Thordon Elastomeric Bearings

ENGINEERING MANUAL

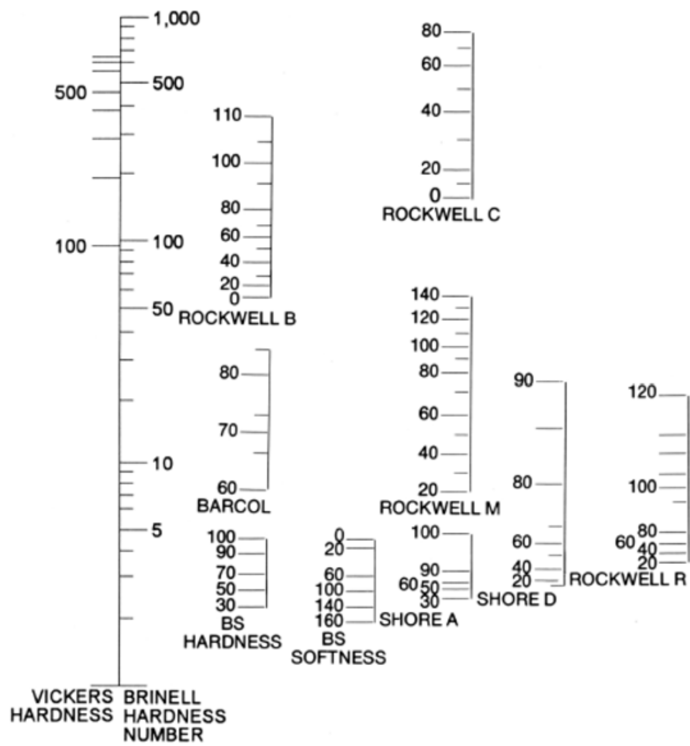
Version: 2022.1

THORDON

SYMBOLS AND UNITS

			Units	
			Metric	Imperial
C_t	=	Thermal Expansion Allowance	mm	inches
C_s	=	Absorption Allowance	mm	inches
d	=	Shaft Diameter	mm	inches
E_o	=	Modulus of Elasticity	MPa	psi
I.D.	=	Inside Diameter of Bearing	mm	inches
O.D.	=	Outside Diameter of Bearing	mm	inches
L	=	Length of Bearing	mm	inches
N	=	Shaft Speed	R.P.M.	R.P.M.
P	=	Pressure	MPa	psi
T_a	=	Machine Shop Ambient Temperature (Nominally 21°C (70°F))	°C	°F
T_o	=	Operating Temperature	°C	°F
W.T.	=	Wall Thickness of Bearing	mm	inches
α	=	Coefficient of Thermal Expansion	$°C^{-1}$	$°F^{-1}$
μ	=	Coefficient of Friction	-	-
V	=	Velocity	m/sec.	ft./min.
γ	=	Poisson's Ratio		

APPROXIMATE COMPARISON OF VARIOUS HARDNESS SCALES



FREEZE FIT COOLANT TEMPERATURES

Dry Ice: -78°C (-109°F)

Liquid Nitrogen: -196°C (-320°F)

Note: All clearances referred to in this manual are diametrical clearances.

METRIC CONVERSION TABLE

- Length
  - 1 Metre (m) = 39.37 Inches (in.)
  - 1 Millimetre (mm) = 0.03937 Inches (in.)
- Mass
  - 1 Kilogram (kg) = 2.205 lbs.
- Force
  - 1 Newton (N) = 0.2248 lbs.
- Pressure
  - * 1 kg/cm^2 = 14.223 psi ($lbs./in.^2$)
  - ** 1 Mega Pascal (MPa) = 145 psi ($lbs./in.^2$)
  - 1 N/mm^2 = 145 psi ($lbs./in.^2$) = 1 MPa
  - 1 MPa = 10.197 kgf/cm^2
  - 1 Bar = 1.0197 kgf/cm^2
  - 1 Mega Pascal (MPa) = 10 Bar

* *Kilo = 1,000*

** *Mega = 1,000,000*

OTHER THORDON TECHNICAL INFORMATION AVAILABLE

a. Thordon Marine Bearing Installation Manual

b. ThorPlas® Bearings Engineering Manual

Please contact your local Thordon Distributor or Thordon Bearings Inc. if you require any of the above.

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1) THORDON DEFINITION

Thordon elastomeric bearing material is made from thermosetting resins which are three dimensional, crosslinked condensation polymers. Thordon elastomeric bearing materials are very hard, tough synthetic polymers that have performance characteristics superior to those of most other bearing materials, both metallic and non-metallic. Thordon elastomeric bearing materials perform particularly well, compared to other materials, in applications where they are exposed to, or submerged in, water, in extremely dirty environmental conditions, and in applications where shock loading is a factor. There are two basic reasons for this superior performance. First, Thordon elastomeric bearing materials return to their original shape after being compressed or deformed under normal operating conditions. Second, due to the basic characteristics of the material, Thordon elastomeric bearing materials have a high natural resistance to abrasion. These two characteristics result in exceptional performance and long life in a number of difficult and dirty environmental conditions in both marine and industrial applications.

Thordon Bearings produces several bearing grades that offer specific operating advantages in different applications.

The grade and colour are noted as follows:

- **XL** (black)
- **SXL** (off-white)
- **SXL TRAXL** (SXL bonded in a metallic shell)
- **COMPAC** (orange)
- **RiverTough/Composite** (yellow outer shell, black inner shell - known as GM2401)
- **HPSXL** (grey)
- **HPSXL TRAXL** (HPSXL bonded in a metallic shell)
- **ThorPlas-Blue:** covered in ThorPlas Bearings Engineering Manual
- **ThorPlas-White:** covered in ThorPlas Bearings Engineering Manual
- **Thorseal:** covered in separate document

This Engineering Manual has been prepared based on the company's many years of experience in manufacturing and installing Thordon bearing products worldwide.

