m) \cdot \cos\alpha + \sin\alpha]}{n_2 \cdot B \cdot z \cdot C_W \cdot \cos^2 \varepsilon}}$$

C_G = Size factor, [-]

$$1{,}1 \geq \sqrt{\frac{f_1 + D}{12{,}2}} \geq 0{,}85 \qquad (2)$$

D has to be inserted in [m],

f_1 = 7,2 for monobloc propellers,

= 6,2 for separately casted blades of variable-pitch or built-up propellers,

C_{Dyn} = Dynamic factor, [-]

$$= \sqrt{\frac{(\sigma_{max} / \sigma_m - 1) + f_3}{0{,}5 + f_3}} \geq 1{,}0 \qquad (3)$$

for $\frac{\sigma_{max}}{\sigma_m} > 1{,}5$ otherwise

= 1,0

σ_{max}/σ_m can be roughly calculated from the thrust-stimulating factor E_T according to formula (5). For a more accurate calculation proceed according to 3.5.

$$\frac{\sigma_{max}}{\sigma_m} = f_2 \cdot E_T + 1 \quad \text{with} \qquad (4)$$

$$E_T \approx \frac{4{,}3 \cdot 10^{-9} \cdot \nu_s \cdot n_2 \cdot (1 - w) \cdot D^3}{T}$$

f_2 = 0,4 - 0,6 for single-screw ships, the lower value applies to stern shapes with a wide propeller tip clearance and no rudder heel, and the larger value to sterns with little clearance and with rudder heel. Intermediate values are to be selected accordingly.

= 0,2 for twin-screw ships

f_3 = 0,2 for propeller materials which satisfy the requirements of B.1.

3.2 The blade thicknesses of controllable pitch propellers are to be determined at radii 0,35 · R and 0,6 · R by applying formula (1).

For ships with more than one design point, the lower diameter/pitch ratio D/H_m applicable to open-water navigation can be used in formula (1).

3.3 The blade thicknesses calculated by applying formula (1) are minima for the finish-machined propellers.

3.4 The fillet radii at the transition from the face and the back of the blades to the propeller boss should correspond, in the case of three and four-bladed propellers, to about 3,5 % of the propeller diameter. For propellers with a larger number of blades the maximum fillet radii allowed by the propeller design should be aimed at, and the radii shall not in any case be made smaller than 0,4 · $t_{0,25R}$.

3.5 For special designs such as propellers with skew angle Ψ ≥ 25°, end plate propellers, tip fin propellers, special profiles etc, special mechanical strength calculations are to be submitted to TL.

A geometry data file and details on the measured make are to be submitted to TL by data carrier or e-mail, together with the design documents to enable the evaluation of the blade stress special designs to be carried out.

D. Propeller Mounting

1. Tapered mountings for fixed propellers

1.1 Where the tapered joint between the shaft and the propeller is fitted with a key, the propeller is to be mounted on the tapered shaft in such a way that approximately the mean torque can be transmitted from the shaft to the propeller by the frictional bond. The propeller nut is to be secured in a suitable manner.

1.2 Where the tapered fit is performed by the hydraulic oil technique without the use of a key, the necessary pull-up distance on the tapered shaft is given by the expression

$$L = L_{mech} + L_{temp} \; \textbf{(1)} \qquad (6)$$

---

(1) *Where appropriate, allowance is also to be made for surface smoothing when calculating L.*

where L_{mech} is determined according to the formulae of elasticity theory applied to shrunk joints for a specific pressure p [N/mm^2] at the mean taper diameter found by applying formula (7) and for an ambient temperature of 35 °C .

$$p = \frac{\sqrt{\theta^2 \cdot T^2 + f \cdot (c_A^2 \cdot Q^2 + T^2)} \pm \theta \cdot T}{A \cdot f} \quad (7)$$

"+" sign following the root applies to shrunk joints of tractor propeller

"-" sign following the root applies to shrunk joints of pusher propeller

$$f = (\mu_o / S)^2 - \theta^2$$

$$L_{temp} = (d_m / C) \cdot 6 \cdot 10^{-6} \cdot (35 - t) \quad (8)$$

t = The temperature at which the propeller is mounted. [°C]

L_{temp} applies only to propellers made of bronze and austenitic steel.

1.3 The von Mises' equivalent stress based on the maximum specific pressure p and the tangential stress in the bore of the propeller hub may not exceed 75 % of the 0,2 % proof stress or yield strength of the propeller material.

1.4 The tapers of propellers which are mounted on the propeller shaft with the aid of the hydraulic oil technique should not be more than 1 : 15 or less than 1 :25.

1.5 The propeller nut must be strongly secured to the propeller shaft.

2. Flange connections for controllable pitch propellers

2.1 Flanged propellers and the bosses of controllable pitch propellers are to be attached using fitted pins and bolts.

2.2 The diameter of the fitted pins is to be calculated by applying formula (4) given in Section 5, D.4.3.

3. Blade retaining bolts

3.1 The blade retaining bolts shall be designed in such a way as to withstand the forces induced in the event of plastic deformation of the blade at 0,35 R caused by a force acting on the blade at 0,9 R. The bolt material shall have a safety margin of 1,5 against its minimum nominal upper yield stress.

The thread core diameter shall not be less than

$$d_k = b \cdot \sqrt{\frac{M0{,}35R \cdot \alpha A}{d \cdot Z \cdot R_{eH}}} \quad (9)$$

$M_{0,35R}$ = $W_{0,35R} \cdot R_{p0,2}$

b = 4,4 propeller fastening bolts
= 2,6 for blade retaining bolts

3.2 The blade retaining bolts are to be tightened in a controlled manner in such a way that the tension on the bolts is about 60 - 70 % of their minimum nominal upper yield stress.

The shank of blade retaining bolts may be designed with a minimum diameter equal to 0,9 times the root diameter of the thread.

3.3 Blade retaining bolts must be secured against unintentional loosening.

E. Controllable Pitch Propellers

1. General

For multi-shaft propulsion plants separated hydraulic systems have to be provided for each controllable pitch propeller.

2. Design

For the design of the components, the following aspects have to be considered.

2.1 The adjustment of the controllable pitch propeller has to be done in a way that at a position "zero" of the operating lever and minimum operation speed, zero thrust is developed. If deviations because of adjustment tolerances are occurring, only thrust ahead shall be created.

Note

The maximum adjustable pitch ahead shall be at least 108 % of the design pitch [mm], the maximum pitch astern shall be at least 70 % of the design pitch [mm].

2.2 The installation and the dismantling of the controllable pitch propellers shall be possible without axial displacement of the shafts. The leading edge of the blade shall lead without overhang to the blade root disc.

2.3 The hub shall be tightened reliably. The space before the blade gaskets shall stay under constant pressure to avoid pressure and volume variations at the gaskets during pitch variation. A device has to be provided which allows flushing of the hub content at the floating ship. The blade position for this procedure has to be marked at a flange of the propeller shaft in the hull with "P" (purging).

2.4 The following blade positions of each blade have to be marked permanently at the hub:

- Maximum pitch ahead
- Design pitch
- Zero thrust position
- Maximum pitch ahead and astern

3. Emergency control

3.1 Controllable pitch propeller plants are to be equipped with means for emergency control to maintain the function of the controllable pitch propeller in case of failure of the remote control system. It is recommended to provide a device enabling the propeller blades to be locked in the “ahead” setting position.

This pitch has to be selected in a way that a start of the propulsion system is possible with the weakest driving machinery and at a standstill of the ship. Afterwards it shall be possible to operate the system like a fixed pitch propeller.

3.2 Suitable devices have to prevent that an alteration of the blade pitch setting can lead to an overload or stall of the propulsion engine.

It has to be ensured that, in the event of failure of the control system, the setting of the blades

– does not change, or
– drifts to a final position slowly enough to allow the emergency control system to be put into operation

4. Hydraulic control equipment

4.1 Where the pitch-control mechanism is operated hydraulically, two mutually independent, power driven pump sets are to be fitted. For propulsion plants up to 200 kW, one power-driven pump set is sufficient provided that, in addition, a hand-operated pump is fitted for controlling the blade pitch and that this enables the blades to be moved from ahead to the astern position in a short enough time.

