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Selection Criteria for Bearings and Housings in Heavy Movable Structures

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Contents:

1 Abstract

This paper addresses two primary topics:

- Bearing type and size, including AASHTO static safety factor, service fatigue life, and bearing and accessory selection for safe easy installation.
- Housing type, size, and material, including loading, sealing, lubrication type and fill rate, and location of bearings in the housing.

Addressed primarily are rolling element bearings for bascule bridge trunnions, vertical lift bridge sheaves, and swing bridge center pivots. We assume that rotating speeds are less than 100 rpm throughout.

2 Bearing Type and Size

a Bearing Type

Bearing size is first and foremost selected based of shaft size and available envelope dimensions. Shaft size requirement is based on torsional strength of material, stiffness requirement, and historical precedence.

i *Why use Spherical Roller Bearings?*

For trunnion bearings in bascule bridges, the choice is generally between non self-aligning bronze sleeves and spherical roller bearings (SRB). Non self-aligning bronze sleeves are significantly less expensive than rolling bearings and are considered where life requirements are low, alignment is maintained and controlled, and high friction torque is acceptable.

SRBs solve all of the above disadvantages of bronze sleeves. They carry very heavy load, and allow both static and dynamic misalignment within the rolling contact. They also provide low friction and long service life.

Bearings in vertical lift bridges usually undergo several complete revolutions in opening and closing and this makes SRBs especially suitable for such applications. Longer life, misalignment capability and reduced power requirements drive the selection of SRBs.

Typically, SRBs are supplied with Normal/CN clearance. This is because there is no differential temperature between bearing and housing and speed is slow. Less clearance allows for more rollers to be in the load zone. This decreases the maximum contact stress, increases fatigue life, and reduces the chance of impact load causing bearing damage on rolling surfaces.

For the purposes of this document, we will concentrate on Spherical Roller Bearings.

b AASHTO Static Safety Factor

The traditional method for determining size for radially loaded bearings in Heavy Movable Structures has been to use calculations from the American Association of State Highway Transportation Officials (AASHTO), which are based on bearing basic static load rating. Calculations are summarized here, as given in AASHTO FLRE 2000 edition:

$P_{or} = C_{or}/N_s$

$F_{oxy} = X_oF_{ur} + Y_oF_{ua}$

Where:

P_{or} = Factored Radial Design Resistance

F_{oxy} = Factored Bearing Load

= P_{or} for this calculation

C_{or} = Basic Static Radial Load Rating of the bearing

N_s = safety factor

F_{ur} = applied radial load

F_{ua} = applied axial load; not less than 0.15 F_{ur}

X_o = static radial load factor

= 1 for spherical roller bearings

Y_o = static axial load factor

The safety factor, N_s, is given as 5 for counterweight sheave trunnion bearings of vertical lift bridges, and 8.5 for bascule spans with a fixed trunnion per the AASHTO specification. In the application, the bearing is subjected to dead load all the time; therefore, these large safety factors are used.

Static safety factor analysis gives information as to whether the bearing will be permanently deformed by applied load. It does not evaluate bearing life.

c Service Fatigue Life:

Here, estimated bearing life in revolutions is calculated based on load and bearing features.

$P = XF_r + Y_1F_a$ (Y_1 is always used because radial load is high compared to axial load)

$L10_{low\ speed} = a(C/P)^{10/3}$

Where:

$L10_{low\ speed}$ = basic bearing theoretical fatigue life, at 90% reliability, in millions of revolutions

C = bearings basic dynamic load rating

P = equivalent applied dynamic bearing load, accounting for both radial and axial load

10/3 = the roller bearing exponent of the basic life equation

a = adjustment factors for low speed applications, can vary between 1 and 2.3 depending on steel type and coatings.

X, Y_1 = calculation factors determined by bearing size/series, calculated by bearing manufacturers, and defined Anti-Friction Rolling Bearing Association (AFBMA) specification.

