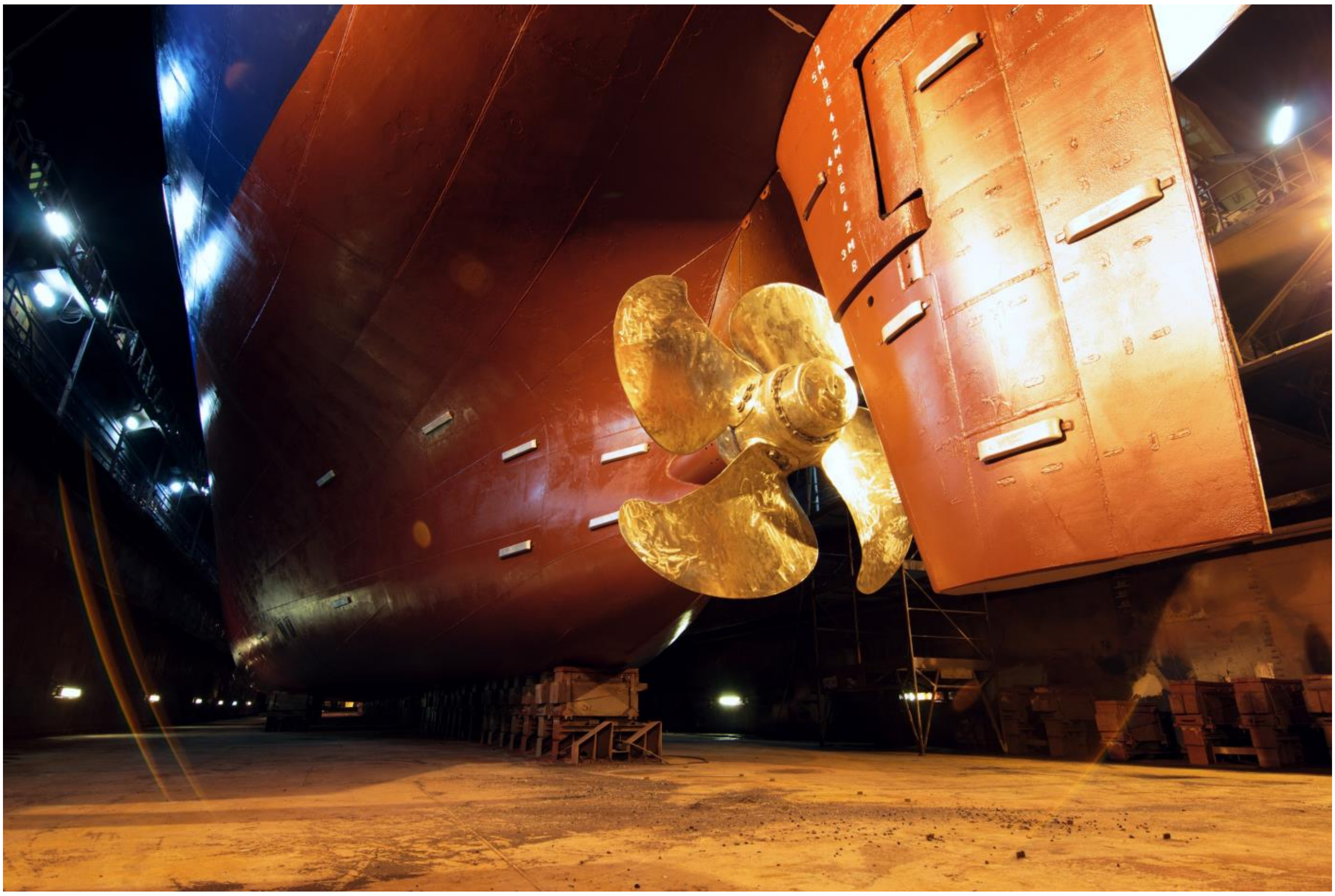
Rudder Bearing Engineering Manual



Synthetic materials are at the core of what we do.
And we do them well.

Contents

1 General

1.1 Overview

The purpose of this manual is to offer a guide to the design of rudder bearings manufactured from Norden materials. This manual will also outline the importance of establishing the correct data required to ensure optimum performance of such bearings.

1.2 Company profile

Norden Marine Bearings AS (NMB AS), including its roots from Norden Maritime AS, have delivered high quality products to maritime customers since 1997. Design and verification of properties and performance of synthetic materials are the company's core competence. Today NMB AS is supplying low friction marine bearing materials and components for worldwide marine applications.

NMB AS' focus is production and processing of synthetic material and supporting systems. The company's various material grades offer unique and differentiated material properties, tailored to suit specific requirements. Production of synthetic materials, testing, certifications and R&D are carried out at the facility in Os, Norway. All Norden composites are produced from raw material to finished machined and controlled at the facility.

Based on NMB AS' technical knowledge, the company offers cost efficient, high quality and environmentally friendly solutions with flexible services.

1.3 Certification

NMB AS holds ISO 9001 : 2008 certification. All the in-house activities are controlled by the Quality Management System.

Testing and quality control measures ensure material conformance. Project traceability is available for all supplied products.

1.4 Service and Support

NMB AS has a highly skilled and experienced staff that offers technical assistance and guide throughout the design and solution phase.

Commercial offerings are backed by technical calculations, drawings, and analysis. The contract managers keep in close contact with the clients throughout the project phase, with emphasis on delivery quality and timeliness. NMB AS' engineers are available for supervision of installation, renewal, repair and modification work.

To minimize the equipment down time, NMB AS will quickly be able to assist the clients that experience unforeseen downtime. Stock keeping for critical parts is available.

