



RULES FOR CLASSIFICATION OF

Ships / High Speed, Light Craft and Naval Surface Craft

PART 4 CHAPTER 14

MACHINERY AND SYSTEMS – MAIN CLASS

Steering Gear

JANUARY 2011

*This chapter has been amended since the main revision (January 2011), most recently in July 2011.
See “Changes” on page 3.*

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CHANGES

General

As of October 2010 all DNV service documents are primarily published electronically.

In order to ensure a practical transition from the “print” scheme to the “electronic” scheme, all rule chapters having incorporated amendments and corrections more recent than the date of the latest printed issue, have been given the date January 2011.

An overview of DNV service documents, their update status and historical “amendments and corrections” may be found through http://www.dnv.com/resources/rules_standards/.

Amendments July 2011

- **General**

— The restricted use legal clause found in Pt.1 Ch.1 Sec.5 has been added also on the front page.

Main changes

Since the previous edition (January 2005), this chapter has been amended, most recently in July 2010. All changes previously found in Pt.0 Ch.1 Sec.3 have been incorporated and a new date (January 2011) has been given as explained under “General”.

In addition, the layout has been changed to one column in order to improve electronic readability.

CONTENTS

Sec. 1 Steering Gear	5
A. General.....	5
A 100 Application	5
A 200 Definitions	7
A 300 Documentation	8
B. Design	9
B 100 General.....	9
B 200 Materials	9
B 300 Arrangement generally.....	10
B 400 Main steering gear.....	10
B 500 Auxiliary steering gear.....	11
B 600 Exceptions where auxiliary steering gear is not required	11
B 700 Additional requirements for vessels above 70 000 gross tonnage.....	12
B 800 Additional requirements for oil carriers, chemical carriers and liquefied gas carriers	12
B 900 Over balanced rudders	12
B 1000 Hydraulics and piping	12
B 1100 Actuator and actuating mechanism.....	13
B 1200 Connection between steering gear and rudder stock.....	18
B 1300 Stopper arrangement	24
B 1400 Bearings	24
B 1500 Oil seals.....	25
C. Inspection and Testing.....	25
C 100 General.....	25
C 200 Inspection and testing of parts	25
D. Workshop Testing	27
D 100 General.....	27
E. Power Supply, Control and Monitoring	27
E 100 General.....	27
E 200 Main power supply	27
E 300 Emergency power supply.....	27
E 400 Control gear and associated protective functions	27
E 500 General requirements, steering gear control system	28
E 600 Arrangement of electric and control systems.....	28
E 700 Monitoring	28
E 800 Additional Requirements for vessels with DP notation	29
F. Arrangement for Installation Onboard	30
F 100 Fastening arrangement to foundation.....	30
F 200 Steering gear compartment	30
G. (Intentionally left blank).....	31
H. Installation	31
H 100 Connection between steering gear and rudder stock.....	31
H 200 Fastening to foundation	31
I. Shipboard Testing	31
I 100 Shipboard testing	31
I 200 Trials	31
I 300 Additional requirements for vessels with DP notation	32
App. A Additional Requirements for Non-Duplicated Rudder Actuators 33	
A. General.....	33
A 100 Application.....	33
A 200 Documentation	33
B. Design	33
B 100 General.....	33
B 200 Dynamic loads for fatigue and fracture mechanics analyses	33
B 300 Allowable stresses.....	33
C. Inspection and Testing.....	34
C 100 Non-destructive testing	34

SECTION 1 STEERING GEAR

A. General

A 100 Application

101 The rules in this section apply to electro hydraulic and hand hydraulic steering gear operating a rudder for the purpose of steering the vessel.

102 Steering gear, other than electro hydraulic type, will be accepted provided that safety and reliability can be documented to be equivalent to or better than the requirements of this section.

103 Requirements for rudder, reference is made to Pt.3 Ch.2 Sec.2 (Rules for Classification of Ships) and Pt.3 Ch.5 Sec.2 (Rules for Classification of HSLC and NSC).

104 Requirements to steering of azimuth thrusters and podded propulsors reference is made to Ch.5 Sec.3. Requirements to steering of water jets are covered in Ch.5 Sec.2.

105 For additional requirements for vessel navigation in ice (**ICE, POLAR, Icebreaker, Sealer**) reference is made to Pt.5 Ch.1 (Rules for Classification of Ships). For additional requirements for Naval vessels (**Naval, Naval Support, Naval Support (....)**) reference is made to Pt.5 Ch.14 Sec.7. For additional requirements to vessels with additional notation Redundant propulsion (**RP, RPS**) and Dynamic positioning systems (**DYNPOS**) reference is made to Pt.6 Ch.2 (Rules for Classification of Ships) and Pt.6 Ch.7 (Rules for Classification of Ships).

A 106 Nomenclature

<i>Symbol</i>	<i>Term</i>	<i>Unit</i>	<i>Rule reference</i>
A_i	Pressurised area	mm ²	B1119
b	Breadth of key	mm	B1212
C_D	Average diametrical clearance of radial bearings	mm	B1121 b)
c_e	Diameter ratio d/D	-	B1208
c_i	Diameter ratio d_i/d	-	B1208
d	Rudder stock diameter	mm	B1204 B1208
D	Outer diameter of hub	mm	B1208
d_i	Diameter of centre bore in rudder stock	mm	B1208
d_m	Mean diameter of cone	mm	B1203 h)
d_s	Designed minimum rudderstock diameter below actuator	mm	B1120
d_t	Diameter of rudder stock at top of cone	mm	B1209
E_e	Module of elasticity of hub	N/mm ²	B1208
E_i	Module of elasticity of rudder stock	N/mm ²	B1208
e	Ram eccentricity	m	B1119, Fig.1
F	Necessary force for pull up	kN	B1210
f_l	Material factor	-	B203
F_{des}	Net radial force on rudderstock in way of actuator due to design torque	kNm	B1121 a)
F_{MTR}	Net radial force on rudderstock in way of actuator due to rule rudder torque	kNm	B1120 a)
h	Distance between upper and lower radial actuator bearing	mm	B1121 b)
h_A	Vertical distance between force and bearing centre	mm	B1120 a)
h_{eff}	Effective height of key contact with hub and shaft respectively	mm	B1212
k	Material utilisation factor	-	B1203 i)
K	Taper of cone = $l_t/(d_s-d_t)$	-	B1209
k_b	Bending moment factor	-	B1120
k_{key}	Key factor	-	B1212
l	Effective cone length	mm	B1203 h)
L	Distance between lower radial actuator bearing and neck bearing	mm	B1121 b)
L_t	Torque arm	m	B1119

<i>Symbol</i>	<i>Term</i>	<i>Unit</i>	<i>Rule reference</i>
L_{eff}	Effective bearing length of key	mm	B1212
M_B	Bending moment in rudderstock	kNm	B1121
M_{TR}	Rule rudder torque	kNm	Ships: Pt.3 Ch.3 Sec.2 D202 HSLC and NSC: Pt.3 Ch.5 Sec.1 E402
p	Surface pressure	N/mm ²	B1208
p_b	Surface pressure due to bending	N/mm ²	B1207
P_{des}	Design pressure	Bar	A211
p_r	Average/local surface pressure	N/mm ²	B1203 h)
p_s	Permissible bearing surface pressure	N/mm ²	B1403
P_{test}	Test pressure	Bar	D101
P_w	Maximum working pressure	Bar	A210
R_{Ae}	Surface roughness of hub	μm	B1209
R_{Ai}	Surface roughness of rudder stock	μm	B1209
S	Safety factor (mechanical)	-	B1111 – 1112
S_c	Safety factor for rudder stock connection	-	B1205
T_{des}	Design torque	kNm	B1119
T_{fr}	Friction torque	kNm	B1203 h)
T_w	Maximum working torque	kNm	A210 B1119
w	Weight in air of rudder and rudder stock	kg	B1204
β	Angular deflection of rudder stock	rad	B1121 b)
δ	Pull-up length	mm	B1209
Δ	Shrinkage allowance	mm	B1208
Δ_{max}	Calculated maximum shrinkage allowance	mm	B1208-1209
Δ_{min}	Calculated minimum shrinkage allowance	mm	B1208-1209
θ	Maximum permissible rudder angle	°	B1119
μ	Friction coefficient	-	B1206
μ_{pu}	Average friction coefficient for pull-up	-	B1210
ν_e	Poisson's ratio of hub	-	B1208
ν_i	Poisson's ratio for rudder stock	-	B1208
φ	Cylinder neutral angle	°	B1119
σ_m	General primary membrane stress	N/mm ²	B1114
σ_B	Tensile strength	N/mm ²	B1114
σ_y	Yield strength (or 0.2% proof stress)	N/mm ²	B1114
σ_t	Nominal design stress	N/mm ²	B1115 Ch.7 Sec.4 B501
σ_f	Minimum upper yield strength	N/mm ²	B203
σ_{fit}	Tangential stress due to shrink fitting connection	N/mm ²	B1113
σ_e	Permissible equivalent stress	N/mm ²	B1109
σ_{bend}	Bending stress	N/mm ²	B1109
σ_{axial}	Axial stress	N/mm ²	B1109
σ_N	Nominal bending stress	N/mm ²	B1116
τ_{nom}	Nominal shear stress	N/mm ²	B1109

A 200 Definitions

201 *Main steering gear* means the machinery necessary for effecting movement of the rudder for the purpose of steering the ship under normal service conditions.

For example this may include:

- rudder actuator(s)
- steering gear power units (if any)
- ancillary equipment
- the means of applying torque to the rudder stock (e.g. tiller or quadrant).

202 *Auxiliary steering gear* means the equipment other than any part of the main steering gear necessary for effecting movement of the rudder for the purpose of steering the ship in the event of failure of the main steering gear but not including the tiller, quadrant or components serving the same purpose.

Guidance note:

Auxiliary steering gear may share the tiller or similar component with the main steering gear.

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203 *Steering gear control system* means the equipment by which orders are transmitted to the steering gear power units and other parts necessary for operating the steering gear.

Steering gear control systems may comprise:

- transmitters
- receivers
- programmable electronic units
- hydraulic control pumps
- associated motors
- associated motor controllers and frequency converters
- piping
- cables.

204 *Rudder actuator* means the component which converts directly hydraulic pressure into mechanical action to move the rudder.

205 *Rudder actuating mechanism* means the parts transmitting force from actuator to rudder stock, including tiller.

206 *Steering gear power unit* means:

- in the case of electric steering gear; an electric motor and its associated electrical equipment
- in the case of electro hydraulic steering gear; an electric motor and its associated electrical equipment and connected pump
- in the case of other hydraulic steering gear; a driving engine and connected pump.

207 *Power actuating system* means the hydraulic equipment provided for supplying power to turn the rudder stock, comprising:

- steering gear power units
- associated pipes and fittings
- rudder actuator.