Service fatigue life calculation should be used in conjunction with the AASHTO static safety method.

d Calculation Example:

Application conditions:
Counterweight sheave trunnion bearings of vertical lift bridge
Required AASHTO safety factor (Ns) = 5
Radial load = 750 kips
Axial load = radial load *0.15 = 113 kips

Required years of bridge service = 75 years
Opening per day = approximately 20
One bridge open/close cycle = approximately 60 bearing revolutions
Total requirement = 33 million revolutions

Shaft diameter requirement = 560 mm or greater
Other selections may including larger shaft diameter.
Ease of installation of the bearing is essential.

i AASHTO calculation:

232/560 mounted on a tapered shaft is an historically appropriate selection due to bore diameter and it's very heavy section size. We consider a tapered bore bearing and tapered shaft for ease of installation.

Static load rating = C_{0r} = 4946 kips.
$X_o = 1$, $Y_o = 1.8$, $X = 1$, $Y_1 = 1.9$
$F_{oxy} = P_{or} = X_oF_{ur} + Y_oF_{ua} = 953$ kips
$C_{or}/P_{or} = 5.2$
This is a good selection

ii Service Fatigue Life Calculation:

Dynamic load rating = C = 3134 kip
P = 953 kip (same calculation method as P_{or} above)
a = 1

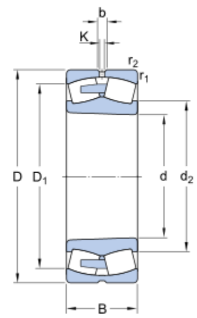
$L10_{low\ speed} = a(C/P)^{10/3} =$ 53 million revolutions
This is confirmed to be a good selection.

Bearing manufacturing catalog data:

232/560 CAK/W33

SKF Explorer

Dimensions



d		560	mm
D		1030	mm
B		365	mm
d_2	≈	706	mm
D_1	≈	878	mm
b		22.3	mm
K		12	mm
$r_{1,2}$	min.	9.5	mm

Tapered bore, taper 1:12

Calculation data

Basic dynamic load rating	C	3133837	lbf
Basic static load rating	C_0	4945797	lbf
Fatigue load limit	P_u	296748	lbf
Reference speed		280	r/min
Limiting speed		430	r/min
Calculation factor	e	0.35	
Calculation factor	Y_1	1.9	
Calculation factor	Y_2	2.9	
Calculation factor	Y_0	1.8	

Mass

Mass bearing	2888	lbs

iii Commercial Viability and Common Sizes:

Some size bearings are used widely in other segments of industry, such as paper and grinding mills. Consider several sizes, and check availability of these with bearing manufacturers.

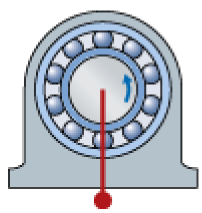
e Design for Easier Installation:

Historical arrangements already exist and have been successful for many years. Use of recommendations for fit and form, and use of arrangements for safe, easy, and accurate installation of bearings is essential for long service life.

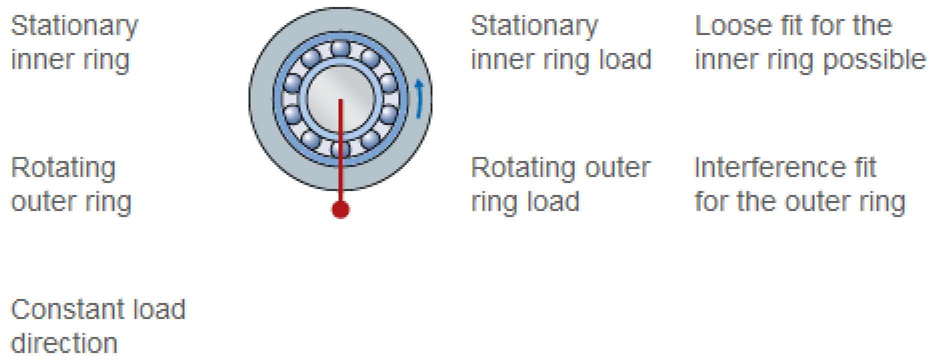
i *Requirement for interference fit:*

For bearings mounted in housings, the operating condition is rotating inner ring, and rotating load inner ring load.

A large "rotating" radial load acts on the inner ring. To avoid damage of the shaft or bearing bore, an interference fit is required between the inner ring of the bearing and the shaft.