1.5 Production Capacity Guide

Norden materials are usually supplied as fully machined components according to customers own drawings. Alternatively, semi-finished materials are supplied in the form of tube or sheet.

The following standard range of sizes is available with other sizes on request, Table 1.1.

Table 1.1: Available standard range of sizes for the materials

Tube	
Minimum ID	8 mm
Maximum OD	2000 mm
Standard lengths	500 / 1000 mm
Sheet	
Minimum thickness	3 mm
Maximum thickness	100 mm
Maximum width	1200 mm
Maximum length	2500 mm

2 Properties and Specifications

2.1 Bearing Material

NMB AS' material portfolio consists of two main types of synthetic materials; composite and elastomer. The composites have high load carrying capability and excellent friction properties. The elastomeric materials have great shock absorption properties and abrasive resistance. The engineering platform allows NMB AS to manipulate the material to the required properties.

2.2 Norden 788 Marine

Norden 788 Marine material is intended for use in high load bushings and bearings applications. The material offers market leading friction properties for composite materials.

The high load composite bearing material is made of specially manufactured synthetic fabric reinforcement using a composite construction process, which is impregnated with thermosetting resins. Solid lubricant fillers are added to make it suitable for dry running applications.

Norden 788 Marine is type approved by DNV GL for rudder applications for both wet and dry running at maximum allowed load.

The technical specifications for Norden 788 Marine is presented in Table 2.1

Table 2.1: Technical specifications for Norden 788 Marine.

NORDEN 788 MARINE – TECHNICAL SPECIFICATIONS		
Tensile strength	60	N/mm^2
Flatwise compressive strength	250	N/mm^2
Edgewise compressive strength	100	N/mm^2
Maximum static load	140	N/mm^2
Maximum dynamic load	60	N/mm^2
Flexural strength	69	N/mm^2
Ultimate shear strength	80	N/mm^2
Density	1,3	g/cm^3
Coefficient of friction	0,08	Dry
Water absorption to saturation	0.5%	Volumetric
Heat Distortion Temperature	140	◦ C
Thermal expansion parallel to laminate	$10 \cdot 10^{-5}$	1 / K
Thermal expansion normal to laminate	$5{,}25 \cdot 10^{-5}$	1 / K
Elongation @ 120 MPa	5	%

3 Rudder Bearings

This section gives the user general advice on rudder bearing design for the composite material and how to establish the essential information for the design process of rudder bearings.

A calculation template and a calculation example for such bearings are provided in section 8 and 9.

3.1 Bearing Design Pressure

Norden 788 Marine for rudder bearings hold type approval for rudder bearing surface pressure up to 10 MPa for both wet and dry running.

3.2 Wall thickness

NMB AS recommends a minimum bearing wall thickness (WT) that can be calculated with the equation below or determined by Figure 3.1.

$$Wall\ thickness_{minimum}[mm] = 0{,}035 \cdot Rudder\ Stock\ Diameter[mm] + 2{,}0[mm]$$

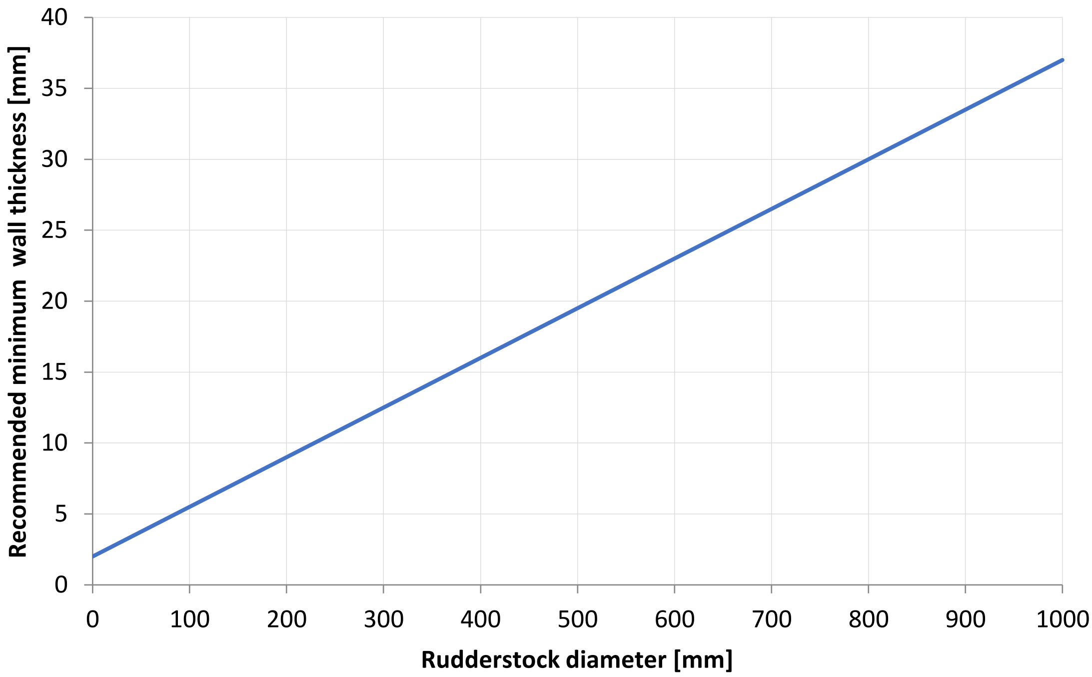


Figure 3.1: The recommended minimum wall thickness of the bearing related to the rudderstock diameter in mm.

The wall thickness of the bearing is often restricted to the dimensions of the rudderstock and housing in retrofits.