The power actuating systems may share common mechanical components, i.e. tiller, quadrant and rudder stock, or components serving the same purpose.

208 *Maximum ahead service speed*

- For vessels complying with rules for ships: means the maximum speed corresponding to maximum nominal shaft RPM and corresponding engine MCR in service at sea on summer load waterline.
- For vessels complying with rules for HSLC and NSC: maximum service speed as defined in Pt.3 Ch.5 Sec.1 E201 at full load condition.

209 *Maximum astern speed* is the estimated speed which the ship can attain at the designed maximum astern power at the deepest seagoing draught.

210 *Maximum working pressure:*

- For vessels complying with rules for ships: the maximum oil pressure in the system when the steering gear is operated according to B401 b1).
- For vessels complying with rules for HSLC and NSC: the expected pressure in the system when the steering gear is operated according to B401 b2).

211 *Design pressure* means the maximum pressure for which the actuator is designed.

Design pressure shall as a minimum be 1.25 times the maximum working pressure and shall not be less than the set pressure of the safety relief valve.

A 300 Documentation

301 Plans and particulars as listed in Table A1 shall be submitted for approval. The plans shall give full details of scantlings and arrangements as well as material specification and data necessary for verifying scantling calculations together with specified ratings.

Set pressure for all relief valves shall be specified.

Material specifications shall include mechanical properties and particulars about heat treatment.

302 For important components of welded construction (e.g. tiller), full details of the joints, welding procedure, filler metal and heat treatment after welding are to be specified on the plans.

303 Steering gear manufacturers who intend their product to comply with the requirements of the IMO Guidelines for non-duplicated rudder actuators shall submit additional documentation as given in Appendix A.

304 For rudders included under DP-control documentation of expected life time of bearings subjected to extra ordinary wear rate due to DP shall be submitted for approval.

Table A1 Documentation				
Components			Status	Rule references
General arrangement drawings of steering gear			I	
Rudder actuator sectional drawing			I	
Specification of rudder type			I	
Drawings of load transmitting parts			A	B1100
	All types of rudder actuator	Bolts and pins		
		Connection to rudderstock		
Rotary vane type rudder actuator	Rotor			
	Vane			
	Housing			
	Cover			
	Stopper /dividing wall			
	Linked cylinder type rudder actuator	Tiller		
Piston				
Piston rod				
Cylinder				
End cover				
Ram type rudder actuator	Tiller			
	Ram			
	Cylinder			
	End cover			
Heat treatment/cool down procedure (if applicable)			I	B204
Allowable bearing pressure			I	B1403
Piping and function diagram			A	B1000
Total delivery capacity of steering gear hydraulic pumps			UR	B1006
Steering gear relief valve discharge characteristics (pressure-flow diagram)			I	B1006
Fastening arrangement, including bolting and chocking			I	F100
Fastening bolts and chocks			A	F100
List of alarms and shutdowns of frequency converters			I	E
General arrangement drawings of steering gear compartment			I	F200
Installation instructions for steering gear			I	
Operation instructions, including emergency operation			A	F200
Rudder stoppers (integrated in steering gear)			A	B1300
Electric systems to be documented as required in Ch.8			A	Ch.8
Control system to be documented as required in Ch.9			A	Ch.9 Sec.1 Table C2
Functional failure analysis of steering gear and control system			UR	
A = for approval I = for information UR= upon request.				

B. Design

B 100 General

101 The requirements in B give criteria for arrangement, function and capacity for steering gear (B100-B800) and strength of steering gear components (B1100-B1200).

For requirements to electric equipment and control systems reference is made to E.

102 Steering gear shall be designed considering all relevant loads from internal and external forces.

Internal loads shall be considered based on:

- design pressure for actuator
- test pressure for actuator.

External loads shall be considered based on:

- maximum rule rudder torque from rudder
- maximum force from rudder.

Guidance note:

The rule requirements imply that the actuator and actuating mechanism shall have strength equivalent as required for the rudderstock.

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103 In case the actuator induces a bending moment in the rudder stock, the effects on rudder stock, fitting of actuator, bearings and fastening arrangement shall be considered.

Such bending moments may origin from asymmetrical actuator forces on tiller/rotor, or when rudder stock bending deflections are larger than what is allowed by the clearances in bearing arrangement.

104 The influence of bending moment due to rudder stock deflection may normally be neglected if horizontal deflection in way of upper bearing at full rule rudder force is less than two times the diametrical bearing clearance. Otherwise, corresponding bending moment at full rudder force is to be taken into account (see B1121).

105 Bending moment and reaction force at upper bearing caused by asymmetrical tiller/rotor forces at both maximum rule rudder force and maximum power of actuator (design pressure) shall be considered, including any operational mode where one or more actuators are not in use (Bending moment arm shall be taken as the distance between resulting bearing force and centre of upper bearing) (see B1121).

B 200 Materials

201 Materials for application in rudder actuator, piping valves, flanges and fittings and all steering gear components transmitting mechanical forces to the rudder stock, excluding bolts, pins and keys, are to be of steel, nodular cast iron or other approved ductile material, duly tested in accordance with Pt.2. Exemptions are made to the requirement to Charpy-V testing.

In general, all materials shall have an elongation of not less than 12%.

The following materials may only be accepted upon special consideration:

- materials with tensile strength in excess of 650 N/mm²
- grey cast iron for use in redundant parts with low stress level, excluding hydraulic cylinders
- structural steel for components exposed to internal hydraulic pressure.

202 Materials in bolts, pins and keys shall be of rolled, forged or cast steel in accordance with Pt.2. In general, such material shall have a minimum specified tensile strength in the range of 400 N/mm² to 900 N/mm². Higher tensile strength may be accepted upon special considerations related to ductility and fatigue properties versus application. Yield stress shall not be less than 200 N/mm².

203 In order to ensure that the material has sufficient fatigue strength, allowable stresses are reduced for high tensile materials. Hence:

Minimum upper yield strength (or 0.2% proof stress), σ_f [N/mm²] for use in calculation shall not to be taken greater than 70% of the ultimate tensile strength.

Material factor, f_1 for forgings (including rolled bars) and castings, f_1 shall be taken as:

$$f_1 = \left(\frac{\sigma_f}{235} \right)^a$$

where

a = 0.75 for $\sigma_f > 235 \text{ N/mm}^2$

= 1.0 for $\sigma_f \leq 235 \text{ N/mm}^2$

= 1.0 when calculating with additional load as described in 1108, or when calculating at internal test pressure, P_{test} , or bolts with significant pre stress.

204 Nodular cast iron and cast steel parts where dimensional stability is important shall be stress relieved, i.e. tiller and rotor transmitting rudder torque by means of keyless conical or cylindrical connection.

Test pull-up or controlled cool-down may be accepted as replacement for stress relief.

The cool-down procedure must be approved. Further, it must be documented that the actual cool-down process is according to the procedure.

205 Welded parts are required to be stress relieved.

B 300 Arrangement generally

301 Unless expressly provided otherwise, every ship shall be provided with a main steering gear and an auxiliary steering gear (see B600).

302 The main steering gear and the auxiliary steering gear shall be so arranged that the failure of one of them will not render the other one inoperative.

Guidance note:

When considering fail scenarios for main/auxiliary steering gear in this context the tiller and connection to rudder stock is considered as a non failing component.

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Guidance note:

As guidance to hydraulic arrangements see Classification Note 41.6 "Guidelines, Schematic Principles for Steering Gear Hydraulics".

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B 400 Main steering gear

401 The main steering gear shall:

- a) be capable of operating the rudder for the purpose of steering the ship at maximum ahead service speed which shall be demonstrated
- b) have capacity to turn the rudder from side to side according to requirements given below at maximum ahead service speed

1) For vessels complying with rules for ships the main steering gear shall comply with the following:

- turning the rudder over from 35° on one side to 35° on the other and visa versa
- turning rudder from 35° on either side to 30° on the other sides respectively within 28 seconds
- for class notations **Tug** or **Supply Vessel**, or Ice Classes: **ICE-05** or **ICE-15** or **POLAR-10** or **POLAR-30**, turning the rudder from 35° on either side to 30° on the other sides respectively within 20 seconds
- for class notation **Icebreaker** turning rudder from 35° on either side to 30° on the other sides respectively within 15 seconds
- turning rudder back to neutral position from any possible steering angle that intentionally or unintentionally may be initiated. See also B900 for over-balanced rudders and rudders of unconventional design.

2) For vessels complying with rules for HSLC and NSC the main steering gear shall have capacity to turn the rudder during the following :

- steering performance (zig zag) test
- turning circle test
- low speed steering test
- single unit steering (for vessels with twin units).

c) be operated by power when the rules require a rudder stock diameter above 120 mm in way of the tiller, excluding strengthening for navigation in ice

d) be so designed that neither steering gear nor rudderstock will be damaged at maximum astern speed and rudder angle.

Guidance note:

A rule rudder stock with diameter of 120 mm equals a rule rudder torque of 23.3 kNm.

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B 500 Auxiliary steering gear

501 The auxiliary steering gear shall:

- a) be capable of operating the rudder for the purpose of steering the ship at navigable speed and of being brought speedily into action in an emergency
- b) have capacity to turn the rudder from side to side according to requirements given below
 - 1) For vessels complying with rules for ships the auxiliary steering gear shall comply with the following :
 - turning the rudder over from 15° on one side to 15° on the other side in not more than 60 seconds with the ship on summer load waterline and running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater.
 - 2) For vessels complying with rules for HSLC and NSC the auxiliary steering gear shall have capacity to turn the rudder during the following:
 - steering performance (zig zag) test
 - low speed steering test
 - turning circle test
 - single unit steering (for vessels with twin units)
- c) be operated by power when the rules require a rudder stock diameter above 230 mm in way of the tiller, excluding strengthening for navigation in ice.

Guidance note:

Speedily normally means less than 15 minutes.

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Guidance note:

Manually operated steering gears are only acceptable when the operation does not require an effort exceeding 160 N under normal conditions.

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B 600 Exceptions where auxiliary steering gear is not required

601 Auxiliary steering gear need not be fitted when the ship is provided with either:

- a) two rudders, each with its own steering gear and capable of steering the vessel with any one of the rudders out of operation
- b) approved alternative means of steering, capable of steering the vessel with the rudder out of operation and provided with approved remote control from the bridge. Such means may be:
 - azimuth thrusters
 - two or more independent propulsion units, located eccentric from the ships centre line
- c) for non-propelled vessels.

602 Where the main steering gear comprises two or more identical power units, an auxiliary steering gear need not be fitted provided that requirements below are complied with:

- a) Isolation:
 - 1) a single failure in the main steering gear piping system or one of the power units can be isolated and steering capability can be maintained or speedily regained.
- b) Capacity:
 - 1) in a passenger ship, the main steering gear is capable of operating the rudder as required in B401b) while any one of the power units is out of operation
 - 2) in a cargo ship, the main steering gear is capable of operating the rudder as required in B401b) while operating with all power units.