Operating conditions	Schematic illustration	Load condition	Recommended fits
Rotating inner ring		Rotating inner ring load	Interference fit for the inner ring
Stationary outer ring		Stationary outer ring load	Loose fit for the outer ring possible
Constant load direction			

When bearings are mounted within sheaves, radial load acts on the outer ring. In this case, an interference fit is required between in the outer ring OD and the bore of the sheave.



ii *Use of hydraulics and accuracy:*

When an interference fit is required at the shaft, installation of bearings may be accomplished by heating the bearing or by utilizing tapered bore bearings and tapered shafts or adapter sleeves. Mounting with tapered components and the use of hydraulics is **safer**, **faster**, and **easier**. Here are two typical arrangements:

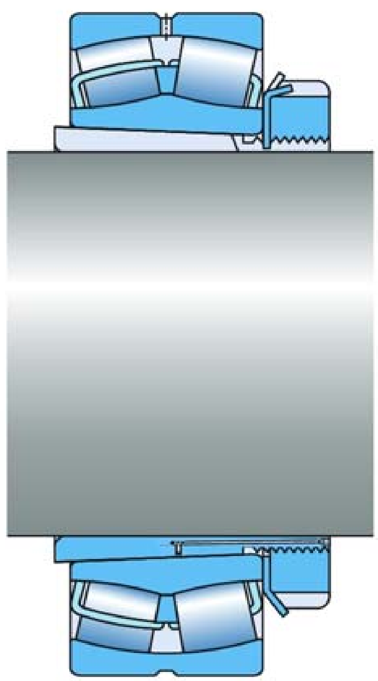


Figure 1

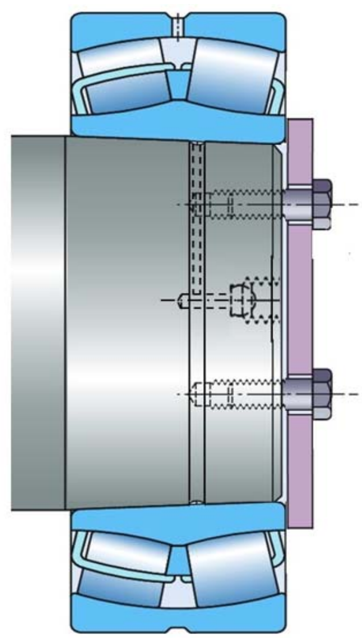


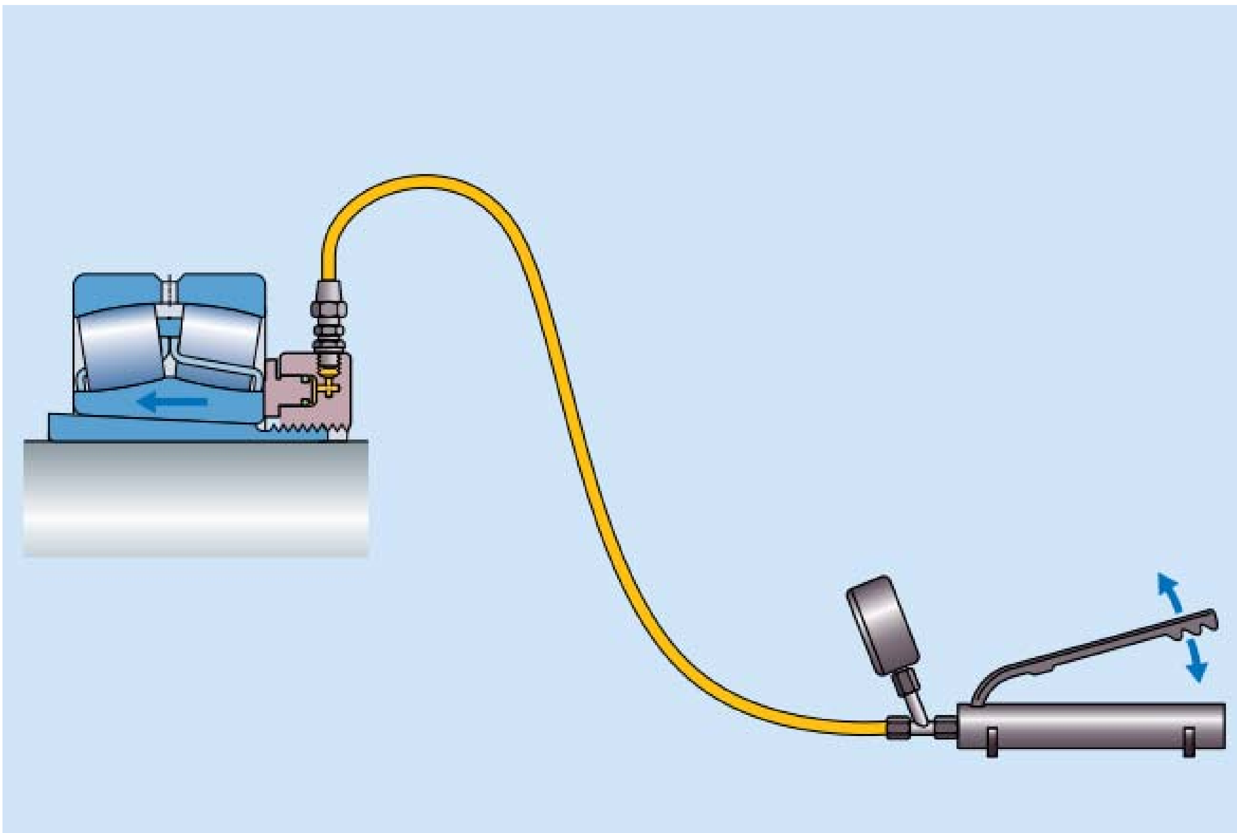
Figure 2

Figure 1 shows mounting on a straight shaft using an adapter sleeve assembly with a hydraulic oil ports built into the sleeve.

Figure 2 shows mounting directly onto a tapered shaft. In this method, the shaft is ground with a taper to accept a tapered bore bearing. Oil ducts and grooves are included in the shaft to make mounting and dismounting possible. Strain gauges may be employed to monitor bearing drive up.