This information is offered as part of our service to customers. **It is intended for use by persons having technical training and skill, at their discretion and risk.**

Global Service & Support

The range of services offered by Thordon Bearings Inc. not only includes advice during the planning stages but also technical service and support after commissioning. This is supported by a worldwide comprehensive network of distributors.

Thordon Bearings Global Service & Support (GSS) team can be contacted at:

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Web: www.ThordonBearings.com

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2) TRIBOLOGY

Tribology is the scientific study of friction, lubrication and wear. It comes from the Greek word 'Tribos' which means 'to rub'.

a. Friction
b. Lubrication
c. Wear

a) FRICTION

Friction is usually defined as a force that resists the motion of an object. With a Thordon bearing, friction occurs when a shaft applies a load to a bearing. When the shaft turns, the friction between the shaft and bearing resists the rotation and therefore a certain amount of torque is required to keep it turning. This torque does not do any useful work and is converted into heat. The magnitude of the friction force F_f is dependent on a value called the coefficient of friction (μ) and the 'normal' applied load (N). The relation is as follows:

$$F_f = \mu N$$

Thus, if the load on the shaft is increased, then the friction force will increase, along with the frictionally generated heat. If the heat cannot be dissipated to a large heat sink or through a lubricant, the surface temperature of the bearing will rise. Because Thordon, like many other synthetic bearing materials, is a poor conductor of heat, the dissipation of frictional heat is a significant consideration in bearing design.

b) LUBRICATION

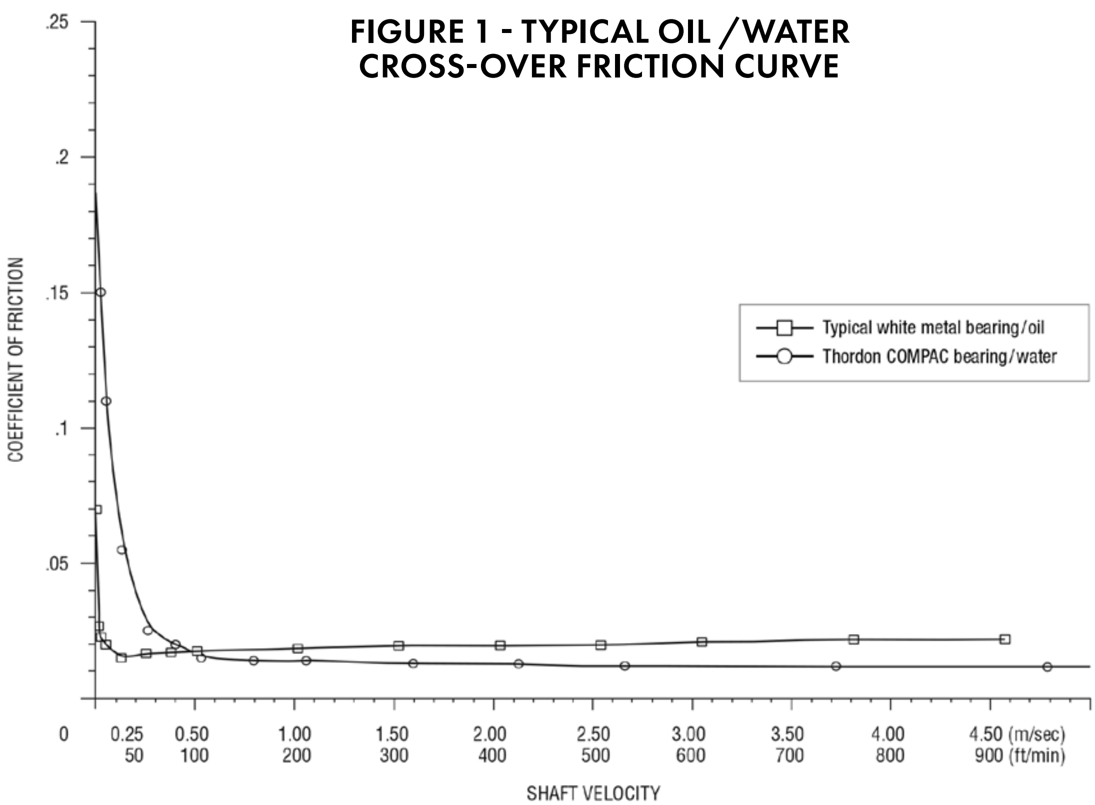
i) Wet Lubrication

Friction is almost always undesirable (except for applications like brakes, clutches and tires). It often leads to problems with overheating, high wear and high running cost. In order to reduce friction, lubrication is employed.

Lubrication is the act of applying a substance, usually a liquid, between two moving surfaces, with the primary aim of reducing friction and/or wear and the secondary aim of carrying away heat. When a bearing is 'wet' lubricated, friction becomes highly dependent on speed and lubricant properties as demonstrated by the two examples in Figure 1.

Figure 1 demonstrates the results of testing with a Thordon water lubricated COMPAC bearing and also a typical oil lubricated white metal bearing. The oil lubricated bearing starts with a lower friction level, which then drops very rapidly to its lowest friction level before slowly climbing back up.