Bearings with wall thickness deviating from the minimum wall thickness will be especially checked by NMB AS to ensure that it meets the requirements.

3.3 Length : Diameter (L:D) ratio

The length to bearing diameter is normally regulated by Class Society rules. For rudder bearings the L : D ratio is typically required to be within 1:1 and 1,2:1.

A higher L:D ratio may be accepted based on prof of clearance at the upper and lower edges.

3.4 Lubrication

Water, grease or oil are applicable lubricating mediums for rudder bearings.

Norden 788 Marine is also suitable for dry running without lubrication.

3.5 Lubrication Grooves

Rudder bearings can be designed with grooves for lubrication. The grooves ensure an even distribution of lubrication for reduced friction between rudderstock and bearing.

The number of grooves, the groove depth and width vary with the rudderstock diameter and wall thickness.

The grooves should not be deeper than half of the minimum wall thickness. The depth and width of the groove must be designed to ensure sufficient lubrication access.

3.6 Housing Requirements

The housing should ideally be designed based on the rudderstock and bearing dimensions.

To ensure a good result, after the bearing is installed, it is important that the bearing housing has an even round surface with minimum deviation on the cylindrical surface.

In retrofits, the dimensions of the housing (inner diameter and length) are given. These dimensions govern the bearing design. When needed a liner can be installed on the rudderstock to compensate wall thickness. When planning for a retrofit the housing should be measured at three points along the housing length to ensure a good bearing fit.

3.7 Rudderstock Requirements

The rudderstock or liner should be smooth without cutting edges. A surface finish at maximum Ra 0,8 is recommended. A rougher surface can be used and will cause higher wear. In an arrangement where the rudderstock mating area is in contact with water, the material should be corrosion resistant to ensure low wear.

3.8 Rudder Bearing Design

This section presents a guide on how to extract relevant information on bearing design variables for bearing calculations. The bearing design variables are as follows; interference fit, machining tolerance, running clearance, transfer of interference thermal and swell effects. These variables including housing and rudderstock dimensions are important inputs in the calculation of the bearing design.

Chamfers on the bearing and housing are recommended to avoid damage to the bearing during installation.

3.8.1 Interference

The bearing is secured to the housing by use of interference fit. The interference (INT) is calculated for each bearing to ensure correct hoop stress holding the bearing in place.

The interference is the distance the bearing OD is compressed when the bearing is pressed into the housing as illustrated in Figure 3.2.

Note that installations with interference affects the bore closure and will be checked for all bearing designs during calculations.

From the graph in Figure 3.3, the recommended interference can be found by the housing diameter.

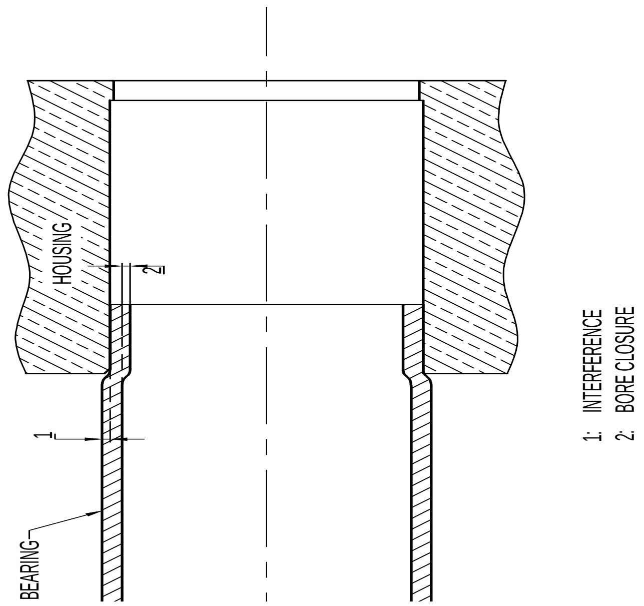


Figure 3.2: Cross section of shaft/rudderstock, bearing and housing illustrating interference and bore closure.

The graph presents interference based on housing diameter, and is valid for optimal bearing wall thickness (100% transfer of interference, explained in section 3.8.7), and the temperature range of -20 C and 40 C.