The figures below shows the concept of mounting with a hydraulic nut. With both of the shaft configurations, the use of hydraulics is also a more accurate and simpler mounting method. The correct fit is achieved by controlling the axial drive-up of the bearing from a predetermined position. The method incorporates the use of hydraulic nuts fitted with a dial indicator, and a high accuracy digital pressure gauge, mounted on the selected hydraulic pump.

With this method, we directly measure axial movement of the bearing ring with respect to its mating component. We are not relying on locknut thread measurement or measuring clearance reduction while mounting the bearing.

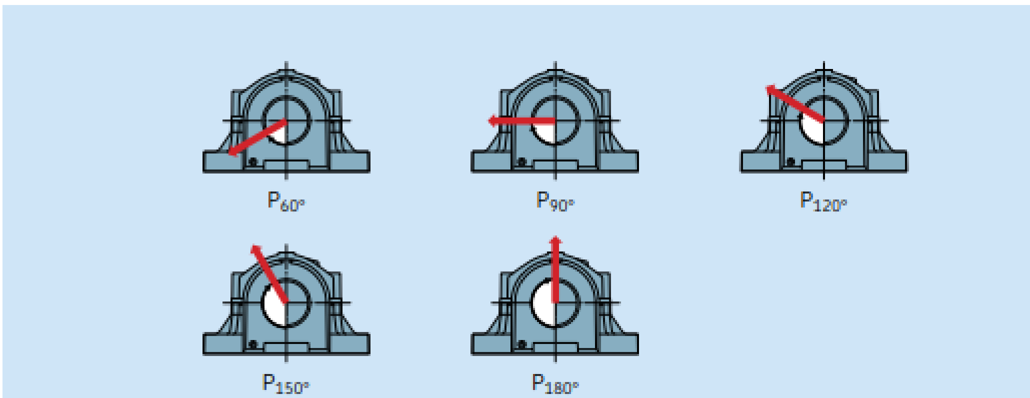


3 Housing Type and Features

Housings are used to transmit load from the bearing into the foundation. They also protect the bearing from contamination ingress and hold in lubricants. They are most often split pillow blocks and are usually constructed of cast steel.

a Safe Load

Directing load into the housing foot allows for the full capability of the bearing to be utilized. Typically, published safe loads at other directions are available as shown below and the needed adjustments need to be incorporated in the design based on housing breaking strength.