FIGURE 1 - TYPICAL OIL / WATER CROSS-OVER FRICTION CURVE



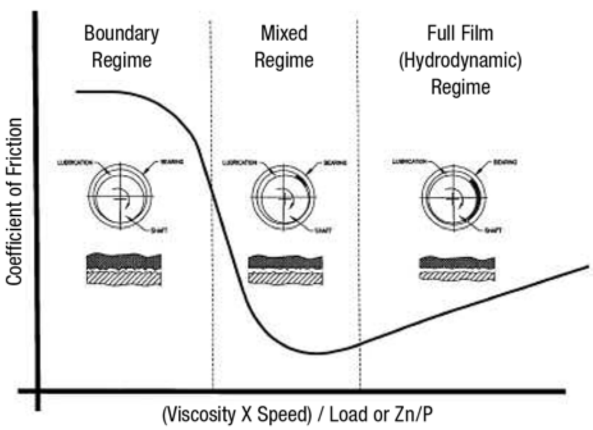
NOTE: Shaft Diameter: 101.4mm (4"); 2:1 L/D ratio; 0.6 MPa (87psi)

The friction force for water lubrication starts higher because of water's poor lubricity and requires a higher speed to achieve hydrodynamic operation. This is due to the low viscosity of water.

An interesting observation is that in the high-speed range, the water lubricated frictional force is actually lower than with oil. Once hydrodynamic operation is achieved, friction increases. However, the higher viscosity of oil results in greater shearing forces and higher friction than with water.

This is illustrated by a typical "Stribeck curve" (Figure 2) which plots the coefficient of friction against the hydrodynamic parameter Zn/P. The curve is divided into three main lubrication regimes.

FIGURE 2 - THE STRIBECK CURVE



The Stribeck curve, illustrating the buildup of hydrodynamic film

In the first (Boundary) regime, direct contact exists between the shaft and the bearing resulting in high friction values. In this region of the curve, high bearing self-lubricity is of significant benefit. As the shaft speed increases we move into the second (Mixed) regime of the curve where the hydrodynamic film starts to build and effectively "lift" the shaft from the bearing surface. The result is less shaft to bearing contact and friction drops rapidly. Further increases in speed take us into the third (Hydrodynamic) regime where the hydrodynamic film builds sufficiently to eliminate all direct contact. As speed continues to increase, friction begins to increase because of the increasing shear resistance imparted by the viscosity of the lubricant.

The transition between lubrication regimes during operation of a bearing depends primarily on lubricant properties, velocity and load. The curve profile and definition of transition points will depend on the bearing geometry, clearance ratio, self-lubricity of the bearing material and surface finish.

A higher viscosity lubricant results in the generation of a hydrodynamic film at a lower shaft speed and effectively moves the transition points to the left. Increasing the viscosity, however, also increases the minimum operating coefficient of friction. Lowering the coefficient of friction of the bearing material results in decreased friction at shaft speeds below the point where full hydrodynamic operation occurs. The geometry of the bearing, and in particular, whether the bearing is grooved also affects the curve. A continuous bearing surface without grooves allows the hydrodynamic film to build quicker than one with grooves. Hydrodynamic calculations show that the necessary speed to achieve a hydrodynamic film is double that for an ungrooved bearing.

Wet lubrication also has the added benefit of being able to carry away frictionally generated heat, the enemy of all bearings. This is especially significant with Thordon because the low thermal conductivity of the material does not allow much heat to be dissipated through the bearing wall (metallic bearings have much higher thermal conductivity and can dissipate more heat through the bearing wall). Wet lubrication can be supplied by several methods varying in complexity and performance. There are drip feed systems (normally oil), which are appropriate for slow to intermediate speeds where heat build up is not a concern. Bath systems are also used - where the bearing is fully or partially submerged in a limited quantity of lubricant. The limiting factor with bath systems is that the whole bath can become overheated if the assembly generates significant heat. A third method is a continuous flow of fresh cool lubricant from an external source, usually force-fed. This method is essential for applications such as marine propeller shafts, vertical pumps and turbines where high RPM and/or significant loads lead to levels of heat generation which cannot be dissipated by a bath of lubricant.

NOTE: WATER FLOW REQUIREMENTS

A Thordon bearing application involving full rotation may require water flow for lubrication and cooling. If required, the minimum recommended flow rate is 0.15 litres per minute per millimetre (1 U.S. gal. per minute per inch) of shaft diameter. Higher cooling water flow rate could be required for other applications (i.e. vertical turbine guide bearings). Please contact Thordon Bearings for review. The water should be as clean and cool as possible. "Cooling" water above 40°C (104°F) should be avoided.

ii) Grease

Grease is a form of lubrication that lowers friction and allows a lubricant film to form. Grease does not have the ability to carry away heat. Fresh grease is applied on a periodic basis to lubricate the bearing and purge the old grease and debris. Periodic lubrication is required to avoid dry running conditions. Grease lubrication of Thordon bearings should be limited to relatively clean environments where heat generation is not a significant problem (see PVT Graph: Figure 14F).

iii) Non-Lubricated – Dry Running

Thordon elastomeric bearing materials can be specified as non-lubricated for relatively low speed applications where regular lubrication is not possible or where abrasives may be attracted to grease lubrication. Thordon SXL exhibits the best properties for dry running due to the high lubricant content of its formulation. This reduces friction and heat generation. Where the pressure on the bearing is beyond the acceptable limit for Thordon SXL, Thordon HPSXL can be considered. It can run dry but does not have as good abrasion resistance as SXL. For even higher pressure dry running applications, a thin wall of HPSXL bonded in a metallic shell or ThorPlas are available.

iv) Pressure Velocity Time (PVT) Curves

Selection of the appropriate method of lubrication can be facilitated by referring to the various PVT (pressure, velocity, time) curves in the Design Guide Section of this manual.