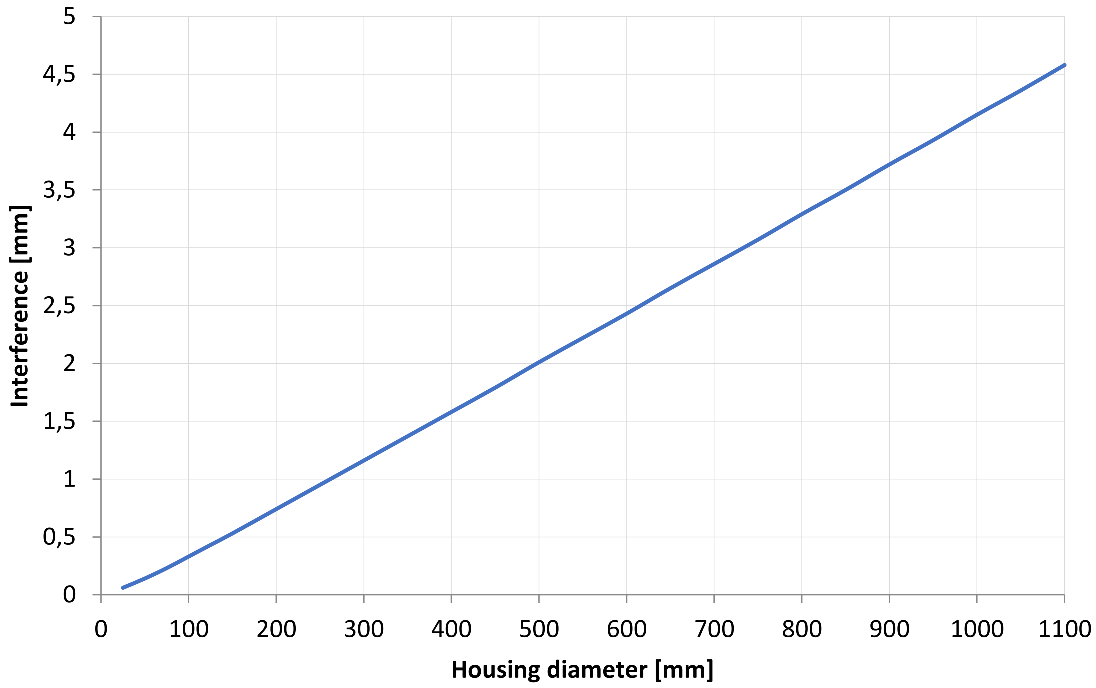


Figure 3.3: Interference related to housing diameter in mm.

Note that the interference may differ from project to project based on application and material. For a thorough calculation of interference and other dimensions, please contact NMB AS.

Note that the graph is valid for optimal bearing wall thickness or 100% transfer of interference in the temperature range of -20 C and 40 C. For other conditions, please contact NMB AS.

Note that the bearing will be shaped to its housing if fitted with an interference. The interference is sufficient to ensure retention and prevents rotation of the Norden bearings in its housing. As an extra safety precaution NMB AS recommends locking the bearing for radial and axial movement.

3.8.2 Machining Tolerance

The machining tolerance (MCT) varies for each type of material. The recommended machining tolerances for Norden composites are presented in Table 3.1.

Table 3.1: Machining tolerances for composite materials

Bearing diameter	M/C Tolerance band
0 – 300 mm	0,10 mm
300 – 700 mm	0,15 mm
700 – 2000 mm	0,20 mm to 0,40 mm

3.8.3 Running Clearance

The running clearance (RC) is the gap between the bearing and the shaft/rudderstock as illustrated in Figure 3.4.

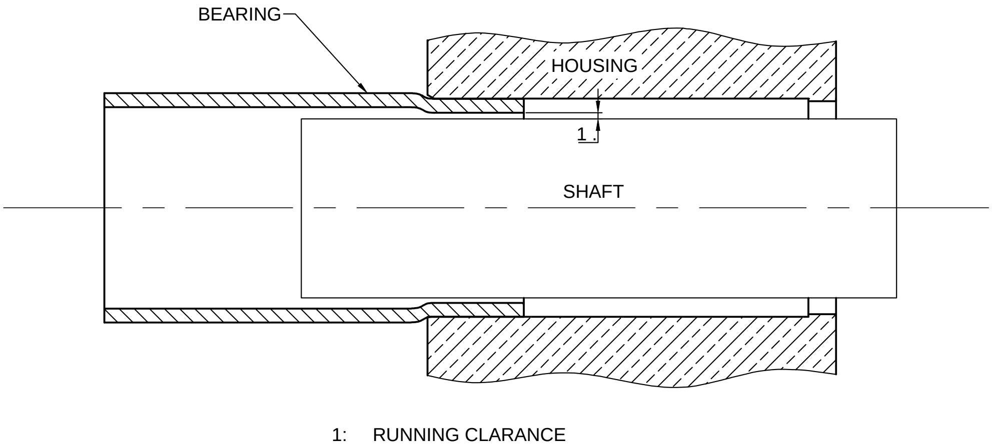


Figure 3.4: Cross section of shaft/rudderstock, bearing and housing illustrating running clearance.

The selected minimum diametrical running clearance should comply with the relevant classification society to which the vessel is registered.

According to the Unified Requirements S10 of IACS, the running clearance for synthetic bearings should not be less than 1,5 mm, considering allowances for swell and thermal effects.

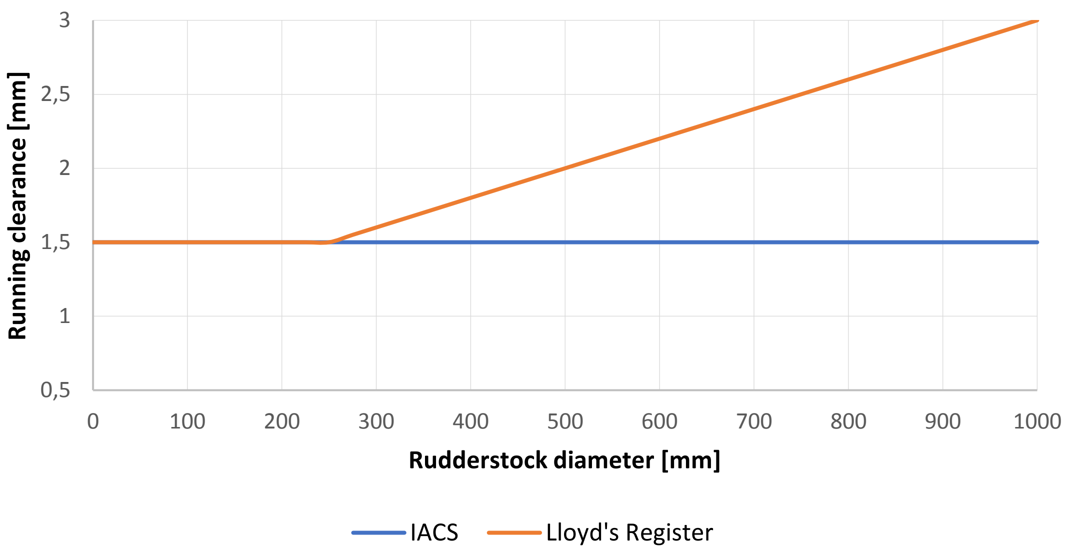


Figure 3.5: The minimum running clearance, recommended by IACS and Lloyd's Register, related to rudderstock diameter in mm.