B 700 Additional requirements for vessels above 70 000 gross tonnage

701 In every ship of 70 000 gross tonnage and upwards, the main steering gear shall comprise two or more identical power units complying with the requirements in B602.

B 800 Additional requirements for oil carriers, chemical carriers and liquefied gas carriers

801 Every oil carrier, chemical carrier or liquefied gas carrier of 10 000 gross tonnage and upwards shall comply with the following:

- a) The main steering gear is to be so arranged that in the event of loss of steering capability due to a single failure in any part of one of the power actuating systems, excluding the tiller or components serving the same purpose, steering capability is to be regained in less than 45 seconds.
- b) Capacity:
 - 1) The main steering gear shall comprise of two independent and separate power actuating systems, each capable of meeting the requirements in B401b).
 - 2) Alternatively, at least two identical power actuating systems may be fitted which:
 - acting simultaneously in normal operation are capable of meeting the requirements in B401 b)
 - are able to detect loss of hydraulic fluid from one system
 - automatically isolates such a defect so that the other actuating system(s) remains fully operational.

Guidance note:

Steering gear complying with requirements in this paragraph are commonly referred to as "IMO steering gears".

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802 For tankers of 10 000 gross tonnage and upwards but less than 100 000 dead weight tons duplication of actuator is not required provided that an equivalent level of safety can be documented according to Appendix A and the following is complied with:

- a) the main steering gear shall comprise two or more identical power units capable of operating the rudder according to B401b) while operating with all power units.
- b) after loss of steering capability due to a single failure of any part of the piping system or in one of the power units, steering capability is to be regained within 45 seconds.

Guidance note:

Steering gear complying with requirements in 802 are commonly referred to as "Appendix A steering gears". See Appendix A.

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B 900 Over balanced rudders

901 Paragraphs in B900 are relevant for steering gear for over-balanced rudders and rudders of unconventional design. See also Pt.3 Ch.3 Sec.2 A301 and C108 (Rules for Classification of Ships).

902 The influence of increased friction due to age and wear of bearings on steering gear torque capacity shall be duly considered. Unless such friction losses are accounted for and specified in submitted approval documentation, the friction coefficient for the bearing in worn condition shall be taken at least twice as when new.

903 Loss of steering torque due to a single failure in the steering gear power or control systems (inclusive failure in power supply) shall not cause a sudden turn of rudder.

904 Steering gear shall be capable of bringing the rudder from any rudder angle back to neutral position. This is to be verified by testing on sea trial.

B 1000 Hydraulics and piping

1001 Piping, joints, valves, flanges and other fittings are to comply with the requirements of Ch.6 (Rules for Classification of Ships) for design pressure as defined in A211 in this section. Power piping is to comply with requirements to Class I pipes.

1002 Hydraulic power operated steering gears are to be provided with:

- a) arrangements to maintain the cleanliness of the hydraulic fluid taking into consideration the type and design of the hydraulic system
- b) a fixed storage tank having sufficient capacity to recharge at least one power actuating system including the reservoir, where the main steering gear is required to be power operated. The storage tank is to be permanently connected by piping in such a manner that the hydraulic systems can be readily recharged from a position within the steering gear compartment and provided with a contents gauge

- c) indicator for clogged filter on all filters with “by-pass” function
- d) arrangement so that transfer between units can be readily effected.

Guidance note:

Specification of a pressure filter for maintaining suitable fluid cleanliness may be 16/14/11 according to ISO 4406:1999 and

$\beta_{6-7(c)} = 200$ according to ISO 16889:1999.

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1003 Hydraulic power actuating system for steering gear shall not to be used for other purposes.

1004 For all vessels with non-duplicated actuators; isolating valves directly fitted on the actuator shall be provided at the connection of pipes to the actuator.

1005 Main and auxiliary steering gear are to be provided with separate hydraulic power supply pipes. When main steering gear is arranged in accordance with B602, each hydraulic power unit is to be provided with separate power pipes. Interconnections between power pipes are to be provided with quick operating isolating valves.

1006 Relief valves shall be fitted to any part of the hydraulic system which can be isolated and in which pressure can be generated from the power source or from external forces. Relief valves shall comply with the following:

- a) the setting pressure is not to be less than 1.25 times the maximum working pressure

Guidance note:

Relief valve located directly after hydraulic pump may have a set value that is lower. However not lower than maximum working pressure.

Such reduction in set value will normally not be accepted for arrangements with overbalanced rudders.

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- b) the setting of the relief valves is not to exceed the design pressure
- c) the minimum discharge capacity of the relief valves is not to be less than the larger of :
 - 110 % of the total capacity of the pumps which can deliver through it (them)
 - oil flow corresponding to a rudder movement of 5 deg./second.

Under such conditions the rise in pressure is not to exceed 10 % of the setting pressure. In this regard, due consideration is to be given to extreme foreseen ambient conditions in respect of oil viscosity.

1007 Where the steering gear is so arranged that more than one system (either power or control) can be simultaneously operated, the risk of hydraulic locking caused by a single failure is to be considered.

For alarm requirement see E700 “Monitoring”.

Guidance note:

”Hydraulic locking” includes all situations where two hydraulic systems (usually identical) oppose each other in such a way that it may lead to loss of steering. It can either be caused by pressure in the two hydraulic systems working against each other or by hydraulic “by-pass” meaning that the systems puncture each other and cause pressure drop on both sides or make it impossible to build up pressure.

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1008 Flexible hoses of approved type may be installed between two points where flexibility is required but are not to be subjected to torsional deflection (twisting) under normal operating conditions. In general, the hose should be limited to the length necessary to provide for flexibility and for proper operation of machinery.

1009 Hoses are to be high pressure hydraulic hoses according to recognised standards and suitable for the fluids, pressures, temperatures and ambient conditions in question. For detailed requirements for construction and testing of flexible hoses, see Ch.6 Sec.6 D (Rules for Classification of Ships).

B 1100 Actuator and actuating mechanism

1101 Actuator housing and cylinders are considered as Class I pressure vessels with respect to testing and certification, except for Charpy-V testing which is not required.

1102 The structural design of the actuator is to be chosen with due respect to transmission of reaction forces to the seating.

1103 The construction shall be such that the local stress concentrations are minimised.

1104 All welding joints within the pressure boundary of a rudder actuator or actuating mechanism are to be full penetration type or of equivalent strength.

1105 The actuator shall be designed to withstand additional reaction forces due to bending moment set up in rudder stock, in case rudder carrier and/or radial bearings are integrated in the actuator.

1106 The actuator and actuating mechanism shall be designed to withstand all possible loads that can be generated from rudder or power unit during operation. As a minimum, sufficient strength in the following conditions shall be considered:

- rudder exposed to a load corresponding to rule rudder torque, M_{TR} , and force, F_R
- actuator(s) working at design pressure, P_{des}
- actuator(s) exposed to internal test pressure, P_{test} .

Relevant additional loading due to bolt pretension, shrink fitting of hubs, from supports and connected piping, etc. shall be duly considered.

1107 Unless fatigue is suspected to be a possible mode of failure, fatigue strength needs not to be documented. Normally, this provides that:

- fillets are smooth and well rounded so that geometrical stress concentration factors do not exceed 1.5 (otherwise safety factor must be increased correspondingly)
- static strength fulfils the criteria in 1108-1118.

1108 If forces from one actuator can be transferred to another, for instance by means of a connecting rod, the actuator and actuating mechanism shall not be permanently damaged when exposed to the sum of actuating forces (actuators working at design pressure). When calculating the material factor f_1 shall be taken as $\sigma_y/235$

1109 Nominal equivalent stresses in actuator and actuating mechanism shall comply with the following:

$$\sigma_e \leq \frac{235 \cdot f_1}{S} \left(1 - \frac{\sigma_{fit}}{\sigma_f} \right) \quad [\text{N/mm}^2]$$

where

σ_e = permissible equivalent stress $[\text{N/mm}^2]$ according to the von Mises criterion

S = safety factor [-] (see 1111 and 1112)

f_1 = material factor [-]

σ_f = minimum upper yield strength $[\text{N/mm}^2]$

σ_{fit} = static stress due to pretension or shrinkage $[\text{N/mm}^2]$ (see 1113).

Guidance note:

Nominal stresses should be taken as follows:

Bending stress:

$$\sigma_{bend} = \frac{M_B}{W_b} 10^3 \quad [\text{N/mm}^2]$$

Axial stress:

$$\sigma_{axial} = \frac{F_A}{A_A} \quad [\text{N/mm}^2]$$

Shear stress:

$$\tau_{nom} = \frac{F_S}{A_S} \quad [\text{N/mm}^2] \quad (\text{from shear force})$$

$$\tau_{nom} = \frac{T}{W_t} 10^3 \quad [\text{N/mm}^2] \quad (\text{from torque})$$

where loads acting on the component are defined as:

M_B = bending moment $[\text{Nm}]$

T = torque $[\text{Nm}]$

F_A = axial force $[\text{N}]$

F_S = shear force $[\text{N}]$

Further, geometrical parameters are defined as:

A_A = cross sectional area [mm²]

A_S = shear area [mm²]

W_b = section modulus in bending [mm³]

W_t = section modulus in torsion [mm³]

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1110 Tiller arms, vanes, pins, bolts and other components exposed to shear forces shall comply with the following criteria for nominal sectional shear stress:

For circular cross sections:

$$\tau_{nom} \leq \frac{175 \cdot f_1}{\sqrt{3} \cdot S} \quad \text{N/mm}^2$$

For other geometries:

$$\tau_{nom} \leq \frac{155 \cdot f_1}{\sqrt{3} \cdot S} \quad \text{N/mm}^2$$

1111 When calculation is based on rule rudder torque (M_{TR}) safety factors as given in 1109 and 1110 are not to be taken less than 2.0 (ensuring equivalent strength as required for the rudder stock).

1112 When calculation is based on actuator pressure, safety factors as given in 1109 and 1110 are not to be taken less than:

a) At design pressure, P_{des} :

- 1.5 for parts subject to reversed load
- 1.25 for parts not subject to reversed load
- 1.0 for parts when calculating with additional load as described in 1108.

Guidance note:

Parts subject to reversing loads are parts where the change of direction of load exposes the part to altering strain and compression.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

b) At internal test pressure, P_{test} :

- 1.2 for clamping bolts in pressurised parts.

1113 For shrink fitted connections, tangential stress at the inner hub surface may be taken as follows:

$$\sigma_{fit} = p \left(\frac{1 + c_e^2}{1 - c_e^2} - 1 \right) \quad [\text{N/mm}^2]$$

where

p = actual pressure due to shrinkage [N/mm²]

c_e = diameter ratio d/D [-] at considered section.