Dowel pins, stops, and other structural features may be required should axial loads be high or direction of load is not into the base. Flat pedistals, typically with a machined surface and no welding, under the housing is essential.

i *Blank feet:*
Housings are typically supplied with blank feet. Drilling on site assures that fixing holes are in the right location on the mounting surface and takes possible reduction of load carrying capability due to oval slots in the foot out of the equation.

b Lubrication

Lubrication is required in bearings applications to lubricate rolling contact. Grease is usually used because it stays in place in the housing and also provides additional sealing protection.

i *Calcium Sulphonate grease:*
When we consider type of grease, we seek water repelling properties, high viscosity oil for slow speed operation, pumpability, a thickener that stays in place, ambient temperature range at the bridge, and the ability to maintain a high fill rate. Some lubricants with solid additives become acidic when exposed to salt water marine environments and should be avoided. Calcium sulphonate thickener and mineral oil is a good choice and the preferred option for HMS applications.

ii *Initial grease fill:*
80 to 100% of the bearings and housing cavities are filled with grease. There are no heat generation considerations at slow speed and protection from contamination ingress is enhanced.

iii *Relubrication intervals:*
Standard intervals, such as every 1000 hours, are easier to put in maintenance instructions; however, they have the potential to be very wasteful. A better method is to start with a short interval, inspect seals for dirty grease purge, and increase interval to suit specific environmental conditions.

c Sealing

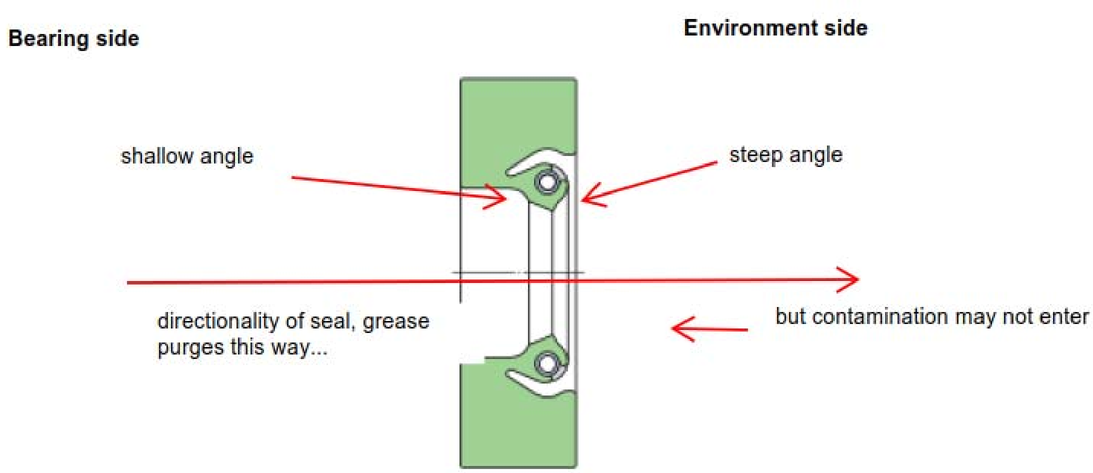
There are many different configurations of housing seals, including labyrinth seals, piston seals and contact seals. Often, a combination of a labyrinth seal/contact seal for smaller housings, and layers of contact seals for larger housings are recommended.

Different combinations are selected because we weigh the requirement for misaligning capability of the seal against sealing capability for this potentially high contamination environment.

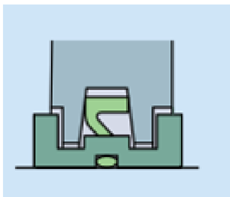
i *Aluminum labyrinth seals:*
Aluminum labyrinth seals offer some advantages:

- Avoid significant shaft and housing damage should misalignment be in excess of seal capability
- The seal will still function effectively under misaligned conditions.
- Visualization of misalignment at installation.
- May be used in conjunction with contact seals.

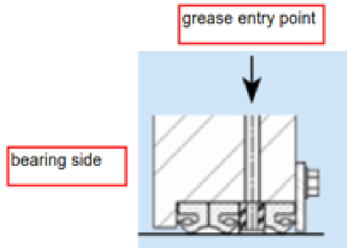
ii *Contact seals:*
Radial lip seals facing outward between housing faces and shaft protects the bearing from contamination ingress and allows purging of grease which also helps to lubricate and maintain the seal lip.