For all operating conditions the adjusting time between design pitch and maximum astern pitch shall be:

- 22 s maximum for propellers with a diameter D≤3,0 m
- 30 s maximum for propellers with a diameter D>3,0 m

4.2 The lay-out of the hydraulic system shall ensure that the electrically driven pumps are activated in case that:

- the mechanically driven pump fails
- parallel operation with the mechanically driven pump in the lower speed range is required
- short adjustment times are necessary, e.g. at

manoeuvring operation

4.3 Each pump for the control oil has to be designed for an angle velocity for blade adjustment of 2,5° per second. This velocity is valid for:

- operation with the electrically driven pump for the complete speed range

- operation with the mechanically driven pump at nominal speed of the propeller

4.4 For hydraulic pipes and pumps Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8 has to be applied.

5. Pitch control mechanism

For the pitch control mechanism proof is to be furnished that when subjected to impact moments T_M as defined by formula (10) the individual components still have a safety factor of 1,5 relative to the minimum nominal upper yield stress of the materials used.

$$T_M = 1{,}5 \frac{R_{P0,2} \cdot W_{0,6R}}{\sqrt{\left(\frac{0{,}15\,D}{L_M}\right)^2 + 0{,}75}} \qquad (10)$$

$W_{0,6R}$ can be calculated by applying the formula (11).

$$W_{0,6R} = 0{,}11\,(B \cdot t^2)_{0,6R} \qquad (11)$$

The components have to be designed fatigue-resistant for the maximum pressure.

An indication of the blade position must be connected mechanically in a form-fitting way with the propeller blades. The adjustment of the blades shall be realized with a total accuracy from the adjusting device to the blades of ± 0,25°.

6. Indicators

Controllable pitch propeller systems are to be provided with an engine room indicator showing the actual setting of the blades. Further blade position indicators are to be mounted on the bridge and in the machinery control centre (see also Chapter 106 - Automation, Section 4 and Chapter 105 - Electrical Installations, Section 9, B.).

F. Balancing and Testing

1. Balancing

The finished propeller and the blades of controllable pitch propellers are required to undergo static balancing. The mass difference between blades of controllable - or built-up fixed pitch propellers - has to be not more than 1,5 %.

Note

Wherever dynamic balancing is required or seems to be appropriate (e.g. n_2 > 500 rpm, circumferential tip speed > 60 m/s) the standard ISO DIN 1940-1 could be applied analogously.

2. Testing

Fixed pitch propellers and controllable pitch propeller systems are to be presented to TL for final inspection and verification of the dimensions.

TL reserve the right to require non-destructive tests to be conducted to detect surface cracks or casting defects.

With regard to the assessment and removal of imperfections at propellers the TL Rules Material, Section 12 shall be observed.

In addition it is required for controllable pitch propeller systems to undergo pressure, tightness and operational tests.

3. Quality classes of propellers

3.1 The quality of manufacturing and the accuracy of the dimensions of propellers must be adequate to their use. The classes "S" and "I" have to be distinguished.

Propellers have to be manufactured within quality class "S", if requirements concerning water-borne noise are specified in the building specification or if
v_0 > 28 kn.

All other propellers have to be manufactured according to class "I", if not otherwise specified in the building specification.

3.2 The requirements for the quality classes used in 3.1 are given in the international standards ISO 484/1 and 484/2.

G. Rudder Propeller Units

The rated power is transmitted to the propeller via a rotating shaft, vertically to the propeller shaft and a gear situated in an underwater housing. This housing is turnable and therefore the steering effect is achieved by changing the direction of the propeller thrust.

1. General

1.1 Scope

The requirements of G. apply to the rudder propeller as main drive, the ship's manoeuvring station and all transmission elements from the manoeuvring station to the rudder propeller.

1.2 Documents for approval

Assembly and sectional drawings as well as component drawings of the gears and propellers giving all the data necessary for the examination are to be submitted in triplicate to TL for approval.

2. Materials

2.1 Approved materials

The selection of materials is subject, as and where applicable, to the provisions of B. and to those of Section 5, B.1. and Section 6, B.1.

2.2 Testing of materials

All important components of the rudder propeller involved in the transmission of torque and bending moments must be tested under the supervision of TL in accordance with the TL Material Rules.

3. Design and equipment

3.1 Number of rudder propellers

For main propulsion duties by means of rudder propellers at least two units have to be provided. Both units shall be capable of being operated independently of the other. For the design of propellers see C.

3.2 Support pipe and locking devices

The dimensional design of the support pipe and its attachment to the ship's hull shall take account of the loads due to the propeller and nozzle thrust including the dynamic components.

Each rudder propeller is to be provided with a locking device for cases where it is necessary to prevent the unintentional rotation of the propeller or the turning mechanism of the unit which is out of service at any time.

3.3 Control

3.3.1 Both the drive and the turning mechanism of each rudder propeller must be controlled from a manoeuvring station on the navigating bridge.

The controls must be mutually independent and so designed that the rudder propeller cannot be shifted unintentionally.

An additional combined control for all rudder propellers is permitted.

3.3.2 The failure of a single element within the control and hydraulic system of one unit shall not lead to the failure of the other units.

3.3.3 Where the hydraulic systems of more than one rudder propeller are combined, it must be possible in case of a loss of hydraulic oil to isolate the damaged system in such a way that the other control systems remain fully operational.

3.4 Position indicators

3.4.1 The position of each rudder propeller must be displayed on the navigating bridge and at each manoeuvring station.

3.4.2 The actual position must also be indicated at the rudder propeller itself.

3.5 Piping, hydraulic control systems

The pipes of hydraulic control systems are subject to the following provisions:

3.5.1 The pipes are to be made of seamless or longitudinally welded steel tubes. The use of cold-drawn, unannealed tubes is not permitted.

3.5.2 High-pressure hose assemblies may be used for short pipe connections if this is necessary due to vibrations or flexibly mounted units.

3.5.3 The pipes are to be installed in such a way as to ensure maximum protection while remaining readily accessible.

Copper pipes for control lines are to be safeguarded against hardening due to vibration by the use of suitable fastenings.

Pipes are to be installed at a sufficient distance from the ship's shell.

Connections to other hydraulic systems are not permitted.

3.5.4 For arrangement and design of pipes, valves, fittings and pressure vessels, see Chapter 107 – Ship Operation Installations and Auxiliary Systems, Section 16 and Section 8, A., B., C., D., U.

3.6 Oil level indicators, filters

3.6.1 Tanks forming part of the hydraulic system are to be fitted with oil level indicators.

3.6.2 The lowest permissible oil level is to be monitored. Audible and visual alarms shall be given on the navigating bridge and in the machinery space. The alarms on the navigating bridge shall be individual alarms.

3.6.3 Filters for cleaning the operating fluid are to be located in the piping system.

3.7 Lubrication

The lubricating oil supply is to be ensured by a main pump and an independent standby pump.

3.7.2 In the case of a separate lubricating system in which the main lubricating oil pumps can be replaced with the means available on board, complete standby pumps ready for mounting may be carried on board.

3.8 Gears

For the design of gears see Section 6. The turning gears are in general to take the form of spur gears or bevel gears.

4. Tests in the manufacturer's works

4.1 Testing of power units

4.1.1 The power units are required to undergo tests on a test stand in the manufacturer's works.

For diesel engines see Section 3.

For electric motors see Chapter 105 - Electrical Installations, Section 14.

4.1.2 For hydraulic pumps and motors, the TL Guidelines for the Design, Construction and Testing of Pumps, are to be applied analogously. Where the drive power is 50 kW or more, this testing is to be carried out in the presence of a TL Surveyor.

4.2 Pressure and tightness tests

Pressure components are to undergo a pressure test. The test pressure is

$$p_c = 1{,}5 \cdot p \qquad (13)$$

p = is the maximum allowable working pressure [bar] = the pressure at which the relief valves open. However, for working pressures above 200 bar the test pressure need not exceed p + 100 bar

For pressure testing of pipes, their valves and fittings, see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 8.

Tightness tests are to be performed on components to which this is appropriate.

4.3 Final inspection and operational test

4.3.1 After inspection of the individual components and completion of assembly, rudder propellers are to undergo a final inspection and operational test. The final inspection shall be combined with a trial run lasting several hours under part or full-load conditions. The tooth clearance and contact pattern have to be checked.

4.3.2 When no suitable test bed is available for the operational and load testing of large rudder propellers, the tests mentioned in 4.3.1 can be carried out on the occasion of the dock test.

4.3.3 Limitations on the scope of the test require TL's consent.

5. Shipboard trials

5.1 The faultless operation, smooth running and bearing temperatures of the gears and control system are to be checked during the sea trials under all operating conditions.