Typical example of bearing with abrasive wear. ▶

c) WEAR

Wear is the destructive removal of material from contacting surfaces moving relative to one another. Wear can take several forms and, as a highly complex process, is difficult to predict.

i) Adhesive Wear

Adhesive wear occurs when minute peaks of two rough surfaces contact each other and weld or stick together, removing a wear particle. Adhesive wear of Thordon elastomeric bearing materials is very minimal at normal temperatures and pressures, but becomes the dominant wear mode as the operating temperature reaches maximum operating limits. The maximum operating temperatures of Thordon elastomeric bearing materials are defined to try and avoid this mode of wear. The amount of adhesive wear is related to the friction between the two surfaces, the pressure on the working surface, and the type and amount of lubrication provided.

ii) Abrasive Wear

Abrasive wear involves the wearing of a softer surface by a hard particle. Examples are sandpaper or a grinding wheel (two body abrasion) or sand particles between a bearing and a shaft (three-body abrasion). Actual abrasive wear will vary with the quantity of abrasives present and with the size, shape and composition of the abrasive particles.

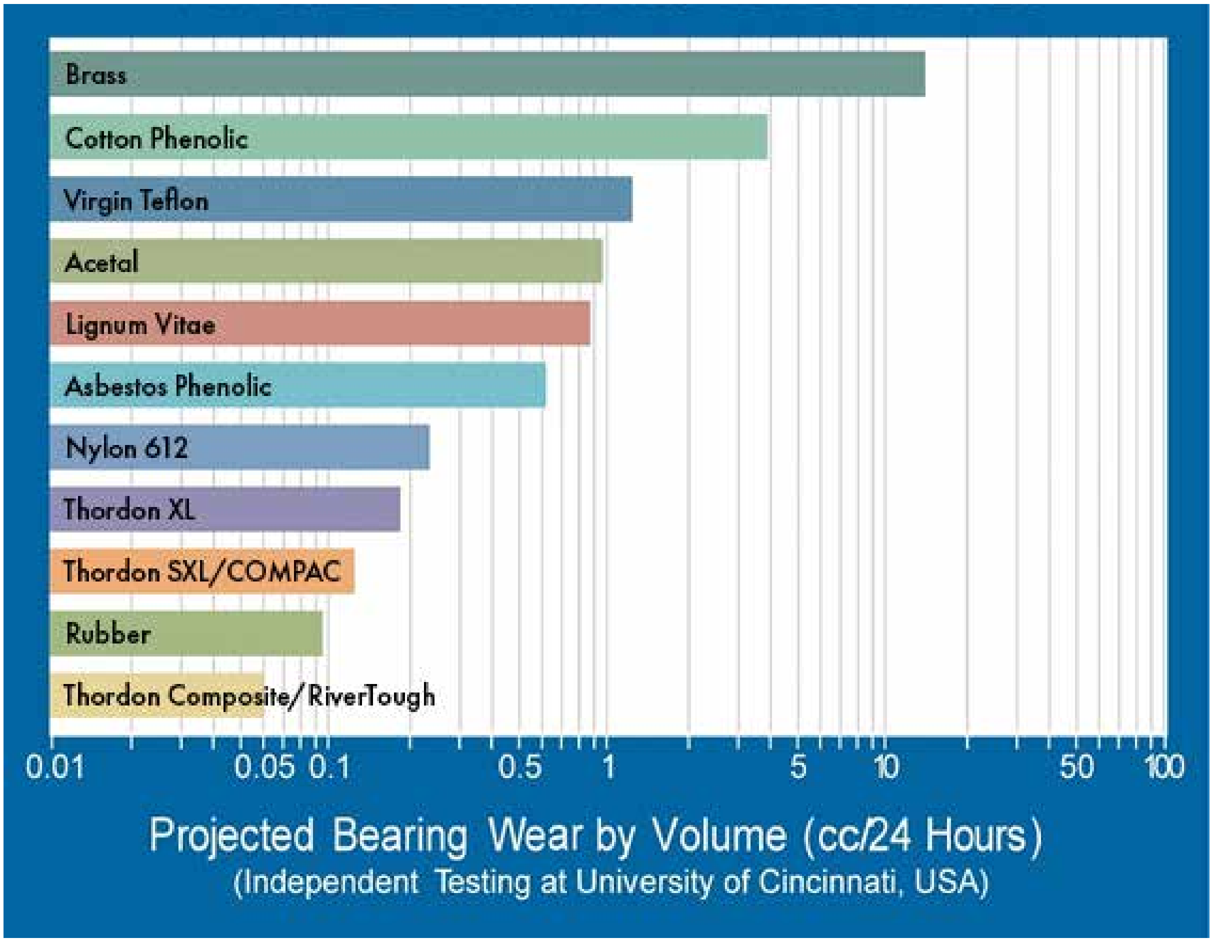
The best approach to minimizing abrasive wear is to reduce or eliminate the quantity of abrasives by using filters or clean water injection. If this is not possible, then a satisfactory alternative for minimizing abrasive wear is to have one surface very hard and the second relatively soft and compliant. Abrasive particles are allowed to be pushed into the softer surface and roll or slide through the contact area with very little damage to the shaft or bearing. The elastomeric nature of Thordon bearings facilitates abrasive wear resistance because the material flexes when it encounters abrasive particles. With shaft rotation the particles are moved along the bearing surface until flushed out through a lubrication groove. With more rigid materials the abrasive particles tend to become embedded in the material and may cause shaft wear.