3.8.4 Operating Temperature

The operating temperature is an important factor when dimensioning the bearing due to thermal expansion and contraction effects.

In bearing calculations, the design temperature is set as the ambient temperature at the machine shop, where the bearing is to be machined.

3.8.5 Thermal Expansion

Materials are subject to thermal expansion and contraction due to temperature changes. This effect must be considered when dimensioning the bearing. For Norden 788 Marine, the thermal expansion coefficients (TEC) are $10 \cdot 10^{-5}$ 1/K (parallel to laminate) and $5{,}25 \cdot 10^{-5}$ 1/K (normal to laminate).

The diametrical and axial thermal expansion can be calculated by the equations below. ΔT is the maximum temperature change the bearing will be exposed to.

$$\boldsymbol{Thermal\ expansion\ (TE_{diamtrical}) = (TEC_{normal} + TEC_{parallel}) \cdot \Delta T_{max} \cdot WT \cdot 2}$$

$$\boldsymbol{Thermal\ expansion\ (TE_{axial}) = TEC_{parallel} \cdot \Delta T_{max} \cdot BL}$$

3.8.6 Swell Effects

Fully or partially submerged bearings are subject to swell due to absorption of seawater. The swell effect will create larger interference, which will reinforce the retention of the bearing in its housing. Due to this effect, the bearing is subject to bore closure and axial expansion, which must be considered when dimensioning the bearing.

The water swell is 0,5% of the wall thickness (WT) and the bearing length (BL) for Norden 788 Marine and can be calculated by the equation below

$$\boldsymbol{Water\ swell\ (WS_{diametrical}) = 0{,}005 \cdot WT \cdot 2}$$

$$\boldsymbol{Water\ swell\ (WS_{axial}) = 0{,}005 \cdot BL}$$

3.8.7 Transfer of Interference

The transfer of interference indicates how much the bearing ID changes relative to the bearing OD.

When installing the bearing in its housing with interference fit, the wall thickness of the bearing may change. If the bearing's OD is reduced the same amount as its ID, the wall thickness is constant, and the transfer of interference is 100 %. When the reduction of the ID is less than the reduction of the OD, the wall thickness becomes less than original, and the transfer of interference is therefore less than 100%.

To achieve the calculated installed ID of the bearing fitted in its housing, the transfer of interference must be accounted for unless it is 100%.

With the bearing wall thickness and the rudderstock diameter, the percentage of the transfer of interference can be estimated by Figure 3.6.

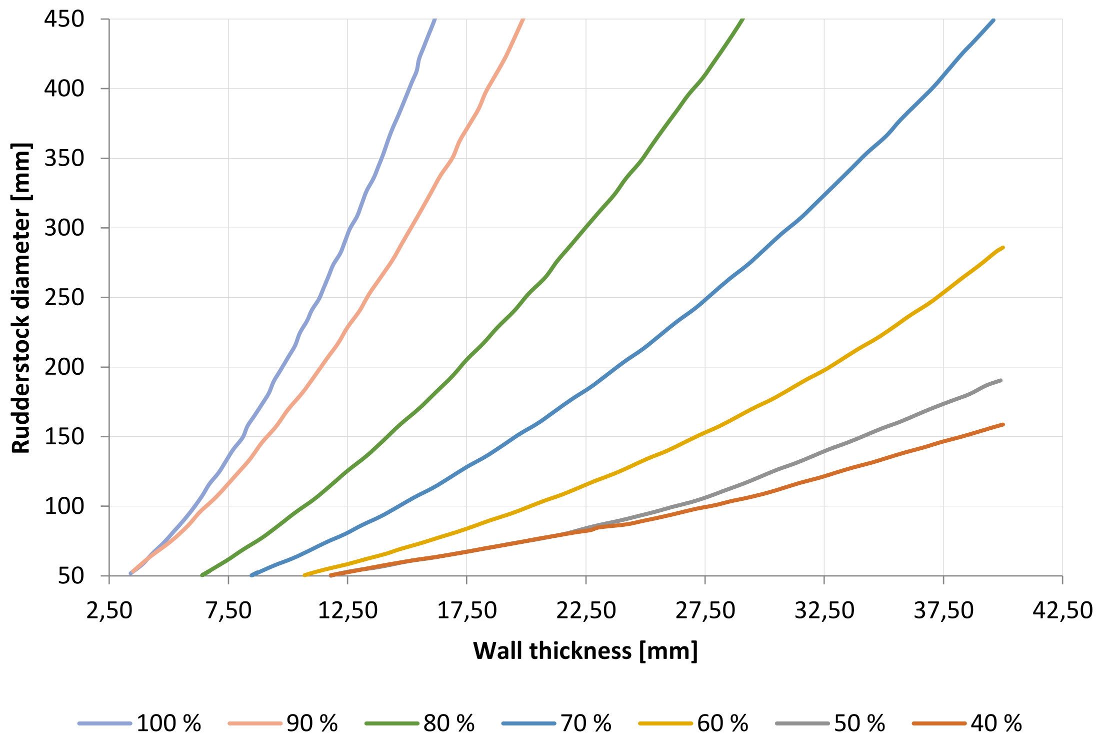


Figure 3.6: Transfer of interference (%) related to rudderstock diameter and wall thickness in mm.