After the conclusion of the sea trials, the toothing is to be examined through the inspection openings and the contact pattern is to be checked. The tooth contact pattern is to be assessed on the basis of the reference values for the percentage area of contact given in Section 6, Table 6.6.

5.2 The scope of the check on contact pattern following the sea trials may be limited with the Surveyor's agreement provided that the checks on contact pattern called for in 4.3.1 have proved satisfactory.

H. Lateral Thrust Units

1. General

1.1 Scope

The requirements contained in H. apply to the lateral thrust unit, the control station and all the transmission elements from the control station to the lateral thrust unit.

1.2 Documents for approval

Assembly and sectional drawings for lateral thrust units with an input power of 100 kW and more together with detail drawings of the gear mechanism and propellers containing all the data necessary for checking are each to be submitted to TL in triplicate for approval. In the case of propellers, this only applies to propulsive power levels above 500 kW.

2. Materials

Materials are subject, as appropriate, to the provisions of Section 6, B. H. applies analogously to the materials and the material testing of propellers.

3. Dimensioning and design

The dimensional design of the driving mechanisms of lateral thrust units is governed by Section 6, that of the propellers by C.

The pipe connections of hydraulic drive systems are subject to the applicable requirements contained in G.3.5.

Lateral thrust units must be capable of being operated independently of other connected systems.

For the electrical equipment of lateral thrust units, see Chapter 105 - Electrical Installations, Section 7, B.

4. Tests in the manufacturer's works

G.4. is applicable as appropriate.

For hydraulic pumps and motors with a drive power of 100 kW or more, the tests are to be conducted in the presence of a TL Surveyor.

For lateral thrust units with an input power of less than 100 kW final inspection and function tests may be carried out by the manufacturer, who will then issue the relevant test protocol.

5. Shipboard trials

Testing is to be carried out during sea trials during which the operating times are to be established.

6. Casting defects

Propellers shall be free of cracks. The correction of defects has to be executed for copper cast alloys according to the TL Material Rules, Section 12.

I. Water Jet Propulsion Systems

1. Scope

These requirements apply to all devices producing a thrust by jet. This includes pump jets as well as water jets and comparable drives.

2. Design

2.1 The lay-out data have to be coordinated with the manufacturer of the water jet propulsion aggregate. At all operating conditions no cavitation shall occur in the pump which can lead to damage of the components. To achieve this already in the design phase, the manufacturer has to indicate the areas of erosive cavitation danger.

2.2 Requirements for the manoeuvring abilities have to be specified in the building specification.

2.3 If it is not planned to equip all propulsion units of a multi-shaft ship with manoeuvring devices, it has to be ensured in the building specification that all requirements concerning rudder effect, stopping time, survivability and redundancy are defined and can be met.

3. Arrangement

Pump shaft and entrance duct have to be arranged parallel to the longitudinal midship plane of the ship. The pump shaft must be parallel to the waterline in the trimmed condition of the ship. The pump is to be arranged in a height that a quick start of the system is ensured for the minimum draught of the ship

4. Construction requirements

4.1 The pump has to be integrated in the hull structure in a way that the maximum longitudinal and transverse forces occurring during acceleration or crash-stop operation and during manoeuvres with the jet in the maximum steering position are safely withstood.

Detachable connections to the ship's hull shall enable an easy installation and dismounting of the pump unit.

4.2 The form of the entrance duct has to be coordinated with the manufacturer of the water jet unit. The stream towards the pump has to be continuous and cavitation shall be avoided in the complete inlet area. The entrance duct has to be arranged to exclude the possibility of air ingress.

4.3 To protect the pump from flotsam a protection grid has to be arranged at a suitable location of the entrance duct. Before this grid an inspection port has to be provided. It must be possible to open this port and have access to it at floating ship. It shall be possible to clean the intake protection grid by reversing the flow direction.

5. Manoeuvring facilities

5.1 Steering nozzle

The adjusting angle of the steering nozzle shall reach 30° to each side. If no time for adjusting is defined in the building specification a value less than 8 s has to be assumed for the complete range of 60°.

5.2 Thrust reversing device

If no time for adjusting is defined in the building specification a value of not more than 10 s has to be assumed for the adjusting from "full ahead" to "full astern". The neutral position of the thrust reversing system (zero thrust position) has to be marked at the control device.

6. Hydraulic system

6.1 In case of multi-shaft propulsion each propulsion unit has to be equipped with its own, independently working hydraulic system.

6.2 Control oil pumps

The lay-out of the control oil pumps shall follow E.4.

J. Special Forms of Propulsion Systems

1. General

1.1 The investigation for a propulsion system most suitable for an actual naval ship should include special forms of propulsion. Lay-out and arrangement of these propulsion systems have to be coordinated closely with the manufacturer of the system.

1.2 Requirements for design and manufacturing have to be specified in the building specification. Concerning strength and model tests the rules for propellers have to be applied accordingly. Model tests have to be performed in order to proof the reliability and check special performance characteristics.

1.3 In the following the design characteristics of several propulsion systems are defined. The scope does not fulfill the demand for entirety.

2. Cycloidal propellers

2.1 Cycloidal propellers are propulsion devices with blades rotating around a vertical axis and are able to change the thrust in size and direction.

2.2 If low noise emission is required, the following principles should be observed:

- the size of the device with a minimum circumferential speed of the wheel body at the nominal acoustic layout point has to be chosen
- an operation mode has to be used where the adjustment of the thrust is achieved by adjusting the number of revolutions
- the arrangement in the hull shall enable a distance to the sonar system which is as big as possible (stern arrangement)
- for the reduction of the intake speed a low-noise gear has to be provided
- the connection of the housing to the ship foundation shall be established by an elastic mounting. The foundation as part of the hull structure shall be of appropriate stiffness
- the surface of the wheel body at the same level as the ship's bottom has to be coated with antidrumming material

2.3 If a low magnetic signature is required, a high content of non-magnetizable materials has to be provided, for reference see Chapter 103 - Special Materials for Naval Ships.

3. Supercavitating propellers

The blades of supercavitating propellers are to be designed to achieve a stable cavitation layer over the complete blade surface at the nominal layout point. Lay-out and design have to observe the foreseen operation characteristics and the demanded reversing and steering ability.

4. Partially submerged propellers

Partially submerged propellers are designed for an arrangement at the ship where the propeller blades break through the water surface.

Because of the high transverse forces this type of propulsion is only applicable for multi-shaft propulsion systems. The degree of submerging has to be chosen to achieve a stable ventilation at the suction side.

5. Podded Drives

5.1 Scope

The propulsion power for this type of drive will be created by an electric motor in the underwater gondola of the drive and directly transmitted to one or two propellers at the gondola ends. The underwater part of the system is turnable in a similar way as foreseen for rudder propellers and therefore a steering effect with full propulsion power can be achieved.

5.2 Structural measures

The space where the podded drive is connected to the ship's hull has to be surrounded by longitudinal and transverse watertight bulkheads. The thickness of the shell has to be increased locally.

As podded drives are of novel design direct calculations of the scantlings have to be submitted to TL.

5.3 Requirements for the components

If the podded drives shall be subject to classification its components must fulfil the requirements of the already existing TL Rules, such as:

- Electrical installation: see Chapter 105 Electrical Installations, Section 13

- Gears, couplings: see Section 6

- Shafting: see Section 5

- Propeller: see A., B., C., D.

- Turning mechanism: analogous to rudder propeller units, see G.

- Hydraulics: see Chapter 107 - Ship Operation Installations and Auxiliary Systems, Section 14.

- Sensor and control system, including excess temperatures, oil levels, leakage indications, unpermissible vibrations, etc., see Chapter 106 -Automation, Section 11

- Any other relevant requirement

K. Dynamic Positioning Systems (DK Systems)

1. General

1.1 Scope

The complete installation necessary for positioning a ship dynamically comprises the sub-systems:

- Power system

- Thruster system and

- Control system

1.2 Position keeping

Position keeping means maintaining a desired position within the normal excursions of the control system and under the defined environmental conditions.

2. Requirements for Class Notations

2.1 Reliability

A DK system consists of components and systems acting together to achieve sufficient reliable position keeping capability. The necessary reliability is determined by the consequence of a loss of position keeping capability. The larger the consequence, the more reliable the DK system shall be.