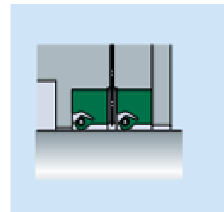
Common configurations:



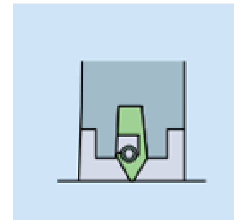
Labyrinth + contact seal



Triple lip seal



Double lip seal



Single lip seal

A labyrinth ring in combination with a contact seal is shown. The OD of the labyrinth ring is machined to be an adequate seal riding surface, the contact seal is protected, and advantages of the labyrinth ring outlined above.

Triple lip seals have two seals to prevent contamination ingress, one seal to prevent grease leakage, and a grease port to allow relubrication and purging of the seals. A spring allows for heavier contact and less leakage at the seal riding area.

Both double and single lip seals prevent contamination ingress and allow purging.

iii *Misalignment:*
Misalignment capability is essential for long service life; therefore, spherical roller bearings are recommended. Spherical Roller Bearing misalignment capability ranges from 1.5 to 3 degrees.

Labyrinth sealing within the housing usually has less misaligning capability than the bearing, in the range of 0.3 degrees.

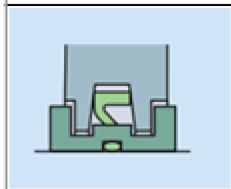
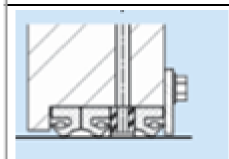
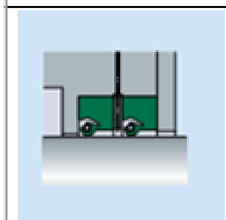
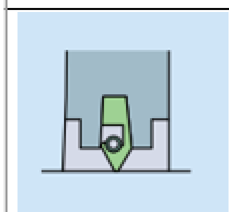
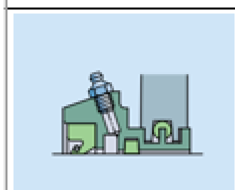
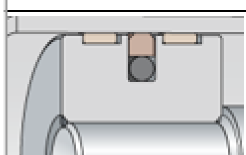
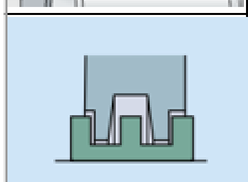
Contacting seals also have misalignment capability in the range of 0.5 to 1.5 degrees.

Other seal types tend to have much less misaligning capability than these options and must be reviewed before selection.

iv *Seal replacement:*
Housings may be designed with external caps so that the inboard seal may be replaced. As the seal may become less effective over time due to dry rot, contamination ingress, or wear, seal cartridge assembly have an advantage. However, if seals are properly lubricated, they have the capability to remain effective for the life of the bearings.

v *High lubrication fill rate:*
For environmental and safety purposes, seals must be capable of holding a high grease fill rate in the housing. Contact seals are very effective as holding grease in place, while allowing purge during scheduled maintenance.

vi Comparison between seal types:

cross section	Type	Relative Sealing	misalignment capability	replacement possible	can hold in grease with high fill rate
	Labyrinth + contact	very good	0.5 degrees	no	yes
	3 contact	excellent	0.5 degrees	yes	yes
	2 contact	very good	0.5 degrees	yes	yes
	1 contact	good	0.5 degrees	no	yes
	Taconite	excellent	<0.1 degrees	no	yes
	Piston	average	<0.1 degrees	no	no
	Labyrinth	average	0.3 degrees	no	no

e Location of bearings in the housing:

One bearing on each shaft has its outer ring located to position the shaft axially while all other bearings on the shaft have outer rings that are floating.

i *Float Control:*
Location of the floating bearing~~s~~ should be approximately in the center of the housing to allow both expansion and contraction of the shaft due to ambient temperature change. Housings that include a feature to set the axial location of the bearing in a floating housing are useful for very large bearing assemblies.

Jacking screws can be used to adjust the bearing in the housing during installation if accommodations in the housing are made.

4 Storage and Handling

Bearings and housings may be stored for years at drive train manufacturing locations or at the job site. While it is typicall for components to be preserved and packed carefully, bearings and housing must be stored indoors in an environment that is dry. They should be kept in original shipping containers until they are to be mounted.

Safety and cleanliness is of utmost importance when handling and mounting bearings and housings. Care to keep oil on bearing components avoids rust formation before operating. There should be no arc welding near or across a bearing at any time throughout its useful life.

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