A continuous flow of fresh lubricant (as in a propeller shaft application), and grooves in the Thordon bearing, will help to flush out abrasive particles and reduce the amount of abrasive wear. Tests have shown that optimum life in an abrasive environment for a water lubricated bearing was obtained with a very hard shaft, a Thordon RiverTough/Composite bearing and a continuous flow of lubricating water.

iii) Wear Comparison

An independent test lab at the University of Cincinnati (USA) has done extensive wear testing of Thordon and other bearing materials. The comparative results are illustrated in Figure 3. All the bearing materials were compared in tests on a specially designed machine using a circulating abrasive slurry – See Note, Figure 3.

FIGURE 3 - TYPICAL BEARING ABRASIVE WEAR RATES



NOTE: Wet third particle abrasion.
Shaft Material: carbon steel
Bearing I.D.: 2.5 cm (1 in.)
Abrasive slurry mixture: 2% bentonite, 6% sand, 6% clay, 86% water

3) PHYSICAL PROPERTIES

a. Thermal Effects	e. Stiffness	i. Hysteresis
b. Effect of Water or Oil	f. Compression Set - Creep - Stress Relaxation	j. Chemical Resistance
c. Shape Factor	g. Shear	k. Typical Physical Properties
d. Stress Strain	h. Impact Resilience	

a) THERMAL EFFECTS

i) Temperature Limits

All bearings are subjected to the combined effects of the ambient environmental temperature and the frictional heat generated during operation. Thordon elastomeric materials, like all other non-metallic materials, have a low thermal conductivity compared to metal so allowances must be made to limit frictional heat build up.

The upper temperature limit for Thordon elastomeric materials operating in a non-aqueous environment is 105°C (225°F). Above 105°C (225°F), softening of the surface occurs. As the surface softens, the coefficient of friction increases. This in turn results in additional heat being generated. The temperature increases further and the process continues until the bearing fails. In some cases (such as misalignment), this may be arrested provided a quenching medium is supplied.

The lower operational limit of Thordon elastomeric materials is -60°C (-80°F). It is possible, however, during shrink fitting to use liquid nitrogen at a temperature of -195°C (-320°F) without Thordon becoming too brittle to fit.

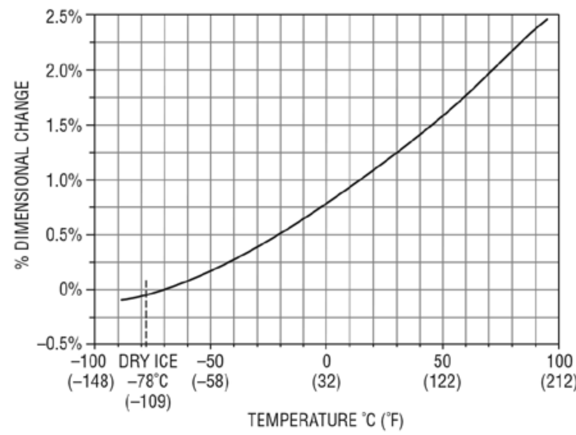
The upper temperature limit for Thordon elastomeric materials operating in a wet environment is 60°C (140°F) due to Hydrolysis. Hydrolysis is explained in more detail in the following subsection b) Effect of Water or Oil. This limit also applies to other liquids with a significant aqueous content. For bearings lubricated with standard mineral grade oil, the upper temperature limit is 75°C (170°F).

Thordon manufactures other polymer grades for higher temperatures - please contact Thordon for details.

ii) Coefficient of Expansion/Contraction

The coefficient of thermal expansion/contraction for Thordon elastomeric materials is non-linear, like other non-metallics, and varies throughout its temperature range. Figures 4 & 5 show typical results of Thordon materials which exhibit lower coefficients of contraction than of expansion. The coefficient of thermal expansion for HPSXL is 12 x 10^{-5} °C^{-1} (6.7 x 10^{-5} °F^{-1}) and does not exhibit the same non-linearity of SXL, COMPAC and XL.

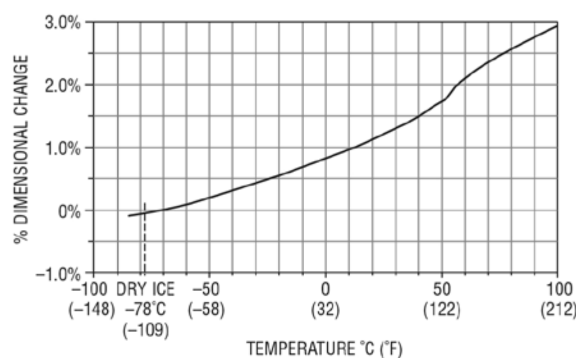
FIGURE 4 - THORDON XL and GM2401 %DIMENSIONAL CHANGE vs. TEMPERATURE



COEFFICIENT OF EXPANSION FOR TEMPERATURE RANGE

<0°C (32°F):	10.2 x 10^{-5} (°C^{-1})	*> 30°C (86°F):*	18.1 x 10^{-5} (°C^{-1})
	5.7 x 10^{-5} (°F^{-1})		10.1 x 10^{-5} (°F^{-1})
0°C to 30°C:	14.8 x 10^{-5} (°C^{-1})		
(32°F to 86°F)	8.2 x 10^{-5} (°F^{-1})		

FIGURE 5 - THORDON SXL and COMPAC %DIMENSIONAL CHANGE vs. TEMPERATURE



COEFFICIENT OF EXPANSION FOR TEMPERATURE RANGE

<0°C (32°F):	10.9 x 10^{-5} (°C^{-1})	*> 30°C (86°F):*	21.1 x 10^{-5} (°C^{-1})
	6.1 x 10^{-5} (°F^{-1})		11.7 x 10^{-5} (°F^{-1})
0°C to 30°C:	15.1 x 10^{-5} (°C^{-1})		
(32°F to 86°F)	8.4 x 10^{-5} (°F^{-1})		

b) EFFECT OF WATER OR OIL

i) Water Absorption

Thordon elastomers expand in water approximately 1.3% by volume under atmospheric conditions at a temperature of 21°C (70°F) due to the isotropic nature of the polymeric structure. At this temperature or less, full expansion may take 6 to 18 months depending upon geometry. Should the temperature be increased, not only does the volumetric absorption percentage increase, but also the rate of absorption. In tests using water at 60°C (140°F) the volumetric absorption increased to 2.0% within 100 hours.