1114 Any part of the actuator exposed to internal hydraulic pressure, the general primary membrane stress shall comply with the following:

$$\sigma_m \leq \frac{\sigma_B}{A} \quad [\text{N/mm}^2]$$

$$\sigma_m \leq \frac{\sigma_y}{B} \quad [\text{N/mm}^2]$$

where

σ_m = general primary membrane stress [N/mm²]

σ_B = specified minimum tensile strength of the material at ambient temperature [N/mm²]

σ_y = specified minimum yield strength (or 0.2% proof stress) of the material at ambient temperature [N/mm²].

A and B are coefficients of utilisation, given by the following table for steel and nodular cast iron (for other materials, A and B are subjects to special consideration):

Table B1 - Permissible primary membrane stress			
	<i>Steel</i>	<i>Cast steel</i>	<i>Nodular cast iron</i>
A	3.5	4	5
B	1.7	2	3

1115 Actuators are in general to be designed in accordance with the requirements for pressure vessels in Ch.7 Sec.4 C100-600.

Hydraulic cylinder type actuator shall be in compliance with Standard for Certification 2.9 Type approval program 5-778.93 “Hydraulic Cylinder”.

For determination of nominal design stress, σ_t , factors A and B given in 1114 apply.

For single actuator steering gear intended for tankers of 10 000 gross tonnage and upwards, but less than 100 000 deadweight tons (see B802), A and B shall be according to Appendix A.

1116 For rotor vanes and dividing walls exposed to hydraulic pressure, membrane stresses as given in 1114 are not relevant. The following requirements related to nominal bending stress are considered equivalent:

$$\sigma_N \leq \frac{1.5\sigma_B}{A} \left(1 - \frac{\sigma_{fit}}{\sigma_f} \right) \quad [\text{N/mm}^2]$$

$$\sigma_N \leq \frac{1.5\sigma_y}{B} \left(1 - \frac{\sigma_{fit}}{\sigma_f} \right) \quad [\text{N/mm}^2]$$

where

σ_N = nominal bending stress [N/mm²]

A and B are given in Table B1.

1117 The rotor/hub must have sufficient thickness, to avoid that loading on tiller arms/rotor vanes introduces unacceptable stresses or insufficient local surface pressure between hub and rudder stock. An average hub thickness not less than 70% of required vane root thickness (as derived from 1109-1116) is normally considered to be sufficient.

1118 Rams and piston rods for hydraulic cylinders shall comply with requirements for buckling strength as given in Ch.6 Sec.5 H300 (Rules for Classification of Ships).

1119 Design torque, T_{des} of a steering gear is to be calculated from:

$$T_{des} = P_{des} L_t \sum_{i=1}^n A_i \frac{\cos \varphi}{\cos \theta} 10^{-3} \quad [\text{kNm}]$$

where

P_{des} = design pressure [N/mm²]

L_t = torque arm [m] (see Fig.1)

A_i = pressurised (projected) area [mm²] of piston or vane number “i”. If areas of all pressurised pistons/vanes are identical, the term

$$\sum_{i=1}^n A_i$$

can be replaced by n A.

n = number of pistons/vanes which may be simultaneously pressurised in normal operation

φ = cylinder neutral angle [°] as defined in Fig.B1 for linked cylinder type steering gear
= 0° for ram and rotary vane type steering gear

θ = maximum permissible rudder angle [°] for ram type steering gear (normally 35°)
= 0° for linked cylinder and rotary vane type steering gear.

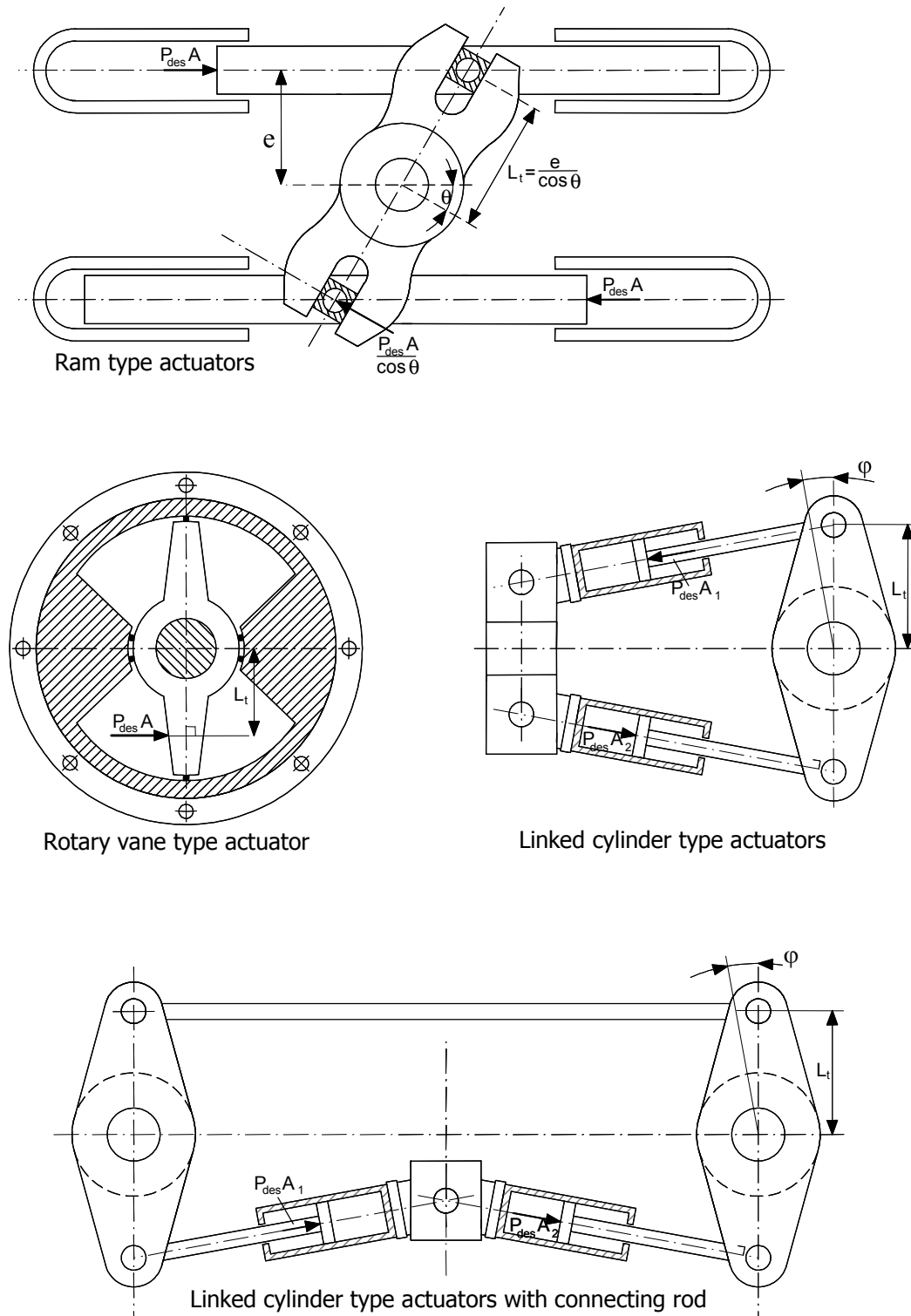


Fig. 1
Illustration of rudder actuator types

1120 The actuator(s) shall not cause permanent deformations to the rudder stock when operated at maximum power. Hence, maximum design torque is not to exceed:

$$T_{des} \leq 2f_1 \left(\frac{d_s}{42k_b} \right)^3 \quad [\text{kNm}]$$

where

d_s = designed minimum rudder stock diameter below tiller or rotor [mm]

k_b = bending moment factor to be calculated from:

$$k_b = \left[1 + \frac{4}{3} \left(\frac{M_B}{T_{des}} \right)^2 \right]^{1/6}$$

where

M_B = bending moment [kN] induced by the rudder actuator at the section in question (see 1121).

In case forces from one actuator can be transmitted to another (see 1108), the sum of design loads from all actuators shall be considered in the calculation of maximum allowable T_{des} . In this respect, f_1 may be replaced by $\sigma_y/235$.

1121 Bending moment, M_B in rudder stock induced by rudder actuator may origin from either:

- a) Actuator forces acting on tiller. Bending moment in way of upper radial bearing shall be taken as greater of the following:

$$M_B = F_{des} h_A \text{ [kNm]}$$

or

$$M_B = F_{MTR} h_A \text{ [kNm]}$$

where

h_A = vertical distance between force and lower radial bearing centre

F_{des} = net radial force on rudder stock in way of actuator, with actuator(s) working at design pressure

F_{MTR} = net radial force on rudder stock in way of actuator, with actuator(s) working at a pressure corresponding to rule rudder torque, M_{TR} .

- b) Radial rotor bearing loads in rotary vane type steering gear, caused by rudder stock bending deflections, shall be taken into account when bending deflections of rudder stock in way of upper bearing exceeds two times the diametrical bearing clearance. Unless otherwise is substantiated, M_B at lower radial actuator bearing is then to be taken as the bending moment needed to force the rudder stock deflections within the above limits, simplified to:

$$M_B = \frac{\pi \left(\beta - \frac{2C_D}{h} \right) d_s^4}{100(L+h)} \text{ [kNm]}$$

where

β = angular deflection of rudder stock [rad], calculated at full rudder force, F_R (see Rules for Classification of Ships Pt.3 Ch.3 Sec.2 D101 and HSLC and NSC Pt.3 Ch.5 Sec.1 E201), assuming the rudder stock to be freely supported in the actuator

C_D = average diametrical clearance of radial bearings [mm], after pull-up of rotor onto rudder stock

h = distance between upper and lower radial actuator bearing [mm]

L = distance between lower radial actuator bearing and neck bearing [mm].

B 1200 Connection between steering gear and rudder stock

1201 The steering gear shall be fitted to the rudder stock in such a way that forces from actuator effectively are transmitted to the rudder stock in all operating conditions.

The connection shall not be permanently damaged if the steering gear is operated at full power, taking into account possible arrangements for transmission of forces between actuators.

Dismantling of connection shall be possible without causing damage to the rudder stock or steering gear.

1202 The connection between steering gear and rudder stock shall have a torque capacity not less than the greatest of:

- a) Twice the rule rudder torque (M_{TR}).
- b) Vessels complying with the rules for ships:
- in case the torque is transmitted by friction alone:
twice the design torque (T_{des})

- in case the torque is transmitted by a combination of friction and shear (i.e. keyed connections):
1.5 times the design torque.

c) Vessels complying with the rules for HSLC and NSC:

- the design torque.