Consequently the requirements have been grouped into three Class Notations. For each Class Notation the associated single failure criteria shall be defined.

The Class Notation of the ship required for a particular operation is based on a risk analysis of the consequence of a loss of position.

2.2 Class Notations

2.2.1 For Class Notation **DK 1**, loss of position may occur in the event of a single fault.

2.2.2 For Class Notation **DK 2**, a loss of position may not occur in the event of a single fault in any active component or system. Static components will not be considered to fail where adequate protection from damage is demonstrated and reliability is to the satisfaction of TL. Single failure criteria apply to:

- any active component or system, e.g. generators, thrusters, switchboards, remote controlled valves, etc.

- any static component, e.g. cables, pipes, manual valves, etc. which is not properly documented with respect to protection and reliability

2.2.3 For Class Notation **DK 3**, a single failure applies to:

- items listed above for Class Notation **DK 2**, additionally any normally static component is assumed to fail

- all components in any one watertight compartment, caused by fire or flooding

- all components in any one fire sub-division, caused by fire or flooding

2.2.4 For Class Notations **DK 2** and **DK 3**, a single inadvertent action shall be considered as a single fault, if such an action is reasonably probable.

2.2.5 The requirements for the DK system arrangement for the different Class Notations are shown in Table 7.3.

2.3 Worst case failure

Based on the single failure definitions the worst case failure shall be determined and used as criterion for the consequence analysis.

2.4 Documents for approval

The documents and drawings specified below are to be submitted for approval at least in triplicate. Operation and maintenance manuals may be submitted in a single set:

- General description of the system

- Documentation for control, safety and alarm systems including test program

- Thruster documentation

- Electric power system documentation

2.5 Failure Mode and Effect Analysis (FMEA) / Redundancy test

Documentation concerning reliability and availability of the DK system shall be provided for the Class Notations **DK 2** and **DK 3** by means of a Failure Mode and Effect Analysis (FMEA). As an alternative to a FMEA the redundancy may be documented in a redundancy test procedure which is to be verified during sea trials.

3. Functional requirements

3.1 All components in a DK system shall be designed, constructed and tested in accordance with TL accepted rules and standards.

3.2 In order to meet the single failure criteria redundancy of components will normally be necessary as follows:

- for Class Notation **DK 2**, redundancy of all active components

- for Class Notation **DK 3**, redundancy of all components and physical separation of the components

3.3 For Class Notation **DK 3**, full redundancy may not always be possible (e.g., there may be a need for a single change-over system from the main computer system to the back-up computer system). Non-redundant connections between usually redundant and separated systems may be accepted, provided that it is shown to give clear safety advantages, and that their reliability can be demonstrated and documented to the satisfaction of TL. Such connections shall be kept to a minimum and made to fail to the safest condition. Failure in one system shall in no case be transferred to the other redundant system.

3.4 Redundant components and systems shall be immediately available and with such capacity that the DK operation can be continued for such a period that the work in progress can be terminated safely. The transfer to the redundant component or system shall be automatic as far as possible, and operator intervention shall be kept to a minimum. The transfer shall be smooth and within acceptable limitations of the operation.

4. Tests

4.1 Factory acceptance test (FAT)

Before a new installation is surveyed and tested as specified in B. factory acceptance tests shall be carried out at the manufacturer's work. These tests are to be based on the approved program.

4.2 Initial survey

The initial survey shall include a complete survey of the DK system to ensure full compliance with the applicable parts of the Rules:

- verification of redundancy and independence (Class Notations **DK 2** and **DK 3**)
- testing of the alarm system and switching logic of the measuring system (sensor, peripheral equipment and reference system)
- functional tests of control and alarm systems of each thruster
- tests of the electrical installations according to the requirements of Rules
- tests of the remote thrust control
- tests of the complete DK system (all operational modes, back-up system, alarm system and manual override)

The initial survey includes a complete test of all systems and components and of the ability of the ship to keep position after single failures associated with the assigned Class Notation.

5. Further details

Further details concerning dynamic positioning are defined in the TL Rules for Classification and Construction, Chapter 22 - Dynamic Positioning Systems.

L. Cavitation Noise of Propellers

Fig. 7.2 shows the probable and unprobable ranges for cavitation depending on the thrust load coefficient.

Cavitation inception number:

$$SIGMA_n = \frac{p_S - p_V}{0{,}5 \cdot \rho \cdot (\pi \cdot D \cdot n_2/60)^2}$$

D has to be inserted in metres

Thrust load coefficient:

$$C_{Th} = \frac{T}{0{,}5 \cdot \rho \cdot v_A^2 \cdot A_D}$$

Table 7.3 DK system arrangement

Subsystem or component		Minimum requirements for Class Notation DK0	DK1	DK 2	DK 3
Power system	Generators and prime mover	---		redundant	redundant, separate compartments
Power system	Main switchboard	1		2	2 in separate compartments
Power system	Bus-tie breaker	---		2 NO[1]	2 NO
Power system	Distribution system	---		redundant	redundant, through separate compartments
Power system	Power management	---		redundant	redundant, separate compartments
Power system	UPS for DP control system	---	1	2	2 + 1 in separate compartments
Thruster system	Arrangement of thrusters	---		redundant	redundant, separate compartments, provided WFC is not exceeded
DP relevant auxiliary systems		---		redundant[2]	redundant, separate compartments
DK-Control system	no. of computer systems	1		2	2+1 in separate compartments
DK-Control system	independent joystick with auto heading	---	1	1	1
Sensors	Position reference systems	1	2	3	3 whereof 1 connected to back-up control system
Sensors	Vessel's sensors – Wind	1		2	2 (one of each connected to back-up control system)
Sensors	Vessel's sensors – VRS	1		2	2
Sensors	Vessel's sensors – Gyro	1		3	3
Essential non-DK systems[3]		---		redundant	redundant, separate compartments
Printer		yes		yes	yes

[1] NC bus-tie breakers may be accepted depending on the findings of the FMEA and additional testing (NO = nominally open, NC = nominally closed)

[2] when active components are used

[3] see TL Rules Chapter 22 – Dynamic Positioning Systems, Section 2, B.6. for essential non-DP systems

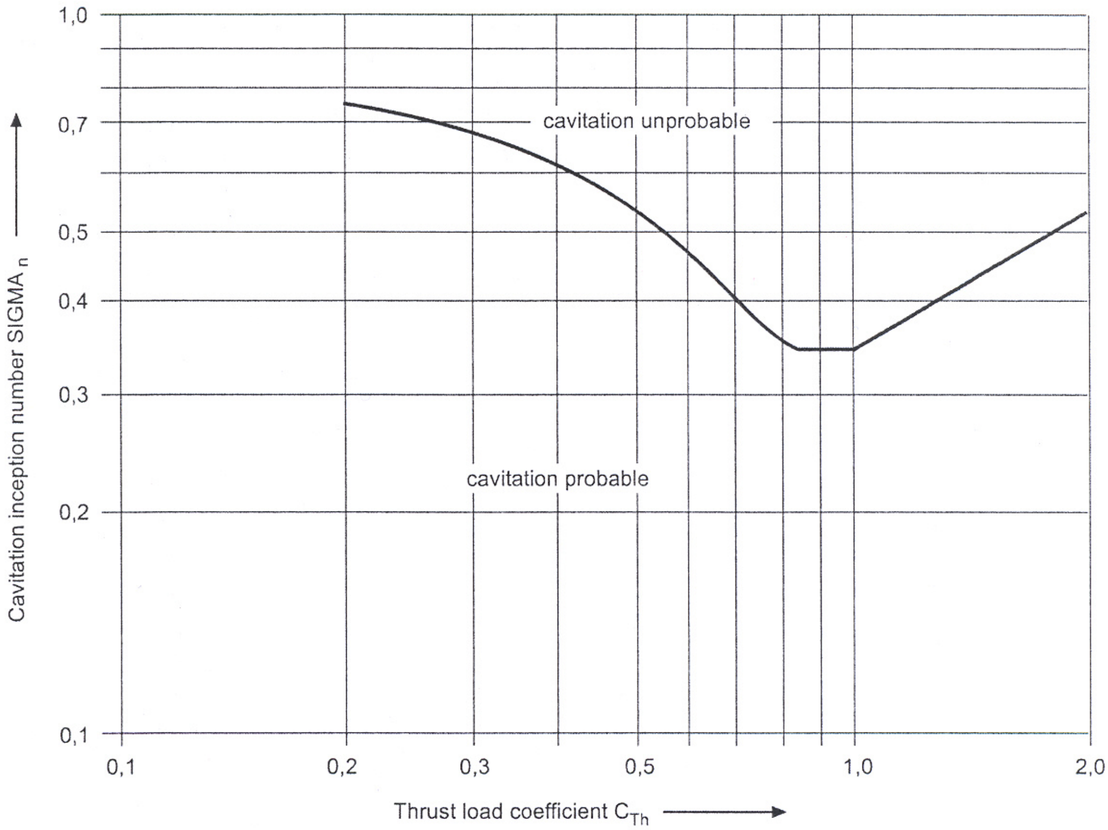


Fig. 7.2 SIGMA$_n$ - C$_{Th}$ - diagram for cavitation noise of propellers

SECTION 8

TORSIONAL VIBRATIONS

Page

A. General

1. Scope

The requirements of this Section apply to the components of the main shafting system and to essential equipment, compare Section 1, B.4.