In order to determine the effects of water absorption on Thordon elastomeric materials as it relates to a bearing press fitted in a housing, a series of tests were performed. These tests showed the approximate average effects of water absorption on both bore closure and axial length at 21°C (70°F). The average effect on bore closure is .011 multiplied by the wall thickness. The average effect on axial swell is .005 multiplied by the length of the bearing.

ii) Hydrolysis

When Thordon elastomers are subjected to continuous immersion in hot water, i.e. above 60°C (140°F), the material chemically deteriorates over time due to a reaction with the hot water. This deterioration or breakdown is known as hydrolysis. The surface of the material softens initially and then eventually cracks and breaks. Hydrolysis will also occur with other liquids with a high aqueous content.

Typical example of bearing with hydrolysis.

iii) Absorption of Oil

Absorption by Thordon elastomers of standard mineral grade lubricating oil is minimal, particularly at low temperatures such as 22°C (72°F). Dimensional changes are small and their consideration is less important than those in water at such temperatures.

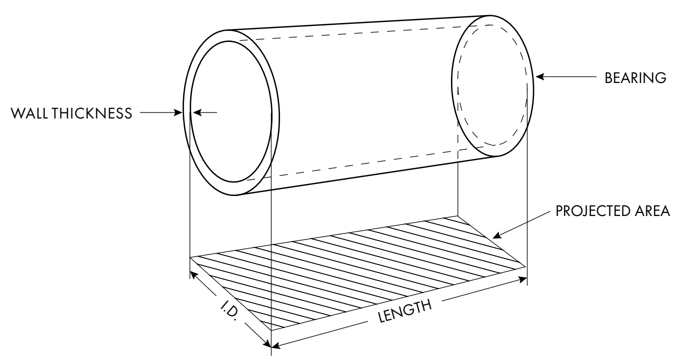
However, in high operating temperatures, volumetrical absorption needs to be considered. For example, at 75°C (167°F), the volumetrical expansion can be above 2.5%.

In practice, the dimensional allowances used for water lubricated bearings are also used for oil lubricated bearings. This is partially because of concern for the lower thermal conductivity of oil compared to water. When a different type of lubricating oil is used, it should be tested for compatibility with Thordon materials before installation of the bearing. Thordon elastomers may react differently to non-standard lubricating oils. A significant change in dimensions (beyond that expected for water), or softening after immersion in the lubricant for more than 24 hours will indicate that the lubricant is not compatible with Thordon elastomeric materials.

c) SHAPE FACTOR

Compression testing of elastomers has determined that the stress strain curve is greatly affected by the shape of the part. This effect is known as the Shape Factor and is determined by dividing the loaded area by the area free to bulge. For a given load, as the shape factor increases the resulting deflection of the elastomer decreases. The load bearing capacity of an elastomer is limited by the amount of deflection it can accept, so increasing the shape factor enables the elastomer to support more load.

FIGURE 6 - SHAPE FACTOR ILLUSTRATION



How the shape factor relates to a sleeve bearing is important. Figure 6 indicates how the calculation is applied to a bearing retained in a housing.

$$\text{Shape Factor} = \frac{\text{Length}}{2 \times \text{Wall Thickness}}$$

Using the shape factor equation, it can be seen that if the thickness is reduced, the shape factor will increase. The shape factor used in most Thordon testing is 8. The results and method of testing are shown in the following sub section, d) Stress Strain.

PHYSICAL PROPERTIES

d) STRESS STRAIN

When a load is applied to Thordon elastomeric bearings, they move in accordance with the force exerted. In compression, the volume will not significantly change, but there can be a significant change to the shape.

The normal stress strain curves are determined experimentally using a tensile test machine and a standard test sample. However, in order to develop data more appropriate to the loading of a Thordon bearing, it was necessary to test the material in the compressive mode using a typical bearing form.