1203 Friction connections, with or without key, shall comply with the following:

- a) Tapered contact area shall be evenly distributed and shall not be less than 70% of total contact area.
- b) If oil (or similar) is used for fitting the design must enable escape of oil from between the mating surfaces. Where necessary tapered connections are to be provided with suitable means to facilitate dismantling of the hub (e.g. oil grooves and bores to connect hydraulic injection pump).
- c) Tapered connections shall be secured against axial displacement between rudder stock and steering gear by means of a nut properly tightened and secured to the shaft.
- d) Tapered connections shall be designed so that correct pull-up easily can be verified (see 1208 to 1210).
- e) Keyless tapered connections shall have a taper $\leq 1:15$, while taper shall be $\leq 1:10$ for keyed tapered connections.

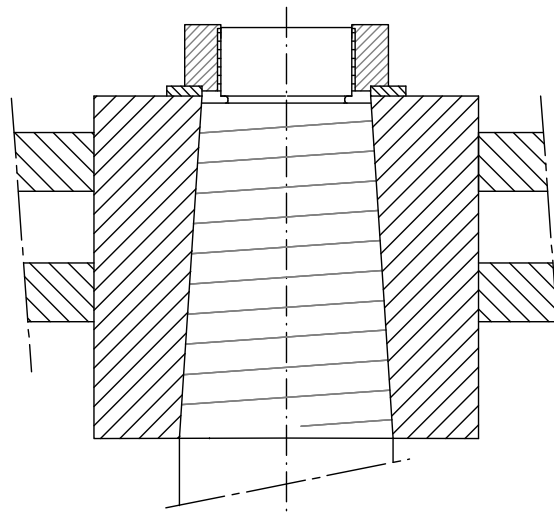


Fig. 2
Example of tapered rudder stock connection

- f) Cylindrical connections shall be duly secured with regard to axial loads.
- g) When special locking assemblies (see also 1204 b)) are applied for fitting of steering gear to rudder stock, the arrangement is to be such that their mutual influence on surface pressure is as small as possible. In case the number of locking assemblies is less than three an arrangement shall be provided to prevent drop of the rudder and stock in case of a slip in the friction connection.
- h) In order to fulfil the requirement in 1202, *average* required surface pressure, p_r for transmission of torque shall as a minimum comply with the following:

$$p_r \geq \frac{2T_{fr} 10^6}{\pi d_m^2 l \mu} \quad [\text{N/mm}^2]$$

where

T_{fr} = required friction torque [kNm] (see 1204)

d_m = mean diameter of cone [mm]

l = effective cone length [mm]

μ = friction coefficient [-](see 1206).

- i) Permissible stresses in the friction surface of the hub due to surface pressure are limited by the material utilisation factor, k as follows:

k = 0.5 for keyed connections

= 0.9 for nodular cast iron

= 0.95 for steel forgings and cast steel.

Other materials are subject to special consideration.

The influence of bending moment (see B103-B106 and B1121) and stress variation due to different hub wall thickness are to be taken into account. Hence, *local* surface pressure shall not exceed:

$$p_r \leq k \sigma_f \frac{1 - c_e^2}{\sqrt{3 + c_e^4}} - p_b \quad [\text{N/mm}^2]$$

where

σ_f = minimum upper yield strength [N/mm²]

p_b = surface pressure due to bending moment [N/mm²]. Need normally only to be considered at bigger end of cone (see 1207). For keyed connections p_b may normally be taken as zero when calculating with

$k = 0.5$ (see 1211)

c_e = diameter ratio rudder stock/hub at considered section [-] (see 1208).

See also 1211 - 1215 for keyed connections

Guidance note:

Contact surface roughness (R_a) should normally not exceed 1.6 m/3.5 m for oil injection fittings/dry fittings, respectively.

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1204 Required torque to be transmitted by means of friction, T_{fr} is related to both rule rudder torque, M_{TR} and design torque, T_{des} . T_{fr} shall be taken as follows:

- For keyed rudder stock connections detrimental mutual micro-movements between hub and rudder stock must be avoided in all normal operating conditions. Therefore, the key is normally considered as a securing device and T_{fr} shall then not be taken less than maximum calculated working torque of steering gear, T_W [kNm]. After special consideration, a lower friction capacity may be accepted for tight key connections. However, T_{fr} shall not be taken less than $0.25T_W$ (See also 1211 – 1215).
- For hubs joined to rudder stock by means of special locking assemblies or by means of tapered connection with intermediate sleeve, which transmit torque and axial forces by means of friction alone, the influence of axial forces shall be taken into account. Axial force shall correspond to twice the weight of the rudder and rudder stock in air, i.e. T_{fr} shall comply with the following:

$$T_{fr} \geq \sqrt{(S_c \cdot T)^2 + (2w \cdot d)^2 \cdot 10^{-10}} \quad [\text{kNm}]$$

- For other keyless shrink fit connections, T_{fr} shall comply with the following:

$$T_{fr} \geq S_c \cdot T \quad [\text{kNm}]$$

S_c = safety factor for connection to rudder stock (see 1205)

T = calculation torque (T_{des} or M_{TR}) [kNm]

w = weight in air of rudder and rudder stock [kg]

d = rudder stock diameter [mm].

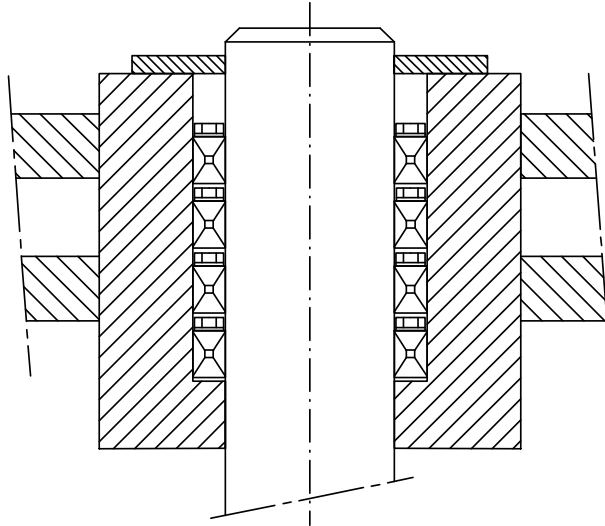


Fig. 3
Example of special locking assemblies: Friction rings

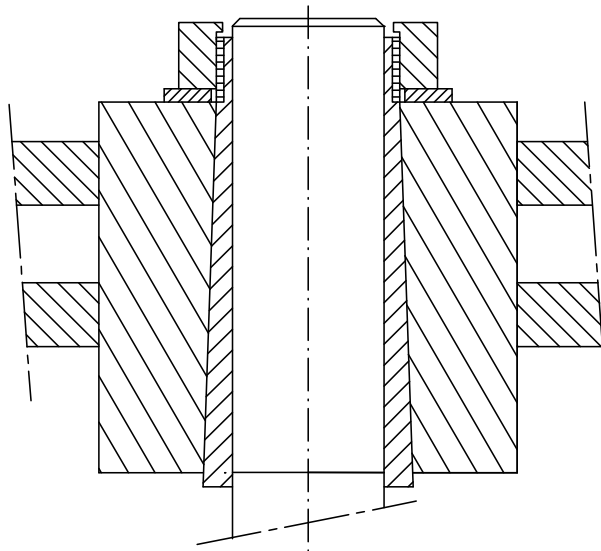


Fig. 4
Example of tapered coupling with intermediate sleeve

1205 Minimum required safety factor, S_c for calculation of connection to rudder stock is to be taken from Table B2:

Table B2 Safety factors for connection to rudder stock		
<i>Rule relevance</i>	<i>Calculation torque</i>	<i>S_c</i>
All vessels	M_{TR}	2.0
	T_{des} for loads as described in 1108	1.0
Vessels complying with rules for ships	T_{des} , keyless connections (except for loads as described in 1108)	2.0
	T_{des} , stresses in keyed connections (except for loads as described in 1108)	1.5
Vessels complying with rules for HSLC and NSC	T_{des}	1.0

1206 Unless otherwise documented and especially agreed upon, friction coefficient, for torque transmission between surfaces of steel or nodular cast iron shall not be taken higher than:

μ = maximum 0.14 for oil injection fitting

μ = maximum 0.17 for dry fitting.

Friction coefficient for other materials will be specially considered.

1207 Surface pressure, p_b at lower end of hub due to bending moment may be taken as:

$$p_b = \frac{3.5M_B}{d_m l_t^2} 10^6 \quad [\text{N/mm}^2]$$

where

M_B = bending moment [kNm], see 103-105 and 1121

l_t = length of hub [mm].

1208 Shrinkage allowance corresponding to a certain surface pressure may be calculated according to the following provided that the hub wall thickness does not have large variations, either circumferentially or longitudinally:

$$\Delta = d \left[\frac{p}{E_e} \left(\frac{1+c_e^2}{1-c_e^2} + \nu_e \right) + \frac{p}{E_i} \left(\frac{1+c_i^2}{1-c_i^2} - \nu_i \right) \right] \quad [\text{mm}]$$

where

p = surface pressure [N/mm²].

d = rudder stock diameter [mm]

E_e = module of elasticity of hub [N/mm²]

E_i = module of elasticity of rudder stock [N/mm²]

c_i = diameter ratio d_i/d [-]

c_e = diameter ratio d/D [-]

D = outer diameter of hub [mm]

d_i = diameter of centre bore in rudder stock [mm]

ν_e = Poisson's ratio of hub [-]

ν_i = Poisson's ratio for rudder stock [-].

For calculation of minimum shrinkage allowance on basis of minimum required average surface pressure, see 1203 h), mean values of D , d and d_i are to be applied.

For calculation of maximum shrinkage allowance on basis of maximum permissible surface pressure, see 1203 i), values of D , d and d_i refer to the considered section.

1209 Pull-up lengths, for tapered connections shall fulfil the following:

$$\delta \geq K \left(\Delta_{\min} + 2(R_{Ai} + R_{Ae}) 10^{-3} \right) \quad [\text{mm}]$$

and

$$\delta \leq K \left(\Delta_{\max} + 2(R_{Ai} + R_{Ae}) 10^{-3} \right) \quad [\text{mm}]$$

δ is not to be taken less than 2 mm for keyless connections and 1 mm for keyed connections, respectively.

Where

K = taper of cone = $l_t/(d_s-d_t)$ [-]

d_t = diameter of rudder stock at top of cone [mm] (d_s , see 1120)

Δ_{\min} = calculated minimum shrinkage allowance according to 1208 [mm]

Δ_{\max} = calculated maximum shrinkage allowance according to 1208 [mm]

R_{Ae} = surface roughness of hub [μm]

R_{Ai} = surface roughness of rudder stock [μm].

Guidance note:

Specified pull-up length should cover a range of minimum 0.5 mm.