Note Please contact NMB AS for bearing calculations if required bearing do not follow 100% line as given in graph. Following calculation guide is valid for 100% transfer of interference.

3.8.8 Bearing Calculations

This section shows stepwise calculations of a recommended rudder bearing design.

Step 1: The minimum bearing OD (BOD_{min}) can be calculated by equation 1, where the variables required are maximum housing ID (HID_{max}) and interference (INT). In retrofits, the housing dimensions are given.

$$1)\ \boldsymbol{Bearing\ OD_{min}(BOD_{min}) = HID_{max} + INT}$$

The interference can be retrieved from Figure 3.3, based on the housing diameter.

Step 2: To calculate the maximum bearing OD (BOD_{max}), the variables required are the minimum bearing OD (BOD_{min}) and the M/C tolerance band (MCT). The minimum bearing OD is taken from step 1 and the M/C tolerances are given in Table 3.1.

$$2)\ \boldsymbol{Bearing\ OD_{max}(BOD_{max}) = BOD_{min} + \mathrm{MCT}}$$

Step 3: The minimum bearing ID (BID_{min}) can be calculated by equation 3, where the required variables are maximum rudderstock diameter (RSD_{max}), running clearance (RC), maximum bearing OD (BOD_{max}), minimum housing ID (HID_{min}), water swell (WS) and thermal expansion (TE).

The rudderstock dimensions are given by the system requirements. The minimum running clearance required depends on the classification society and can be retrieved from Figure 3.5.

The diametrical water swell, and thermal expansion can be calculated by the equations given in the respective sections.

$$3)\ \boldsymbol{Bearing\ ID_{min}(BID_{min})} \\ = \boldsymbol{RSD_{max} + RC + (BOD_{max} - HID_{min}) + WS_{diamtrical} + TE_{diametrical}}$$

Note that equation 3 applies to fitted bearings with 100% transfer of interference. If the bearing wall thickness deviates from ideal wall thickness, please contact NMB AS.

Step 4: The maximum bearing ID can be calculated by the minimum bearing ID from step 3, the absolute M/C tolerance band given in Table 3.1.

$$4)\ \boldsymbol{Bearing\ ID_{max}(BID_{max}) = BID_{min} + \mathrm{MCT}}$$

Step 5 and 6: The minimum and maximum fitted bearing ID can be calculated by equation 5 and 6.

$$5)\ \boldsymbol{Fitted\ Bearing\ ID_{min}\ (FBID_{min}) = BID_{min} - (BOD_{max} - HID_{min})}$$

$$6)\ \boldsymbol{Fitted\ Bearing\ ID_{max}\ (FBID_{max}) = BID_{max} - (BOD_{min} - HID_{max})}$$

Step 7 and 8: The minimum and maximum fitted clearance can be calculated by the equation 7 and 8

$$7)\ \boldsymbol{Fitted\ Clearance_{min}\ (FC_{min}) = FBID_{min} - RSD_{max}}$$

$$8)\ \boldsymbol{Fitted\ Clearance_{max}\ (FC_{max}) = FBID_{max} - RSD_{min}}$$

Calculation template and example of rudder bearing are supplied in Section 8 and 9. For calculation assistance, please contact NMB AS.

4 Bearing Installation Methods

In this section, methods for bearing fitting and retention are presented. The installation methods are dependent on the bearing design and application.

4.1 Bearing Fitting Methods

4.1.1 Freeze Fitting

All Norden bearings are capable of being freeze fitted using Liquid Nitrogen. The procedure described in this section applies for fitting polymer bearings into steel or plastic housing. The composite bearings will maintain a good structural integrity when cooled, so normal care in handling applies. Consider lifting equipment for large bearings.

Tools/equipment needed:

1. Liquid nitrogen
2. Container capable of withstanding cryogenic temperatures. The container should be insulated for longer cooling times. Large diameter containers may be fitted with an inner wall to limit the amount of nitrogen needed for filling the chamber.
3. If bearings are completely submerged in nitrogen during cooling, a rod, pliers or similar for picking the bearings up.
4. Safety goggles
5. Thermally insulated gloves
6. A template of the housing if the housing is not in the immediate vicinity of the cooling site. Alternatively measuring equipment.

Safety Precautions

Liquid nitrogen has a temperature of -196 °C. Avoid skin contact. Avoid splashing when pouring the nitrogen and when handling the bearings in the nitrogen bath.

Ensure adequate ventilation as the nitrogen, while not being toxic, may replace the available oxygen thus causing suffocation. Bearings cooled in nitrogen are very cold and should only be handled using thermally insulated gloves.

Procedure

1. Prepare the installation site according to the points above. Make sure that all required equipment is in place before installation start.
2. Pour liquid nitrogen in the container. The bearings do not have to be completely submerged, but the level should be high enough to cover the wall thickness on a bearing laying on its side. Complete submersion is recommended for larger bearings that may be difficult to handle in the bath.
3. Put one or more bearings into the container. Turn the bearings so that the entire surface is soaked in the bath.
4. Cooling time is dependent on bearing size. Very small bearings may only take a few minutes, up to 90 minutes for the large bearings. After a soaking period, pick up the bearings and check if they fit the housing or the template, alternatively measure the bearing diameter. If not, return them to the bath to soak some more before rechecking. As the nitrogen boils away over time, top up as needed.
5. Bearings that are sufficiently cooled should slide into the housing easily. Make sure the bearing is completely inserted into the housing. Make sure the bearing does not slide out of the housing as it returns to ambient temperature. After a period, a tight fit should be established. Try to rotate the bearing inside the housing by hand. If not possible,

eventual retainers for keeping the bearing in place may be removed. Leave for at least an hour to let the bearing return fully to ambient temperature.