FIGURE 7 - STRESS-STRAIN TESTING APPARATUS

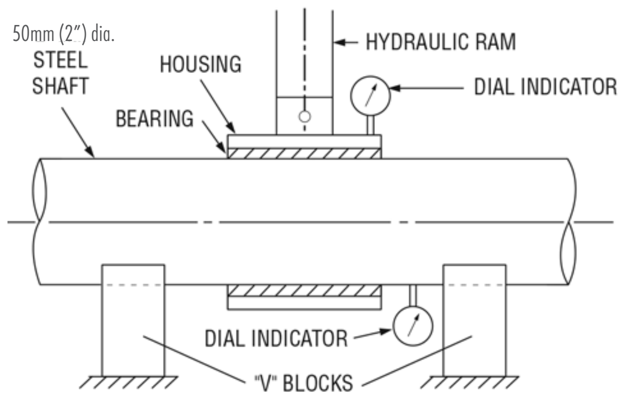
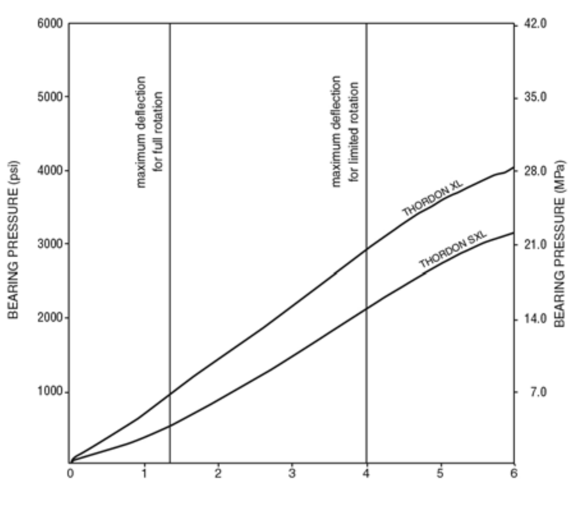


Figure 7 shows how the bearing was loaded and how the deflection was measured. Note that the shaft deflection was subtracted from the housing deflection in order to obtain net bearing deflections.

FIGURE 8 - THORDON ELASTOMERS STRESS-STRAIN CURVES



BORE: 50mm (2")   LENGTH: 65mm (2.5")
WALL THICKNESS: 4.0mm (0.155")   SHAPE FACTOR: 8

In compression, the Stress-Strain Curve for Thordon elastomers in Figure 8 is dependent on the shape factor of the material and its ability to move against both the mating and housing material. For the same deflection, a bonded sample will carry more load than a sample where the bearing can expand axially. If lubrication is added to the mating surface allowing the elastomer to freely move during the loading process, the curve is expected to be flatter than if the mating surface is dry.

Using a shape factor of 8, testing indicated a maximum deflection limit of 1.25% for full rotation installations, and 4% for oscillating motion. Beyond these limits, bearing performance may deteriorate. These limits do not take into consideration any frictional heat generated by shaft movement.

By taking the shape factor concept to its logical conclusion, it is possible to design Thordon sleeve bearings capable of operating at high pressures. The Thordon HPSXL TRAXL bearing, for example, develops very high shape factors by bonding a thin layer of Thordon HPSXL into a metallic shell. Depending on the operating environment, HPSXL TRAXL bearings can accept loadings as high as 70 MPa (10,000 psi).

Thordon XL, SXL and COMPAC are true elastomers and as such do not have an ultimate compressive strength.

Higher load bearings with a thin wall polymer bonded to a metallic shell can also be made using XL or SXL.

e) STIFFNESS

Bearing stiffness is dependent on both size parameters and physical properties. The size parameters are the bearing length, diameter and wall thickness. The physical property to be considered is the Compressive Young's Modulus (E_o) of the bearing material, which is equal to compressive stress divided by compressive strain.

Stiffness $= (L \times D \times E_o)/t$

where:
- L = Bearing Length: mm (in.)
- D = Bearing Diameter: mm (in.)
- E_o = Compressive Young's Modulus: MPa (psi)
- t = Wall Thickness (W.T.): mm (in.)

For bearings with equal size parameters the bearing stiffness is directly proportional to the value of Compressive Young's Modulus of Elasticity for the material.

Figure 9 gives the value of Eo, Compressive Young's Modulus of Elasticity for various materials commonly used as bearings.

NOTE: The bearing shape factor was assumed to be 8 for these calculations. For elastomeric materials, the effective Compressive Modulus of Elasticity, Eo, increases a small amount for correspondingly large increases in shape factor. Therefore, the values of stiffness assumed are estimated to be accurate to +/- 20% over a wide range of bearing shape factors.

In engineering calculations, the stiffness of bearing support structures is typically in a range between 0.5 to 1.0 MN/mm (2.8 to 5.7 x 10^6 lbs./in.). This is much less than the typical bearing material stiffness of 5.0 to 20.0 MN/mm (28.0 to 112.0 x 10^6 lbs./in.). The typical stiffness of Thordon is approximately 5 MN/mm (28 x 10^6 lbs./in.) and the typical water film stiffness is approximately 50 MN/mm (280 x 10^6 lbs./in.). As a result, the stiffness of the bearing material is normally not considered in shaft whirling vibration calculations. When rubber bearings are being specified, due to the low stiffness characteristics of rubber (20% to 25% of that of Thordon), shaftline designers may be accustomed to considering the bearing flexibility when making whirling vibration calculations. However, this is not the case with Thordon XL, SXL, COMPAC or HPSXL where, due to a much higher stiffness, the Thordon bearing can be assumed to be very often stiffer than the bearing support structure.

FIGURE 9 - COMPRESSIVE YOUNG'S MODULUS OF ELASTICITY (E_O)

Material	E_o (MPa)	E_o (psi)
Thordon SXL/COMPAC	**440**	**64,000**
UHMWPE	480	70,000
Thordon XL	**490**	**71,000**
Thordon HPSXL	**650**	**94,250**
Laminated Phenolic	2,500	362,594
Nylon	2,750	400,000
ThorPlas Family	**3,280**	**476,000**
White Metal	33,500	4,860,000
Steel	206,900	30,000,000

f) COMPRESSION SET, CREEP AND STRESS RELAXATION

i) Compression Set

Compression set or permanent set is the residual deformation remaining after the removal of the deforming compressive stress. Under normal Thordon bearing operating conditions, compression set is not a problem. Please consult with Thordon Bearings if a Thordon bearing will be exposed to constant high pressure combined with temperatures above 50°C (122°F).