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1210 For tapered connections necessary force for pull-up, F may be found from:

$$F = \pi d_m l p_r \left(\frac{1}{2K} + \mu_{pu} \right) 10^{-3} \quad [\text{kN}]$$

where

μ_{pu} = average friction coefficient for pull-up (for oil injection: usually in the range 0.01 to 0.03).

1211 Keyways shall not be located in areas with high bending stresses in the rudder stock. Fillets in keyways must be provided with sufficient radii. Fillet radius larger than 2% of key breadth is normally considered as satisfactory.

1212 The key shear stress and surface pressures in the rudder stock and hub keyways shall be calculated taking into account the friction torque depending on method for verification of frictional fitting.

Shear stress, τ in key:

$$\tau = \frac{S_c T - k_{key} T_{fr}}{\frac{d_m}{2} L_{eff} b} 10^6 \quad [\text{N/mm}^2]$$

Side pressure, σ_p (for contact with rudder stock and hub):

$$\sigma_p = \frac{S_c T - k_{key} T_{fr}}{\frac{d_m}{2} L_{eff} h_{eff}} 10^6 \quad [\text{N/mm}^2]$$

where

T = calculation torque (M_{TR} or T_{des}) [kNm]

k_{key} = factor determined by expected accuracy of the method for verification of fitting:

Table B3 Correction for verification method	
<i>Verification method</i>	k_{key}
Diametrical expansion of hub	1.0
Interference, cylindrical connection	1.0
Pull-up force, dry fitting	1.0
Pull-up length	0.9
Bolt tightening (clamped connections)	0.7

T_{fr} = torque capacity of friction connection [kNm], can be derived from formula in 1203 h)

S_c = safety factor, (see 1205)

L_{eff} = effective bearing length of key [mm]

b = breadth of key [mm]

h_{eff} = effective height of key contact with shaft and hub, respectively [mm]. I.e. key chamfer and keyway fillets are to be accounted for.

In case two keys are fitted, uneven loading shall be considered, reducing the load by only 2/3 of the value achieved when calculating with one key.

1213 Shear stresses in key, τ [N/mm²] as calculated in 1212 shall not exceed:

$$\frac{\sigma_f}{\sqrt{3}} \quad \text{in case } T_{fr} \geq T_W$$

$$\frac{\sigma_f}{2\sqrt{3}} \quad \text{in case } T_{fr} < T_W$$

See also 1204 a).

1214 Maximum permissible surface pressures for key and keyway, σ_p [N/mm²] as calculated in 1212 shall not exceed the values found from Table B4:

Table B4 Maximum permissible surface pressures for key and keyway		
	$T_{fr} \geq T_W$	$T_{fr} < T_W$
Key material	1.0 σ_f	0.5 σ_f
Keyway material, rudder stock	1.2 σ_f	0.6 σ_f
Keyway material, hub	1.5 σ_f	0.75 σ_f

1215 Connection between steering gear and rudder stock by means of split type hub shall additionally comply with the following:

- if split on both sides; minimum two clamping bolts shall be fitted on each side
- if split on one side; minimum two clamping bolts shall be fitted
- one or two keys shall be fitted.

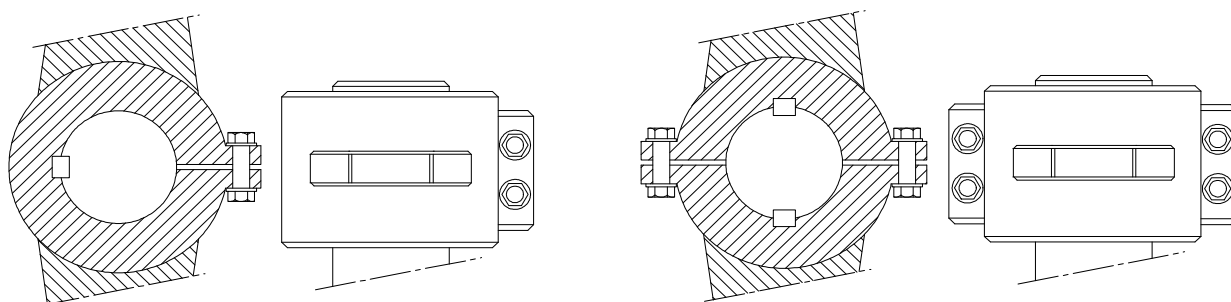


Fig. 5
Examples of split hub connection

B 1300 Stopper arrangement

1301 Suitable stopping arrangements, mechanically limiting the maximum rudder angle, shall be provided. The stoppers may be an integrated part of the rudder actuator. In such case strength of stopper and relevant load carrying parts of actuator shall be evaluated for load from MTR. The load shall be distributed on active stoppers.

For calculation purposes the number of active stoppers shall not be taken higher than three. See also requirement for rudder angle limiter in E505.

B 1400 Bearings

1401 Bearing hardness shall be at least 65 Brinell less than the mating surface.

1402 Synthetic bearing materials shall be of an approved type.

1403 The maximum permissible surface pressure p_s for the bearings in the steering gear arrangement shall be taken in accordance with the maker's specification. Values shall be documented by tests.

Guidance note:

It is a condition that expected lifetime of bearings as a minimum correspond to normal steering gear inspection interval which is 5 years, unless otherwise specified in the makers operating instruction delivered with the product.

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1404 Loading of bearings shall be determined taking the following loads from the actuator into account (as applicable):

- radial forces
- axial forces
- bending moment.

1405 Expected life time of bearings where the main steering gear is included under DP-control shall not to be less than 10 000 hours.

Guidance note:

For calculation of bearing life time, continuous operation at average loading in a DP condition shall be considered. The least favourable combination of ambient temperature and manufacturing tolerances should be taken into account.

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1406 Steering gear included under DP-control shall be provided with an arrangement enabling the measurement of wear of the vertical bearing.

B 1500 Oil seals

1501 Oil seals between non-moving parts, forming part of the external pressure boundary, shall be of the metal upon metal type or of an equivalent type.

1502 Oil seals between moving parts, forming part of the external pressure boundary, shall be duplicated so that the failure of one seal does not render the actuator inoperative. Alternative arrangements providing equivalent protection against leakage may be accepted.

C. Inspection and Testing

C 100 General

101 The certification principles are described in Ch.2 Sec.2. The principles of manufacturing survey arrangement is described in Ch.2 Sec.2 C100.

C 200 Inspection and testing of parts

201 Steering gear components are to be inspected and tested according to Tables C1, C2, C3 and C4. Visual inspection of components shall be performed to verify compliance with approved drawings. Emphasis shall be paid to critical dimensions, clearances and stress raisers.

For requirements related to inspection and testing of electrical equipment, reference is made to Ch.8.

202 Steering gear shall be delivered with a NV product certificate.

203 Autopilots are required to be type approved according to applicable IMO performance standard.

204 The control and monitoring systems for:

— steering gears

shall be certified according to Ch.9.

Table C1 Certification requirements – general						
<i>Component / product</i>	<i>Product certificate</i>	<i>Material certificate</i>	<i>NDT testing</i>	<i>Pressure testing</i>	<i>Other</i>	<i>Rule reference</i>
Piping		NV/TR ¹⁾		1.5 P _{des} ¹⁰⁾		Pt.4 Ch.6 Sec.2 Table A2 Pt.4 Ch.6 Sec.7 E101 and 201 (Rules for Classification of Ships)
Hose				4 P _w ^{6)/} 1.5 P _{des} ¹⁰⁾	Type approval required	Pt.4 Ch.6 Sec.6 D101, 104, 106 Pt.4 Ch.6 Sec.7 E101 and 201 (Rules for Classification of Ships)
Piping flange/bolt		TR				Pt.4 Ch.6 Sec.2 Table A2 (Rules for Classification of Ships)
Valve/valve housing/fitting	NV if D _N > 100 mm and P _{des} > 16 bar	W/TR ²⁾		1.5 P _{des} ¹⁰⁾		Pt.4 Ch.6 Sec.2 Table A2 (Rules for Classification of Ships)
Pump	NV				Type test ³⁾ and capacity test ⁴⁾	Pt.4 Ch.6 Sec.6 B101, B401 (Rules for Classification of Ships)
Pump housing		W/TR ⁷⁾		1.5 P _w		Pt.4 Ch.6 Sec.2 Table A2 Pt.4 Ch.6 Sec.6 B301 (Rules for Classification of Ships)
Weld			RT/MT/ PT			Pt.4 Ch.6 Sec.7 A501 (Rules for Classification of Ships)
Bolts/pins		TR/W ¹¹⁾				
Hydraulic actuator assembly	NV			1.5 P _{des}		Sec.1 D101, Standard for Certification 2.9 5-778.93

Table C2 Certification requirements - rotary vane type rudder actuator			
<i>Component / product</i>	<i>Material certificate</i>	<i>NDT testing</i>	<i>Rule reference</i>
Rotor	NV	MT/PT/ UT 8), 12)	Pt.2 Ch.2 Sec.7 C501
Vane	W	MT/PT/ UT 12)	Pt.2 Ch.2 Sec.7 C501
Housing	NV	MT/PT/ UT 9), 12)	Pt.2 Ch.2 Sec.7 C501 Pt.4 Ch.7 Sec.1 Table B2
Cover	W	MT/PT/ UT 9), 12)	Pt.2 Ch.2 Sec.7 C501 Pt.4 Ch.7 Sec.1 Table B2
Stopper/dividing wall	W	MT/PT/ UT 12)	Pt.2 Ch.2 Sec.7 C501

Table C3 Certification requirements - linked cylinder type rudder actuator			
<i>Component / product</i>	<i>Material certificate</i>	<i>NDT testing</i>	<i>Rule reference</i>
Tiller	NV	MT/PT/ UT 8), 12)	Pt.2 Ch.2 Sec.7 C501
Hydraulic cylinder assembly	NV		Standard for certification 2.9 5-778.93
Piston	W	MT/PT/ UT 12)	Pt.2 Ch.2 Sec.7 C501 Standard for certification 2.9 5-778.93
Piston rod	NV		Pt.2 Ch.2 Sec.7 C501 Standard for certification 2.9 5-778.93
Cylinder	NV	RT/MT/ WPT 5)	Pt.2 Ch.2 Sec.7 C501 Standard for certification 2.9 5-778.93
End cover	W	MT/PT/ UT 9), 12)	Pt.2 Ch.2 Sec.7 C501 Pt.4 Ch.7 Sec.1 Table B2

Table C4 Certification requirements - ram type rudder actuator			
<i>Component / product</i>	<i>Material certificate</i>	<i>NDT testing</i>	<i>Rule reference</i>
Tiller	NV	MT/PT/ UT 8), 12)	Pt.2 Ch.2 Sec.7 C501
Ram	NV	MT/PT/ UT 12)	Pt.2 Ch.2 Sec.7 C501 Standard for certification 2.9 5-778.93
Cylinder	NV	RT/MT/ WPT 5)	Pt.2 Ch.2 Sec.7 C501 Standard for certification 2.9 5-778.93
End cover	W	MT/PT/ UT 9), 12)	Pt.2 Ch.2 Sec.7 C501 Pt.4 Ch.7 Sec.1 Table B2

- 1) NV if $D_N > 50$ mm, TR if $D_N \leq 50$ mm (D_N = nominal diameter of pipe).
- 2) W if $D_N > 100/50$ mm (steel/copper), TR if $D_N \leq 100/50$ mm (steel/copper).
- 3) Type test may be omitted if the pump has proven to be reliable for marine purposes.
- 4) Capacity test may be omitted for pumps produced in series when satisfactory tests have been carried out on similar pumps.
- 5) See Ch.7 Sec.1 Table B2 and Ch.7 Sec.8 D.
- 6) New types of non-metallic hoses with couplings to be subject to prototype test (bursting pressure > 4 times working pressure).
- 7) W if piping class I, TR if piping class II or III.
- 8) May be required for cast steel or iron castings if surface defects are expected. Surface crack detection shall cover all stress raisers (fillets etc.).
- 9) For steering gear required to comply with Appendix A, MT/PT shall be carried out for all machined surfaces of the housing and cover.
- 10) After installation on board, testing at minimum 1.5 times maximum working pressure (P_w) shall be performed.
- 11) TR is required for standard bolts (of the shelf). W is required for bolts uniquely made for the steering gear, and that are in particular critical (stay bolts, fitted bolts, etc.).
- 12) For machinery components made of cast steel: MT or PT. Additionally UT is required.