2. Definitions

2.1 For the purposes of these Rules, torsional vibration stresses are additional loads due to torsional vibrations. They result from the alternating torque which is superimposed on the mean torque.

2.2 The speed range in which the plant can be operated continuously is the service speed range. It covers the range between n_{min} (minimum speed) and 1,05 n_N (nominal speed).

B. Calculation of Torsional Vibrations

1. A torsional vibration analysis covering the torsional vibration stresses is to be submitted to TL for examination. The following data shall be included in the analysis:

- Equivalent dynamic system comprising individual masses and inertialess torsional elasticities

- Prime mover

  engine design (in line, V-type, etc.)

  rated power, rated speed

  number of cylinders, firing order

  cylinder diameter, stroke

  stroke to connecting rod ratio oscillating weight of one crank gear

- Vibration dampers, damping data

- Coupling, dynamic characteristics and damping data

- Gearing data

- Shaft diameter of crankshafts, intermediate shafts, gear shafts, thrust shafts and propeller shafts

- Propellers

  diameter, number of blades

  pitch and expanded area ratio

- Natural frequencies with their relevant vibration forms and the vector sums for the harmonics of the engine excitation

- Estimated torsional vibration stresses in all important elements of the system within the service speed range

2. The calculations are to be performed both for normal operation and for deviations from normal operation due to irregularities in ignition. In this respect, the calculations are to assume operation with one cylinder without ignition.

3. Where the arrangement of the installation allows various operation modes, the torsional vibration characteristics are to be investigated for all possible modes, e.g. in installations fitted with controllable pitch propellers for zero and full pitch, with power take off for loaded and idling condition of the generator unit, with clutches for engaged and disengaged branches.

4. The calculation of torsional vibrations shall also take account of the stresses resulting from the superimposition of several harmonics in so far as this has a bearing on the assessment of the system.

5. If modifications are introduced into the system which have a substantial effect on the torsional vibration characteristics, the calculation of the torsional vibrations is to be repeated and submitted for checking.

6. Where an electrical machine, e.g. static converter controlled motors, can generate periodic excitation leading to relevant torsional vibration stresses in the system as a whole, this is to be taken into account in the calculation of the forced torsional vibration. The manufacturer of the electrical machine is responsible for defining the excitation spectrum in a suitable manner for performing forced torsional vibration calculations.

C. Permissible Torsional Vibration Stresses

1. Shafting

1.1 The alternating torsional vibration stresses are judged against the limits τ_1 and τ_2. The limit τ_1 shall not be exceeded for continuous operation within the service speed range. For seldom occurring events within the service speed range or under transient conditions (starting up and stopping the engine) the limit τ_2 shall not be exceeded.

Fig. 8.1 indicates the τ_1 and τ_2 limits for intermediate and propeller shafts of common design and for the location deemed to be most severely stressed (c_K = 0,55 or c_K = 0,45 for propeller shafts, and c_K = 1,0 and c_K = 0,8 for intermediate shafts). The limits depend on the design and the location considered and may in particular cases lie outside the indicated ranges according to Fig. 8.1. They are to be determined in accordance with the following equations and Table 8.1.

$$\tau_1 = \pm c_W \cdot c_K \cdot c_D \cdot (3 - 2 \cdot \lambda^2) \quad [N/mm^2] \quad (1)$$

where $\lambda < 0,9$

$$\tau_1 = \pm c_W \cdot c_K \cdot c_D \cdot 1,38 \quad [N/mm^2] \quad (2)$$

where $0,9 \le \lambda \le 1,05$

$$\tau_2 = \pm 1,7 \cdot 6,0 \cdot \tau_1 / \sqrt{c_K \cdot c_W} \quad [N/mm^2] \quad (3)$$

d = Shaft diameter, [mm]

λ = Speed ratio [-] = n/n_o

n = Speed, [min^{-1}]

n_o = Nominal speed, [min^{-1}]

R_m = Tensile strength of shaft material, [N/mm^2]

c_W = Material factor. [-]

$$= \frac{R_m + 160}{18} \quad (4)$$

For materials with a tensile strength R_m of less than 450 N/mm^2, a material factor c_W of 33,9 is to be applied.

In the case of suitable shaft materials with a higher tensile strength and a high forging factor, subject to the arrangement of TL a higher tensile strength up to R_m= 800 N/mm^2 may, can be used in formula (4) for the calculation of c_W.

c_D = size factor [-]

= $0,35+0,93 \cdot d^{-0.2}$

c_K = Form factor [-]

For intermediate and propeller shafts determined by the type and design of the shafting and connection elements. The value of c_K is shown in Table 8.1

1.2 In the speed range $0,9 \le \lambda \le 1,05$ the alternating torques in the shafting systems of rigidly coupled plants (without gear box and elastic coupling) may not exceed 75 % of the mean full-load torque transmitted by the shafting.

With the consent of TL, 90 % of the mean torque may be permitted provided that the torque is only transmitted by frictional connection.

For plants with gear boxes 3.4 applies analogously.

2. Crankshafts

2.1 Crankshafts have to be designed according to TL Rules - Guidelines for the Calculation of Crankshafts for I.C. Engines. The maximum alternating torsional load on which this calculation is based shall not be exceeded in any operating state within the service speed range.

Table 8.1 Form factors c_K for intermediate and propeller shafts

c_K	Shaft type
1,00	Intermediate shafts with integrally forged flanges and/or oil-press-mounted couplings
0,80	Intermediate shafts with keyed mountings
	Propeller shafts in the forward **(1)** propeller shaft area
0,50	Intermediate shafts with transverse holes
0,40	Intermediate shafts with through slots
0,55	Propeller shafts with integrally forged flanges in the after **(2)** propeller shaft area
0,55	Propeller shafts with a propeller mounted by a method approved by TL in the aft **(2)** propeller shaft area
0,45	Propeller shafts with tapered and keyed mountings and oil lubrication in the stern tube in the aft **(2)** propeller shaft area
0,40	Propeller shafts with grease lubrication in the stern tube in the aft **(2)** propeller shaft area

The part of propeller shafts outside the stern tube (the engine room area) is subject to the same c_K factors as the intermediate shaft.

(1) *The forward propeller shaft area is the area inside the stern tube adjoining and lying forward of the after bearing position. In constructions with shaft bossings, the forward are is that adjoining and lying forward of the position of the after bossing bearing.*

(2) *The aft propeller area is the area inside the stern tube extending from the after stern tube bearing to the forward supporting edge of the propeller hub. In constructions with shafts bossings, it is the area between the after bossing bearing and the forward supporting edge of the propeller hub. The aft propeller shaft area shall have an axial extent of at least 2,5 · d.*

2.2 Torsional vibration dampers used to reduce the stresses in the crankshaft must be suitable for use with diesel engines. TL reserve the right to call for proof of this.