6. The remaining liquid nitrogen will boil away completely over time. In the meantime, ensure that it will not cause harm or damage to humans, environment or property.

4.1.2 Thermal Contraction

Thermal contraction coefficient of Norden composite bearings is $3.5 \times 10^{-5}\ K^{-1}$. However, as a safety margin, assume a coefficient of $2.0 \times 10^{-5}\ K^{-1}$.

4.1.3 Press Fitting

Smaller bearings are proved to be easier to press into its housing than larger bearings. For larger bearings, freeze fitting with either dry ice or nitrogen is the preferred method to install the bearing in its housing.

When press fitting it is important to keep the equipment available for the required force to press the bearing into its housing. A continuous operation is preferable since a disrupted operation may require extra force. An entry chamfer on the bearing can be helpful in the initiation of the pressing process.

The housing should not under any circumstances be heated or lubricated with grease or oil to assist the pressing process. In addition, the bearing should also be kept clean and free from grease and oil.

4.1.4 Bonding

The bearings can be bonded to its housing with adhesive bonding. This is an alternative installation method to interference fit.

It is important to follow the instructions of the adhesive manufacturer. The housing bore and bearing OD should be kept grease and oil free. A stable temperature during curing is important hence temperature changes may weaken the bond strength. In contrast, a rougher inner and outer surface of the housing and bearing respectively will increase the bond strength.

With this installation method, there is no need to design the bearings with interference. However, the thickness of the adhesive layer must be considered when dimensioning the bearing OD, which will create a clearance between the bearing and the housing. How to estimate the clearance required, please follow the adhesive manufacturer's recommendations. The bearing will therefore not be exposed to bore closure by bonding since there is no interference.

Bonding is not available in combination with freeze fitting since moisture and frost have a negative impact on the bond strength.

4.2 Bearing Retention Methods

In this section, methods for retaining the bearing in its housing to prevent rotational and axial movements are presented. The retention methods for bearing are dependent on the bearing design and can be combined to ensure the bearing is fully retained in its housing and that rotation is impossible. E.g. Interference fit and a mechanical retainer.

Some Classification Societies require mechanical retention of composite bearings. Restraining the bearing from circumferential and axial movement will ensure the bearing position throughout its lifetime.

4.2.1 Interference Fit

By interference fit, the pressure from the bearing on its housing should be enough to prevent rotational and axial movement.

4.2.2 Mechanical

The bearing can also be retained in its housing by mechanical features to prevent rotational and axial movement.

An anti-rotation key, can be of single key or split key design, prevents rotation of the bearing. A retainer ring can be installed to lock the bearing in its housing for safety precautions.

For rudder bearings, a combination of interference and mechanical retention is often used and is recommended by NMB AS.

4.2.3 Bonding

Adhesive bonding can prevent rotational and axial movement, but is not preferred though removal of bearing is made more difficult.

5 Rudder Bearing Monitoring

NMB AS offers bearing monitoring as an option to our bearing supplies.

The monitoring platform can monitor bearing wear of rudder bearings, and can also be expanded to incorporate monitoring of rudderstock and the steering gear.

Optional sensors for; rudderstock torque and bending, steering time and positioning, and pressure and temperature of the steering gear, is available. Through integration with manufacturer of steering gear, the steering gear bearings can also be monitored.

The monitoring system gives a visualization and an overview of the system status. The stored data can be retrieved locally, or through optional remote access.

Alarm limits can be set for each sensor, and be interfaced to the ship's common alarm system.

Condition monitoring of rudder bearings and system can give valuable data for maintenance planning, and facilitate cost saving through extended maintenance intervals and avoidance of unnecessary inspections.

6 Inquiry Information

To design a bearing for a specific application, the requested information is listed below. This set of information will form the basis for the design and price calculations.

- Type of equipment
- Specific application
- Quantity
- Preferred bearing material (if any)
- Rotational rudderstock speed
- Lubrication (if any)
- Lubrication regime
- Maximum operating surface pressure
- Minimum and maximum operating temperature
- Minimum and maximum housing diameter
- Maximum housing length or length of bearing
- Minimum and maximum rudderstock diameter
- Preferred method of retention (if any)
- Preferred method of fitting (if any)
- Other restrictions (If any)

7 Abbreviation and Acronyms

BID	Bearing inner diameter
BL	Bearing length
BOD	Bearing outer diameter
D	Diameter
DNV GL	Det Norske Veritas Germanischer Lloyd
HID	Housing inner diameter
HL	Housing length
IACS	International Association of Classification Societies
ID	Inner diameter
INT	Interference
L	Length
M/C	Machining
MCT	Machining tolerance band
NOV	November
OD	Outer diameter
Ra	Surface roughness, Arithmetical mean deviation in micrometers
RC	Running clearance
RSD	Rudderstock diameter
TA	Type approved
TE	Thermal expansion
TEC	Thermal expansion coefficient
WS	Water swell
WT	Wall thickness
ΔT	Temperature difference

8 Rudder Bearing Calculation Template

All values are in mm unless otherwise stated.