NV: NV- certificate
W: Works certificate
TR: Test report
MT: Magnetic particle inspection
PT: Liquid penetrant testing
RT: Radiographic testing
UT: Ultrasonic testing
WPT: Weld production testing
 P_{des} : Design pressure
 P_w : Working pressure

D. Workshop Testing

D 100 General

101 The requirements of the rules relating to the testing of class I pressure vessels, piping and related fittings apply.

The steering gear is subject to internal pressure testing for a test pressure 1.5 times the design pressure.

Holding time shall normally be minimum 30 minutes (as required in Ch.7 Sec.8 D505).

102 Each type of power unit pump shall be subjected to a type test.

- a) The type test shall be for duration of not less than 100 hours.
- b) The test arrangements are to be such that the pump may run in idling conditions, and at maximum delivery capacity at maximum working pressure.
- c) During the test, idling periods are to be alternated with periods at maximum delivery capacity at maximum working pressure.
- d) The passage from one condition to another should occur at least as quickly as on board.
- e) During the whole test no abnormal heating, excessive vibration or other irregularities are permitted.
- f) After the test, the pump is to be dismantled and inspected.

Type tests may be waived for a power unit which has been proven to be reliable in marine service.

E. Power Supply, Control and Monitoring

E 100 General

101 Main and auxiliary steering gear power units shall be:

- arranged to restart automatically when power is restored after a power failure
- capable of being brought into operation from a position on the navigating bridge.

102 Electro motors for steering gear shall according to IEC60034-1 at least have a rating of S6-25% for electro hydraulic and S3-40% for electro mechanical. Additional class notations or special types of vessels may require other ratings.

E 200 Main power supply

201 Power supply shall be arranged with redundancy. At least two separate circuits shall be provided for each electric or electro hydraulic steering gear arrangement comprising one or more power units.

202 Each of the separate circuits shall be fed from the main switchboard, alternatively one may be fed from the emergency switchboard.

203 In ships of less than 1 600 gross tonnage, if provided with an auxiliary steering gear independent of electrical power supply, the main steering gear may be fed by one circuit from the main switchboard.

E 300 Emergency power supply

301 Where the rudder stock is required to be over 230 mm diameter in way of the tiller, excluding strengthening for navigation in ice, an alternative power supply shall be provided automatically within 45 seconds. (Exceptions granted for fishing vessels and other vessels not required to comply with SOLAS)

The alternative power supply may either be from the emergency source of electrical power or from an independent source of power located in the steering gear compartment. This independent source of power shall be used only for this purpose.

The alternative power supply shall be sufficient to supply the steering gear power unit which complies with the requirements in B500, and its associated control system and the rudder angle indicator.

302 In every ship of 10 000 gross tonnage and upwards, the alternative power supply shall have a capacity for at least 30 minutes of continuous operation and in any other ship for at least 10 minutes.

303 Where the alternative power source is a generator, or an engine driven pump, starting arrangements are to comply with the requirements relating to the starting arrangements of emergency generators.

E 400 Control gear and associated protective functions

401 Steering gear circuits shall only trip upon short circuit. However if additional over-current trip is used the release current shall be at least 200% with a time delay of minimum 60 seconds. An overload alarm shall

be activated when the current exceeds full load working current.

402 Control gear and cables shall be dimensioned for the maximum load according to 401.

403 The protective shutdown functions associated with the steering gear shall be limited to those necessary to prevent immediate machinery breakdown. Any protective shutdown shall initiate an alarm.

E 500 General requirements, steering gear control system

501 Steering gear control system is defined in A203.

502 Steering gear motors are to be remote controlled from the bridge and local controlled from the steering gear compartment. When remote control is arranged from two or more positions, the arrangement is to be such that the motor can be started independently from any of these positions.

503 Steering gear control shall be provided:

- a) For the main steering gear, both on the navigating bridge and in the steering gear compartment.
- b) When the main steering gear is arranged in accordance with B602 by two independent control systems, both operable from bridge. If the control system consists of an hydraulic telemotor, a second independent system operable from the bridge need not be fitted, except in an oil carrier, chemical carrier or liquefied gas carrier of 10 000 tons gross and upwards.
- c) For the auxiliary steering gear, in the steering gear compartment and, if power operated, it shall also be operable from the navigating bridge. Any control system for auxiliary steering gear shall be independent of the control system for the main steering gear.

504 Any main and auxiliary steering gear control system operable from the navigating bridge shall comply with the following:

- a) If electric, it shall be served by its own separate circuit supplied from a steering gear power circuit from a point within the steering gear compartment, or directly from switchboard busbars supplying that steering gear power circuit at a point on the switchboard adjacent to the supply to the steering gear power circuit.
- b) Means shall be provided in the steering gear compartment for disconnecting any control system operable from the navigating bridge from the steering gear it serves.
- c) The system shall be capable of being brought into operation from a position on the navigating bridge.
- d) Short circuit protection only shall be provided for steering gear control supply circuits.
- e) Failure detection and response to failures shall be arranged in accordance with Ch.9 Sec.2 B and Sec.3 A204.

Guidance note:

The least critical condition is normally to freeze the rudder position.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

505 The actuator is to be equipped with necessary device in order to limit maximum helm angle of rudder enforced by the steering gear. Such a device shall be:

- activated at smaller helm angle than limited by the mechanical stopper arrangement
- synchronised with the physical actuator position and overriding the control system.

E 600 Arrangement of electric and control systems

601 The electric power circuits shall be separated as far as practicable throughout their length.

602 When two or more control systems are used, these shall be kept separated and not be located in the same enclosure, and the cables and pipes shall be separated as far as practicable throughout the length.

603 The requirement in 602 may be waived for main steering stand provided the systems are separated as far as practicable and cables and components are securely installed.

604 Steering order devices for control systems may be operated by the same lever shaft.

605 Steering mode and steering station selectors may also be operated by the same shaft, provided the arrangement is of reliable construction.

606 If additional steering stations are arranged with control circuits branched off from a main steering station, it shall be possible to disconnect each such circuit by a multipole switch on the main steering station.

E 700 Monitoring

701 Alarm and indication requirements are specified in Table E1.

702 All alarms associated with steering gear faults are to be indicated on the navigating bridge and in machinery space. The alarm indicators on bridge shall be readily observable from main steering stand.

703 The rudder angle indicating system is to be independent of any control system. For vessels complying with rules for steel ships the rudder angle indicating system shall be so arranged that a single failure in power supply or anywhere in the indicating system does not cause loss of rudder angle indication on the bridge.

704 Where hydraulic locking, caused by a single failure, may lead to loss of steering, an alarm, which identifies the failed system, is to be provided.

Guidance note:

This alarm should be activated when there is disagreement between the given order versus control system output/execution.

For instance when:

- position of the variable displacement pump control system does not correspond with given order, or
- incorrect position of 3-way full flow valve or similar in constant delivery pump system is detected.

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E 800 Additional Requirements for vessels with DP notation

801 For steering gears included under DP-control the rudder control systems position feedback shall be arranged such that upon feedback failure the rudder remains in its present position.

802 For steering gears under DP-control, the sensors for high temperature alarm and the temperature indication of the steering gear hydraulic oil system (see Table E1) shall normally be located in oil inlet to actuator.

Table E1 – Control and monitoring of steering gear				
<i>System/Item</i>	<i>Gr 1 Indication Alarm</i>	<i>Gr 2 Automatic start of stand- by pump with alarm</i>	<i>Gr 3 Shut down with alarm</i>	<i>Comment</i>
1.0 General				
Rudder position	IR,IL			<i>Local and on bridge</i>
Auto pilot	A			<i>Indication at bridge and machinery space for “running”.</i>
Hydraulic locking	A			<i>Shall identify failed system</i>
Power actuating system				
El. Power failure	A			<i>Indication at bridge and machinery space for “running”.</i>
El. Phase failure	A			
El. Motor overload	A			
Hydraulic oil - Temperature	HA, IL			<i>Applies for steering gears under DP control only. Sensor shall normally be located in oil inlet to actuator.</i>
Hydraulic system oil tank				
Hydraulic system oil tank Level	LA			1)
Storage tank level	IL			
Steering gear control system				
Power failure	A			
Disconnection of bridge control	IR			
Control failure	A			<i>See E504 e)</i>
Gr 1 Sensor(s) for indication and alarm. Gr 2 Sensor for automatic start of standby pump Gr 3 Sensor for shut down IL = Local indication (presentation of values), i. e. in vicinity of the monitored component IR = Remote indication (presentation of values), i. e. on bridge or other manoeuvring stand A = Alarm activated for logical value LA = Alarm for low value HA = Alarm for high value				
1) Low level alarm in separate steering gear control system oil tanks may be substituted by low pressure alarm. It is provided that each of the systems is able to control the main steering gear alone, and that oil leakage in one system has no effect on the other one.				

F. Arrangement for Installation Onboard

F 100 Fastening arrangement to foundation

101 The fastening arrangement for fixing the steering gear to the foundation shall be designed to withstand all possible loads generated from rudder or power unit during operation. As a minimum sufficient strength and capacity in the following conditions shall be considered:

- rudder exposed to a load corresponding to rule rudder torque, M_{TR}
- actuator working at design pressure, P_{des} .

Reaction forces due to bending set up in rudder stock and radial/axial forces shall be taken into account as applicable.