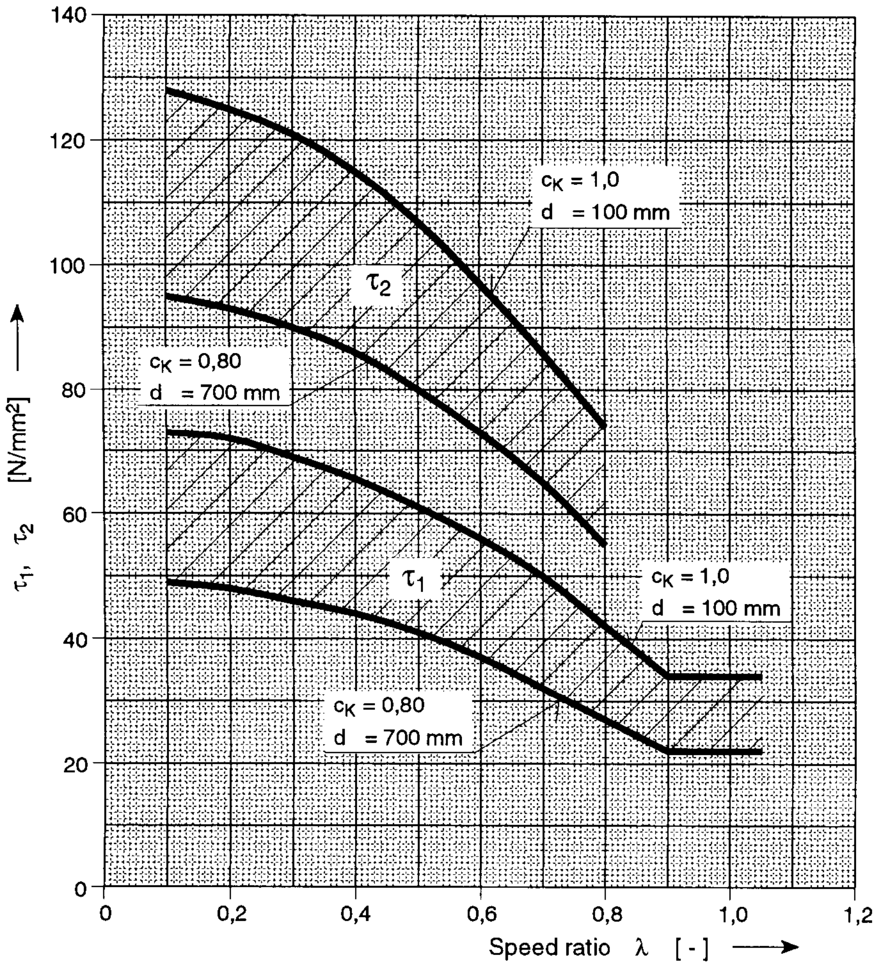
Torsional vibration dampers shall be capable of being checked for serviceability in the assembled condition or shall be capable of being dismantled with reasonable ease for checking.

3. Gears

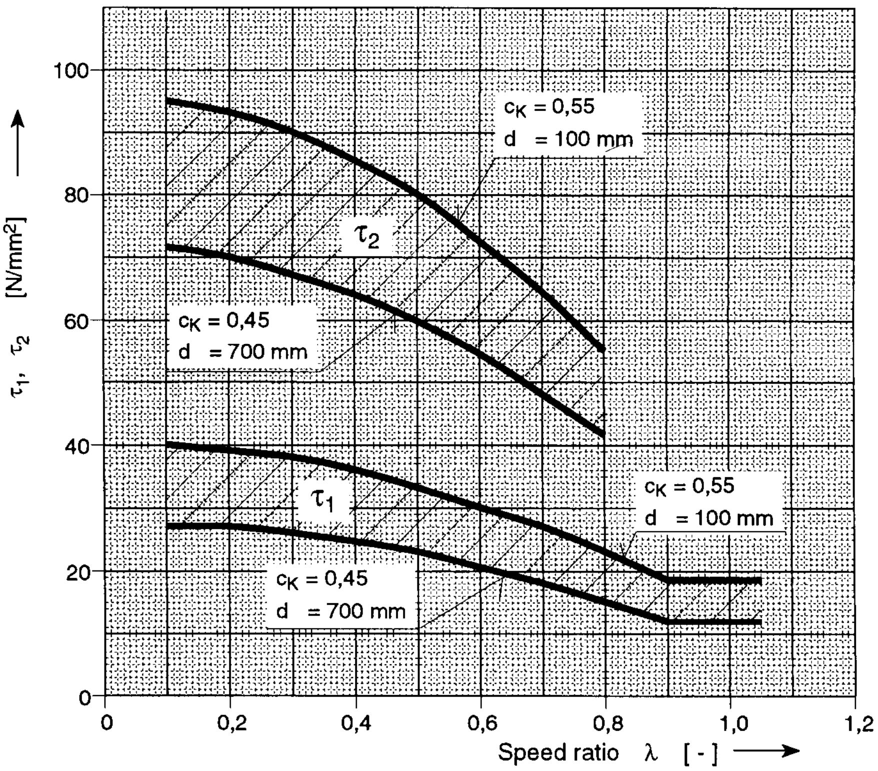
3.1 In the service speed range 0,9 ≤ λ ≤ 1,05, no alternating torque higher than 30 % of the mean torque at nominal speed should normally occur in any gear stage. The mean nominal torque is the value of the maximum mean torque transmitted by the gear stage.

If the gearing is demonstrably designed for a higher power, then, in agreement with TL, 30 % of the design torque of the gear stage concerned may be taken as the limit. Otherwise, the reference values for the permissible bending stresses at the tooth root and for the tooth flank (Hertzian) pressures are to be reduced accordingly.

3.2 The gearing must be capable to take the higher alternating torque, which can occur during deviation from normal operation according to B.2., during continuous operation within the service speed range.



Intermediate shafts



Propeller shafts

Fig. 8.1 Permissible torsional vibration stresses in shafting systems is accordance with formulas (1)-(3) for shaft materials with a tensile strength of 450 N/mm^2

3.3 The alternating torque in the gear at resonant speeds during starting up or stopping the engine may not exceed twice the nominal mean torque for which the gear has been designed.

3.4 Gear hammering due to alternating torque is normally permitted only while passing through the lower speed range of up to $\lambda \leq 0{,}35$.

This rule does not apply to gear stages which run without load, e.g. the idling stage of a reversing gear or the idling gears of an unloaded shaft-driven generator. These are covered by the provisions of 3.5.

3.5 In installations where parts of the gear train run without load, the torsional vibration torque in continuous operation should not exceed 20 % of the nominal torque in order to avoid unacceptable stresses due to gear hammering. This applies not only to gear stages but also to parts which are particularly subject to torsional vibrations, e.g. multiple-disc clutch mountings. The loaded parts of the gear system are subject to the provisions of 3.1.

Higher alternating torques may be approved by TL if proof is submitted to TL that measures have been taken and the design takes into account these higher loadings see 3.1.

3.6 Gear hammering due to alternating torque and the resulting impact reaction shall not conflict with any requirements regarding mechanical vibrations.

4. Flexible couplings

4.1 Flexible couplings must be designed to with stand the torsional vibration loads which occur in the operation of the ship. In this context, the total load resulting, in accordance with B.4., from the superim position of several orders is to be taken into account, see also Section 6.

4.2 Flexible couplings must be capable to take in higher alternating torque which can occur during deviation from normal operation according to B.2, during continuous operation within the service speed range.

5. Shaft-driven generators

5.1 In installations with generators directly coupled to the engine (free crankshaft end) it is necessary to ensure that the accelerations do not exceed the values prescribed by the manufacturer in any part of the generator.

The crucial criterion is the tangential acceleration, which is the product of the angular acceleration and the effective radius. The angular acceleration is determined by means of forced torsional vibrations calculations and is to be regarded as the synthesised value of all major orders. However, for marked points of resonance the value of the individual harmonics may be used instead as the basis for assessment.

5.2 The torsional vibration amplitude (angle) of shaft-driven generators shall not normally exceed an electrical value of ±5°. The electrical vibration amplitude is obtained by multiplying the torsional vibration amplitude by the number of pole pairs. Whether TL is able to permit higher values depends on the configuration of the ship's electrical system.

6. Connected units

6.1 If further units, e.g. power turbines or compressors, are coupled positively or non-positively to the main propulsion system, due attention is to be paid to these when establishing the torsional vibration loadings.

In the assessment of their dynamic loads, the limits laid down by the respective manufacturers are to be considered in addition to the factors mentioned in 1. If these limits are exceeded, the units concerned are to be disengaged. Disengaging of these units shall in general not lead to an overload of the main system.

6.2 In particularly critical cases, the calculations of forced torsional vibrations, also for disturbed operation (uncoupled set), as stated in B.1. are to be submitted to TL. In such cases TL reserve the right to stipulate the performance of confirmatory measurements, see D., also for disturbed operation.