The following values are required to perform bearing calculations		The following values can be retrieved from the design section in the engineering manual	
Housing max ID (HID_{max})		Interference (INT)	
Housing max L (HL_{max})		M/C tolerance (MCT)	
Rudderstock min D (RSD_{min})		Running clearance (RC)	
Rudderstock max D (RSD_{max})		**Thermal expansion coefficients for Norden 788 Marine**	
Max operating temperature [C]		Thermal expansion coefficient ($TEC_{parallel}$) [1/K]	10 x 10^{-5}
Design temperature [C]		Thermal expansion coefficient (TEC_{normal}) [1/K]	5,25 x 10^{-5}

(A) Wall thickness min (WT_{min})	= 0,035	· RSD	+ 2		
	= 0,035	·	+ 2		
(B) Wall thickness actual (WT_{actual})	= (HID	- RSD	- 1,5)	/ 2	
	= (	-	- 1,5)	/ 2	
(C) Thermal expansion diametrical ($TE_{diametrical}$)*	= (TEC_{normal}	+ $TEC_{parallel}$)	· ΔT_{max}	· WT_{actual}	· 2
	= 5,25 · 10^{-5}	+ 10 · 10^{-5}	·	·	· 2
(D) Water swell diametrical ($WS_{diametrical}$)*	= 0,005	· WT_{Actual}	· 2		
	= 0,005	·	· 2		

* Thermal expansion and Water swell to be evaluated for the specific operational situation. If N/A it should not be considered for below bearing machining dimensions.

Bearing machining dimensions						
(1) Bearing min OD (BOD_{min})	= HID_{max}	+ INT				
	=	+				
(2) Bearing max OD (BOD_{max})	= BOD_{min} **(1)**	+ MCT				
	=	+				
(3) Bearing min ID (BID_{min})	= RSD_{max}	+ RC	+ BOD_{max} **(2)**	- HID_{min}	+ $WS_{diametrical}$	+ $TE_{diametrical}$
	=	+	+	-	+	+
(4) Bearing max ID (BID_{max})	= BID_{min} **(3)**	+ MCT				
	=	+				
(5) Fitted Bearing min ID ($FBID_{min}$)	= BID_{min} **(3)**	- BOD_{max} **(2)**	+ HID_{min}			
	=	-	+			
(6) Fitted Bearing max ID ($FBID_{max}$)	= BID_{max} **(4)**	- BOD_{min} **(1)**	+ HID_{max}			
	=	-	+			
(7) Fitted min Clearance (FC_{min})	= $FBID_{min}$	- RSD_{max}				
	=	-				
(8) Fitted max Clearance (FC_{max})	= $FBID_{max}$	- RSD_{min}				
	=	-				

9 Rudder Bearing Calculation Example

All values are in mm unless otherwise stated.

The following values are required to perform bearing calculations		**The following values can be retrieved from the design section in the engineering manual**	
Housing max ID (HID_{max})	550.12	Interference (INT)	2
Housing max ID (HID_{min})	550,05	M/C tolerance (MCT)	0,15
Rudderstock min D (RSD_{min})	499,98	Running clearance (RC)	1,5
Rudderstock max D (RSD_{max})	500,03	**Thermal expansion coefficients for Norden 788 Marine**	
Max operating temperature [C]	40	Thermal expansion coefficient ($TEC_{parallel}$) [1/K]	10 x 10^{-5}
Design temperature [C]	20	Thermal expansion coefficient (TEC_{normal}) [1/K]	5,25 x 10^{-5}

(A) Wall thickness min (WT_{min})	= 0,035	· RSD	+ 2		
= 19,5	= 0,035	· 500	+ 2		
(B) Wall thickness actual (WT_{actual})	= (HID	- RSD	- 1,5)	/ 2	
= 24,25	= (550	- 500	- 1,5)	/ 2	
(C) Thermal expansion diametrical ($TE_{diametrical}$)*	= (TEC_{normal}	+ $TEC_{parallel}$)	· ΔT_{max}	· WT_{actual}	· 2
= 0,148	= 5,25 · 10^{-5}	+ 10 · 10^{-5}	· 20	· 24,25	· 2
(D) Water swell diametrical ($WS_{diametrical}$)*	= 0,005	· WT_{Actual}	· 2		
= 0,242	= 0,005	· 24,25	· 2		

* Thermal expansion and Water swell to be evaluated for the specific operational situation. If N/A it should not be considered for below bearing machining dimensions.

Bearing machining dimensions							
(1) Bearing min OD (BOD_{min})	= HID_{max}	+ INT					
= 552,12	= 550,12	+ 2					
(2) Bearing max OD (BOD_{max})	= BOD_{min} **(1)**	+ MCT					
= 552,27	= 552,12	+ 0,15					
(3) Bearing min ID (BID_{min})	= RSD_{max}	+ RC	+ BOD_{max} **(2)**	- HID_{min}	+ $WS_{diametrical}$	+ $TE_{diametrical}$	
= 504,14	= 500,03	+ 1,5	+ 552,27	- 550,05	+ 0,243	+ 0,148	
(4) Bearing max ID (BID_{max})	= BID_{min} **(3)**	+ MCT					
= 504,29	= 504,14	+ 0,15					
(5) Fitted Bearing min ID ($FBID_{min}$)	= BID_{min} **(3)**	- BOD_{max} **(2)**	+ HID_{min}				
= 501,92	= 504,14	- 552,27	+ 550,05				
(6) Fitted Bearing max ID ($FBID_{max}$)	= BID_{max} **(4)**	- BOD_{min} **(1)**	+ HID_{max}				
= 502,29	= 504,29	- 552,12	+ 550,12				
(7) Fitted min Clearance (FC_{min})	= $FBID_{min}$	- RSD_{max}					
= 1,89	=501,92	- 500,03					
(8) Fitted max Clearance (FC_{max})	= $FBID_{max}$	- RSD_{min}					
= 2,31	= 502,29	- 499,98					

Norden Marine Bearings AS

Industriveien 13

N-5210 Os

Norway

Phone: +47 56 56 55 70

www.nordenmarinebearings.no

post@nordenmarinebearings.no

The engineering manuals content is believed to be correct at time of publishing.