Relevant additional loading due to thermal expansion etc. shall be duly considered.

102 The safety factors applicable for acting forces shall not be taken less than:

When calculating against M_{TR} : $S = 2.0$

When calculating against P_{des} : $S = 1.5$

103 Equivalent stresses in foundation bolts, pins and stoppers shall not exceed yield strength when exposed to loads as described in B401, including the relevant safety factors and pretension of bolts.

In case fitted bolts are applied a condition with loose bolts shall additionally be evaluated.

Bolt pretension shall be duly considered, ensuring that there is always contact between the mating surfaces.

Number of foundation bolts shall normally not be less than four per actuator.

104 If an epoxy chocking compound is applied between foundation flanges, surface pressure due to weight and bolt pretension must not exceed the allowable value stated in type approval certificate for an ambient temp of minimum 55°C.

105 If Epoxy chocking compound is applied it shall be used in combination with fitted bolts, unless stoppers capable of carrying the full shear force are applied.

Further, bending moments in fitted bolts shall be taken into account. Such loads may be caused by deflections in the chocking compound when exposed to shear forces.

F 200 Steering gear compartment

201 The steering gear compartment shall be:

- readily accessible and, as far as practicable, separated from machinery spaces
- provided with suitable arrangements to ensure working access to steering gear machinery and controls. These arrangements shall include handrails and gratings or other non-slip surfaces to ensure suitable working conditions in the event of hydraulic fluid leakage.

202 Electrical power units are to be placed on elevated platforms in order to avoid water splash.

203 Steering gear shall be arranged so that local steering control can be performed by a single person.

Means of communication to bridge shall be available from control position.

Rudder indicator and heading information shall be visible from control position.

Heading information shall be arranged for automatically update when power is restored after a power failure.

204 Operation instructions shall be permanently displayed on the bridge and in steering gear compartment.

The instruction shall contain:

- arrangement and function of steering gear and control system
- instruction for how to handle failure modes
- Procedure for change-over to/from local control and emergency steering
- procedure for change-over between control modes on the bridge and in steering gear compartment
- procedure for operation of power units in normal and in emergency mode.

G. (Intentionally left blank)

H. Installation

H 100 Connection between steering gear and rudder stock

101 Contact area of conical connections shall be (minimum 70%) verified by means of paint test (e.g. tool-maker blue) in presence of the surveyor. Circumferential or full length non-contact bands are not acceptable.

102 Test pull-up followed by control of contact area may be required before final assembly for conical keyless connections intended for injection fitting, if calculations are considered inaccurate due to a non-symmetric design or other relevant reasons. Pull-up length during test pull-up shall not be less than final pull-up length.

103 Final connection of steering gear to rudderstock shall be performed according to approved procedure, in presence of the surveyor.

H 200 Fastening to foundation

201 For mounting on metallic chocks the clearance between mating surfaces shall be checked with feeler gauge and shall be less than 0.1 mm unless otherwise approved.

202 For mounting on epoxy resin, it shall be checked that:

- the resin is type approved
- the mixing, casting and curing is carried out as per maker's instructions
- the cleanliness of tank top and bedplate before casting is as per maker's instructions
- the area and height of resin are within approved dimensions
- the resin is properly cured before bolt tightening.

203 Stoppers taking load in longitudinal and/or transversal direction (as applicable) shall be checked according to the arrangement drawing.

204 The tightening of the holding down bolts shall be checked versus approved specification.

I. Shipboard Testing

I 100 Shipboard testing

101 After installation on board the vessel, and prior to seatrial the steering gear shall be subjected to the required hydrostatic and running tests.

The test shall as a minimum comprise of:

a) hydrostatic testing

- parts of steering gear that has not been pressure tested at workshop shall be tested at 1.5 times design pressure
- assembly shall be tested at minimum 1.5 times maximum working pressure

b) function testing of the steering gear

c) testing alarms and indicators

d) autostart test of power units

e) testing all start and stop functions

f) test control transfer between bridge and local control

g) test safety valve setting (if not performed during in Workshop)

h) testing function and setting of overcurrent protection

i) test and check functions and settings in frequency converter (if applicable)

j) checking mechanical rudder indicator.

102 On double rudder installation where the two units are synchronised by mechanical means, mutual adjustment is to be tested.

I 200 Trials

201 The steering gear shall be tested on sea trial in order to demonstrate the function of the steering gear and

that the requirements of the rules have been met. Design requirements in B401d) need normally not be proved at trials by going with maximum astern speed and maximum rudder angle.

The test shall include the following:

- a) Testing of steering gear function and capacity. Acceptance criteria's are given in B401.
- b) The steering gear power units, including transfer between steering gear power units.
- c) The isolation of one power actuating system, checking the time for regaining steering capability.
- d) The hydraulic fluid recharging system.
- e) The emergency power supply required in E300.
- f) The steering gear controls, including transfer of control and local control.
- g) The means of communication between the steering gear compartment and the wheelhouse. Also the engine room if applicable.
- h) Where steering gear is designed to avoid hydraulic locking this feature shall be demonstrated.
- i) Steering gear for over-balanced rudders or rudders of unconventional design (such as flap rudders) shall additionally be tested turning the rudder over from maximum rudder angle on one side to maximum rudder angle on the other side and vice versa (See B400).

Test items d) and g) may be effected at the dockside.

202 The trial shall be performed under the following operational conditions:

For vessels complying with the rules for ships:

- loaded on summer load waterline. If this can not be done alternative trial conditions may be specially considered. See 204 and 205
- running ahead at maximum service speed corresponding to maximum nominal shaft RPM and maximum continuous rating (MCR) of the main engine(s) and if equipped with controllable pitch propeller(s), the propeller pitch is to be at the maximum design pitch corresponding to the nominal shaft RPM and MCR of the main engine(s).

For vessels complying with the rules for HSLC and NSC:

- full load condition
- running ahead at maximum service speed as defined in Rules for Classification of HSLC and NSC Pt.3 Ch.5 Sec.1 E201
- both in calm water and, as far as practically possible, in a sea state corresponding to upper part of operational condition.

203 Real time recordings shall be performed. As a minimum the following measurements shall be recorded: steering angle, corresponding hydraulic pressure, electric load (Amps) and time used (seconds) for moving of rudder as defined. Recording interval shall be such that sudden pressure peaks or stick-slip performance of steering gear may be detected.

204 When performance test is carried out with reduced draught with partly submerged rudder, calculations showing corresponding rudder force and torque for the trials are to be submitted on request.

205 Ships fitted with semi-spade rudders are normally to be tested with the rudders completely submerged. However, when satisfactory results are proved by sister ships, tests according to I204 with partly submerged rudder may be accepted.

Calculations of the expected rudder force and torque for the trials are to be submitted.

If test results for sister vessels are not available, steering gear test with rudder partly submerged may be accepted upon special consideration in each case.

I 300 Additional requirements for vessels with DP notation

301 For steering gears included under DP-control it shall be verified that the steering gear is designed for continuous operation by testing according to Pt.6 Ch.7 Sec.1 E600 (Rules for Classification of Ships). This can be effected at the dockside.

APPENDIX A

ADDITIONAL REQUIREMENTS FOR NON-DUPPLICATED RUDDER ACTUATORS

A. General

A 100 Application

101 The requirements given in this Section are in compliance with IMO “Guidelines” for the acceptance of non-duplicated rudder actuators for oil carriers, chemical carriers and liquefied gas carriers of 10 000 gross tonnage and upwards but of less than 100 000 tonnes deadweight.

A 200 Documentation

201 In addition to documentation required in Sec.1 A300, the following shall be submitted:

- a) A detailed stress analysis of the pressure retaining parts of the actuator, exposed to design pressure (for information)
- b) Detailed calculations showing the suitability of the design for the intended service (upon request).
- c) Where considered necessary because of the design complexity or manufacturing procedures: fatigue analysis and fracture mechanics analysis (upon request). In connection with these analyses, all foreseen dynamic loads should be taken into account.

Experimental stress analysis may be required in addition to, or in lieu of, theoretical calculations depending upon the complexity of the design.

B. Design

B 100 General

101 Special consideration shall be given to the installation of sealing arrangements, to testing and inspection and to the provision of effective maintenance.

B 200 Dynamic loads for fatigue and fracture mechanics analyses

201 Where applicable, dynamic loads for evaluation of fatigue strength and fracture mechanics shall comprise both the case of high cycle and cumulative fatigue.

B 300 Allowable stresses

301 For the purpose of determining the general scantlings of parts of rudder actuators subject to internal hydraulic pressure the allowable stresses are not to exceed:

$$\sigma_m \leq f$$

$$\sigma_l \leq 1.5 f$$

$$\sigma_{\text{bend}} \leq 1.5 f$$

$$\sigma_l + \sigma_{\text{bend}} \leq 1.5 f$$

$$\sigma_m + \sigma_{\text{bend}} \leq 1.5 f$$

where

σ_m = general primary membrane stress [N/mm²]

σ_l = local primary membrane stress [N/mm²]

σ_{bend} = nominal bending stress [N/mm²]

f = the lesser of:

$$\frac{\sigma_b}{A} \text{ or } \frac{\sigma_y}{B}$$

σ_b = specified minimum tensile strength of the material at ambient temperature [N/mm²]

σ_y = specified minimum yield strength (or 0.2% proof stress) of the material at ambient temperature [N/mm²].

A and B shall be taken as follows:

Table B1 Permissible stresses			
	<i>Steel</i>	<i>Cast steel</i>	<i>Nodular cast iron</i>
A	4.0	4.6	5.8
B	2.0	2.3	3.5

For other materials A and B will be especially considered.

See also Sec.1 B1114.

302 Burst test

303 Pressure retaining parts not requiring fatigue analysis and fracture mechanics analysis may be accepted on the basis of a certified burst test and the detailed stress analysis required by A200 need not to be provided.

304 The minimum bursting pressure, P_B is to be calculated as follows:

$$P_B = P_{des} A \frac{\sigma_{ba}}{\sigma_b} \quad [\text{N/mm}^2]$$

where

P_{des} = design pressure $[\text{N/mm}^2]$ as defined in Sec.1 A211

σ_{ba} = actual tensile strength $[\text{N/mm}^2]$

σ_b and A = as defined in Sec.1 B1114

C. Inspection and Testing

C 100 Non-destructive testing

101 The rudder actuator shall normally be subjected to suitable and complete non-destructive testing to detect the following:

- surface flaws
- volumetric flaws.

If recognised test methods are expected to fail, testing may be omitted, provided that the risk and consequence of material defects are especially considered. See also requirements for non destructive testing in Sec.1 Table C1.

The procedures and acceptance criteria for non-destructive testing shall be in accordance with requirements of recognised standards.

If found necessary, fracture mechanics analysis may be used for determining maximum allowable flaw size.