D. Torsional Vibration Measurements

1. During the ship's sea trials, the torsional vibrations of the propulsion plant are to be measured over the whole operating range. Where measurements of identical propulsion plants are available, subject to TL agreement, further torsional vibration measurements may be dispensed with.

2. Where existing propulsion plants are modified, TL reserve the right to require a renewed investigation of the torsional vibration characteristics.

E. Prohibited Ranges of Operation

1. In general, no operational restrictions are allowed within the service speed range.

2. For special operational conditions, e.g. ignition irregularities, restrictions from the engine manufacturer are to be observed and to be displayed on instruction plates, which are to be affixed to all engine control stations.

F. Auxiliary Machinery

1. Essential auxiliary machinery must be designed in a way that the service speed range is free of unacceptable stresses due to torsional vibrations in accordance with C.

2. Generators

2.1 For diesel generator sets with a mechanical output of more than 150 kW torsional vibration calculations must be submitted to TL for approval. They must contain natural frequencies as well as forced vibration calculations. The speed range 90 % to 105 % of the nominal speed must be investigated under full load conditions (nominal excitation).

2.2 For rigidly coupled generators (without elastic coupling) the alternating torque in the input part of the generator's shaft must not exceed 250 % of the nominal torque.

It has to be proved that this limit can be kept within the speed range 90 % to 105 % of the nominal speed.

Exceeding the limit of 250 % may be considered in exceptional cases, provided that the generator's manufacturer has designed the generator for a higher dynamical torque.

3. Bow thruster

3.1 For bow thrusters as well as for other essential auxiliary machinery driven by diesel engines with a mechanical output higher than 150 kW, natural as well as forced torsional vibration calculations must be submitted to TL for approval. The torsional vibration calculation must focus on the real load profile of the set.

3.2 For bow thrusters as well as for other essantial auxiliary machinery driven by electrical motors the manufacturer must ensure that relevant excitation forces, e.g. propeller blade frequency, may not lead to unacceptable torsional vibration stresses within the set. In special cases TL may require the submission of relevant calculations.

SECTION 9

MACHINERY FOR SHIPS WITH ICE CLASSES

Page

A. General

1. Notation B affixed to the Character of Classification

The machinery of naval ships strengthened for navigation in drift ice in the mouth of rivers and in coastal regions is designated after the Character of Classification by the additional Notation **B**, provided that the rules in B. are satisfied.

2. Measures for other conditions of navigation in ice

Measures for conditions of navigation in ice, different from the conditions relevant for 1. will be defined by TL case by case.

If other Class Notations are required by the Naval Authority see TL Rules Chapter 4 - Machinery Installations, Section 13.

B. Requirements for Notation B

1. Necessary Propulsion Power

The rated output of the main engines in accordance with Section 3, A.3. must be such to cover the power demand of the propulsion plant for the ice class contitions under consideration and for continuous service.

2. Necessary reinforcements

2.1 Propeller shafts, intermediate shafts, thrust shafts

2.1.1 General

The necessary propeller shaft reinforcements in accordance with formula (1), in conjunction with the formulae and factors specified in Section 5, C.3., apply to the area of the aft stern tube bearing or shaft bracket bearing from the forward end of the propeller cone or the aft propeller shaft flange and up to a minimum axial distance of 2,5 · d.

The diameter of the adjoining part of the propeller shaft (beyond 2,5 d) but still within the stern tube may be designed by applying an ice class reinforcement factor reduced by 15 % as calculated by formula (2).

2.1.2 Reinforcements

$$d_E = C_{EW} \cdot d \qquad (1)$$

= increased diameter of propeller, intermediate or thrust shaft [mm]

d = Shaft diameter according to Section 5, C.3. [mm]

C_{EW} = Ice class strengthening factor, [-]

$$C_{EW} = c \cdot \sqrt[3]{1 + \frac{85 \cdot m}{P_W^{0,6} \cdot n_2^{0,2}}} \geq 1,0 \qquad (2)$$

P_W = Main engine power, [kW]

n_2 = Propeller shaft speed in rev/min, [min^{-1}]

m = Ice class factor, [-]

= 8

c = 0,7 for shrink fits in gears, [-]

= 0,71 for the propeller shafts of fixed-pitch propellers,

= 0,78 for the propeller shafts of controllable pitch propellers

= 0,6 for intermediate and thrust shafts

In the case of ducted propellers, the values of c can be reduced by 10 %.

2.2 Coupling bolts, shrunk joints

When designing shrink fits in the shafting system and in gearboxes, the necessary pressure per unit area p_E [N/mm^2] is to be calculated in accordance with the following formula (3).

$$p_E = \frac{\sqrt{\theta^2 \cdot T^2 + f \cdot (c_A^2 \cdot c_e^6 \cdot Q^2 + T^2)} \pm \theta \cdot T}{A \cdot f} \qquad (3)$$

+ sign following the root applies to conical shrink joint without an axial stop to absorb astern thrust.

- sign following the root if the conical shrink joint has an axial stop to absorb astern trust.

c_A = see Section 5

$$c_e = 0{,}89 \cdot C_{EW} \geq 1{,}0 \qquad (4)$$

C_{EW}, c_e = ice class reinforcement factors in accordance with formula (2) or (4) as applicable [-]

Other symbols in accordance with Section 5, D.4.

2.3 Propellers

2.3.1 General

The propellers of ships with ice class **B** must be made of the cast copper alloys or cast steel alloys specified in Section 7.

2.3.2 Strengthening

2.3.2.1 Blade sections

t = blade section thickness in accordance with Section 7, C.3 [mm]

t_E = Increased thickness of blade section, [mm]

$$= t \text{ if } C_{EP} \leq C_{Dyn}$$

$$= \frac{C_{EP}}{C_{Dyn}} \cdot t \quad \text{if} \quad C_{EP} > C_{Dyn}$$

C_{EP} = Ice class strengthening factor, [-]

$$C_{EP} = f \cdot \sqrt{1 + \frac{21 \cdot z \cdot m}{P_w^{0,6} \cdot n_2^{0,2}}} \geq 1{,}0 \qquad (6)$$

= 0,62 for solid propellers

= 0,72 for controllable pitch propellers

z = Number of blades, [-]

C_{Dyn} = Dynamic factor [-] in accordance with Section 7, formula (3).

Other terms in the formula same as for formula (2).

2.3.2.2 Blade tips

(7)

$$t_{1,0E} = \sqrt{\frac{500}{C_W}} \cdot (0{,}002 \cdot D + t')$$

$t_{1,0E}$ = Strengthened blade tip, [mm]

t' = Increase in thickness, [mm]

= 10 for ice class **B**

D = Propeller diameter, [mm]

C_w = Material factor [N/mm^2] in accordance with Section 7, C.2, Table 7.1.

2.3.2.3 Leading and trailing edges

For ice class **B** the thickness of the leading and trailing edges of solid propellers and the thickness of the leading edge of controllable pitch propellers must be equal to at least 35 % of the blade tip $t_{1,0E}$ when measured at a distance of 1,25 · $t_{1,0E}$ from the edge of the blade.

2.3.2.4 Propeller mounting

Where the propeller is mounted on the propeller shaft by the oil injection method, the necessary pressure per unit area p_E [N/mm^2] in the area of the mean taper diameter is to be determined by formula (8).

$$p_E = \frac{\sqrt{\theta^2 \cdot T^2 + f \cdot (c_A^2 \cdot c_e^6 \cdot Q^2 + T^2)} \pm \theta \cdot T}{A \cdot f} \qquad (8)$$

c_e = ice class reinforcement factor [-] in accordance with formula (4)

Other symbols in accordance with Section 7, D.1.2.

In the case of flanged propellers, the required diameter d_{sE} of the fitting bolts is to be determined by applying formula (9).

$$d_{sE} = C_{EW}^{1,5} \cdot d_s \qquad (9)$$

d_{sE} = reinforced root diameter of fitting bolts [mm]

d_s = diameter of fitting bolts for attaching the propeller [mm] in accordance with Section 5, D.4.3.

C_{EW} = ice class reinforcement factor in accordance with formula (2) [-]

3. Flexible couplings

Flexible couplings in the main propulsion installation must be so designed that, given the load on the coupling due to torsional vibrations at $T_{nominal}$ are able to withstand safely brief torque shocks T_E [Nm] of magnitude:

$$T_E = K_E \cdot T_{nominal} \qquad (10)$$

$T_{nominal}$ = nominal torque moment of the coupling [Nm]

K_E = ice class strengthening factor [-]

c_1 = 17,5 for the gears of engine plants

= 30 for the gears of turbine plants

4. Sea chests and discharge valves

Sea chests and discharge valves are to be designed in accordance with Chapter 107-Ship Operation Installations and Auxiliary Systems, Section 8.

5. Steering gear

The dimensional design of steering gear components is to take account of the rudderstock diameter specified in Chapter 102 - Hull Structures and Ship Equipment, Section 12.

6. Electric propeller drive

Where electric propeller drives are used, the conditions set out in Chapter 105 - Electrical Installations, Section 13 must be fulfilled.

SECTION 10

SPARE PARTS

A. General

1. In order to be able to restore engine operation and manoeuvring capacity to the ship in the event of damage at sea spare parts for the main drive and the essential equipment (see Section 1, B.4.) are to be carried on board every ship, together with the necessary tools.

These requirements are considered to be complied with if the range of spare parts corresponds to the following Tables considering the extent of the actually installed systems and components at the time of commissioning.

2. Depending on the design and arrangement of the engine plant, the intended service and operation of the ship, and also the manufacturer's recommendations, a different volume of spare parts may be agreed between the Naval Authority and TL.

Where the volume of spare parts is based on special arrangements between the Naval Authority and TL, technical documentation is to be provided.

A list of the relevant spare parts is to be carried on board.

3. In the case of propulsion systems and essential equipment which are not included in the following tables, the requisite range of spare parts is to be established in each individual case between Naval Authority, shipyard and TL.

B. Volume of Spare Parts

The volume of spare parts has to be in accordance with the following Tables.

A = Unlimited range of service and **Y**
B = All other ranges of service
Explanations:

Restricted International Service – Y

This range of service is limited, in general, to operate along the coast, provided that the distance to the nearest port of refuge and the offshore distance do not exceed 200 nautical miles. This applies also to operation in the North Sea and within enclosed seas, such as the Mediterranean Sea, the Black Sea, the Caspian Sea and waters with similar seaway conditions.

Coastal Service - K50/K20

This range of service is limited, in general, to operate along the coasts, provided that the distance to the nearest port of refuge and the offshore distance do not exceed 50/20 nautical miles. This applies also to operation within enclosed seas, such as the Baltic Sea, Marmara Sea and gulfs with similar seaway conditions.

Coastal Service – K6

This range of service is limited to operate along the coasts, provided that the distance to the nearest port of refuge and the offshore distance do not exceed 6 nautical miles. This area of service is restricted to operate in shoals, bays, haffs and firths or similar waters, where heavy seas do not occur.

1. Internal combustion engines

For internal combustion engines, see Section 3, the volume of spare parts is defined in Tables 10.1 to 10.3.

2. Gears and thrust bearings

For gears and thrust bearings, see Section 6, the volume of spare parts is defined in Table 10.4.

3. Other spare parts

For other spare parts for main and auxiliary engines the volume is defined in Table 10.5.

Table 10.1 Spare parts for main engines (1), (4), (5)

Range of spare parts		A	B
Main bearings	Main bearings or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1	
Main thrust block (integral)	Pads for "ahead" face of Michell type thrust block, or complete white metal thrust shoe of solid ring type	1 set	1 set
		1	1
Connecting rod bearings	Bottom end bearings or shells of each size and type fitted, complete with shims, bolts and nuts, for one cylinders	1 set	-
	Trunk piston type: Gudgeon pin complete with bush/bearing shells and securing rings for one cylinder	1 set	-
Cylinder liner	Cylinder liner, complete with joint rings and gaskets	1	-
Cylinder cover	Cylinder cover with full equipment and ready for installation, including gaskets	1	-
	Cylinder cover bolts and nuts, for one cylinder	¼ set	-
Valves	Exhaust valves, with full equipment and ready for installation, for one cylinder	1 set	1 set
	Inlet valves, with full equipment and ready for installation, for one cylinder	1 set	1 set
	Starting air valve, with full equipment and ready for installation	1	1
	Overpressure control valve, complete	1	1
	Fuel injection valves of each type, ready for installation, for one engine **(2)**	1 set	¼ set
Hydraulic valve drive	High-pressure pipe/hose of each type	1	-
Piston: Trunk piston type	Piston of each type, ready for fitting, with piston rings, gudgeon pin, connecting rod, bolts and nuts	1	-
Piston rings	Piston rings for one cylinder	1 set	-
Piston cooling	Telescopic cooling pipes and fittings or their equivalent for one cylinder unit	1 set	-
Cylinder lubricator	Complete lubricator, largest type, with drive	1	-
Fuel injection pumps	Fuel injection pump complete or, when replacement of individual components at sea is practicable, complete pump element with associated valves, seals, springs, etc.	1	-
Fuel injection pipes	High pressure fuel pipe of each size and shape fitted, complete with couplings	1	-
Charge air system (3)	Auxiliary blower, complete including drive	1	-
	Exhaust-gas turbocharger: rotor complete with bearings, nozzle rings and attached lube oil pump	1 set	-
	Suction and pressure valves of each type for one cylinder	1 set	-
Gaskets and packings	Special gaskets and packings of each type for cylinder covers and cylinder liners, for one cylinder	-	1 set
Exhaust gas system (engine-related)	Compensator of each type	1	-

(1) *in the case of multi-engine installations, the minimum required spares are only necessary for one engine*

(2) *a) engines with one or two fuel-injection valves per cylinder: one set of fuel valves, complete*

b) engines with more than two fuel injection valves per cylinder: two valves complete per cylinder plus a corresponding number of valve parts (excluding the valve bodies) which make it possible to form a complete spare set by re-using the operational parts of the dismantled valves

(3) *spare parts for exhaust-gas turbocharger and auxiliary blower may be omitted if emergency operation of the main engine after failure is demonstrably possible.*
The requisite blanking and blocking arrangements for the emergency operation of the main engine are to be available on board.

(4) *the necessary tools and equipment for fitting the required spare parts must be available on board*

(5) *spare parts are to be replaced immediately as soon as they are "used-up"*

Table 10.2 Spare parts for auxiliary engines driving electric generators for essential equipment

Range of spare parts		A
Main bearings	Bearings or shells for one bearing of each size and type fitted, complete with shims, bolts and nuts	1
Valves	Exhaust valves, complete with casings, seats, springs and other fittings for one cylinder	2 sets
	Inlet valves, complete with casings, seats, springs and other fittings for one cylinder	1 set
	Starting air valve, complete with casing, seat, springs and other fittings	1
	Overpressure control valve, complete	1
	Fuel valves of each size and type fitted, complete, with all fittings, for one engine	¼ set
Connecting rod bearings	Bottom end bearings or shells of each type, complete with all fittings	1
	Gudgeon pin with bush for one cylinder	1
Piston rings	Piston rings, for one cylinder	1 set
Fuel injection pumps	Fuel injection pump complete or, when replacement of individual components at sea is practicable, complete pump element with associated valves, seals, springs, etc.	1
Fuel injection pipes	High pressure fuel pipe of each size and shape fitted, complete with couplings	1
Gasket and packings	Special gaskets and packings of each size and type fitted, for cylinder covers and cylinder liners for one cylinder	1 set

Note

1. *Where the number of generating sets (including stand-by units) is greater than called for by the Rules, no spares are required for the auxiliary engines.*

2. *Where several diesel engines of the same type are installed by way of generator drive spare parts are required for one engine only.*

3. *No spares are required for the engines driving emergency generator sets.*

Table 10.3 Spare parts for prime movers of essential equipment other than generators

Range of spare parts
The range of spare parts required for auxiliary drive machinery for essential consumers is to be specified in accordance with Table 10.2

Note

Where an additional unit is provided for the same purpose no spare parts are required.

Table 10.4 Spare parts for gears and thrust bearings in propulsion plants

Range of spare parts	A	B
Wearing parts of gear-driven pump supplying lubricating oil to gears or one complete lubricating oil pump if no stand-by pump is available	1 set	-
	1	
Thrust pads for ahead side of thrust bearings	1 set	1 set

Table 10.5 Other spare parts for main and auxiliary engines

Range of spare parts	A	B
Hoses and compensators	20%	20%
Testing device for fuel injection valves	1	1

Note

For carrying out maintenance and repair work, a sufficient number of suitable tools and special tools according to the size of the machinery installation must be available on board.