To reduce compression set, the shape factor should be increased. This reduces the initial deflection and therefore the amount of possible compression set. Increasing the shape factor is especially important when the pressure is in excess of 10 MPa (1450 psi). In such applications, Thordon TRAXL or ThorPlas bearings should be used.

ii) Creep

When an elastomer is subjected to a load, it will deform proportionally to that load and in inverse proportion to the shape factor. Some deformation will also continue with time. This effect is known as 'creep'. In the normal operating range of Thordon bearings, creep is not a significant factor. As with compression set, it only becomes significant when bearings are continuously exposed to high pressure and high temperature. The amount of creep, like compression set, can be reduced by increasing the shape factor as the load increases, thereby reducing strain for any given pressure.

iii) Stress Relaxation

Stress relaxation is the direct result of creep and varies depending on the stress level. Stress relaxation is usually expressed in terms of percentage stress remaining after a specified period of time at a given temperature. This factor is significant when calculating dimensions for interference fit bearings. The interference must be sufficient to ensure that adequate retention force exists over time.

It has been determined by testing that Thordon bearings can lose their interference fit (by stress relieving) in the housing when subjected to elevated temperatures. Thordon SXL and COMPAC stress relieve at temperatures greater than 60°C (140°F) while Thordon XL and RiverTough/Composite stress relieve at temperatures greater than 80°C (175°F). Bearings exposed to temperatures above these levels should not be fitted using an interference fit. Bonding is the recommended alternative.

PHYSICAL PROPERTIES

g) SHEAR

The shear force on a sleeve bearing is a function of the coefficient of friction between the bearing, the shaft and the nominal load. When bearings are installed using an interference fit, the relative force is sufficient to prevent rotation. If the friction force or normal load should increase dramatically, such as an accumulation of significant abrasives, the shear force may exceed the retention force. If there are concerns regarding increases in the coefficient of friction, please contact Thordon Bearings.

h) IMPACT/RESILIENCE

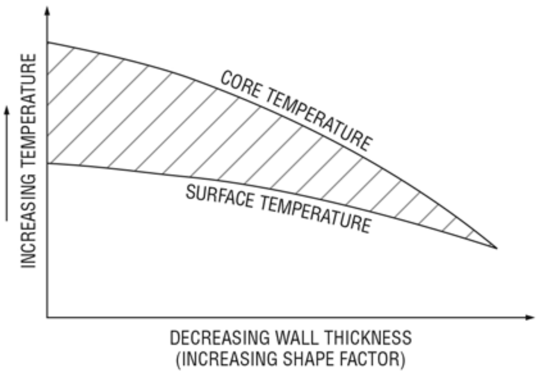
Thordon elastomeric materials, which possess high impact strength, have the ability to absorb shock loads and the resilience to return to original shape. Resilience is defined as the ratio of energy given up in recovery from deformation to the energy required to produce the deformation. This combination allows Thordon elastomeric materials to resist pounding out of shape which frequently occurs and can lead to failure with white metal or plastics. At almost 10 times the impact strength of nylon, Thordon elastomeric materials are almost unbreakable. In applications where there are significant low frequency impact loads, the bearing should be designed with a heavier wall thickness.

i) HYSTERESIS

Hysteresis is a type of dynamic failure due to high frequency flexing. The failure occurs when the material absorbs an impact load and, before the material can fully recover from the first impact, it is subjected to a second one. The result is an energy build up below the surface of the material in the form of heat. This heat, if allowed to accumulate, will eventually damage the material. Hysteresis is the percentage energy loss per cycle of deformation and can be measured as the difference between the percentage resilience and 100%.

Thordon elastomeric materials, due to the nature of their formulations, can be subject to damage by hysteresis. If the application being considered will subject Thordon elastomeric materials to dynamic impact loading that could result in hysteresis, there are design considerations that will minimize the potential for problems. Figure 10 illustrates that increasing the shape factor (reducing the wall thickness) will reduce the deflection and increase the rate of recovery, thus reducing heat creation and build up. A thinner wall thickness also allows increased dissipation of heat through the bearing wall to the housing.

FIGURE 10 - EFFECTS OF HYSTERESIS



j) CHEMICAL RESISTANCE

Thordon is non-corrosive and is resistant to oil, water and most chemicals. It is not affected by lubricants normally used with sleeve bearings. Thordon elastomeric materials are unaffected by mild acid or caustic baths (pH range 5-10) or other chemical environments which would be harmful to metallic bearings. See the Thordon Elastomeric Bearings Chemical Resistance guide in Figure 11.

For critical applications it is recommended that an immersion test be performed to determine whether or not Thordon will be safe to use. Significant softening or dimensional changes after twenty-four hours of immersion at application temperatures will indicate that Thordon is unsuitable for that application. For further information, please contact your Thordon distributor or Thordon Bearings Inc.

FIGURE 11 - THORDON ELASTOMERIC BEARINGS CHEMICAL RESISTANCE

Chemical/Fluid	Chemical Resistance	Chemical/Fluid	Chemical Resistance
Salt solutions	A	Hydrocarbon/fuels	A-B
Sodium chloride	A	Aromatic – benzene, toluene	B
Weak acids	B-D	Aliphatic – gasoline, grease	A-B
Acetic acid	D	Lubricating oils (petroleum)	B
Lactic acid	B	Chlorinated solvents	D
Strong acids	B-D	Alcohols	D
Sulphuric, 5%	B-C	Ethanol	D
Sulphuric, concentrated	D	Methanol	D
Hydrochloric, 10%	B	Ketones	D
Weak bases	A-B	Methyl ether ketone	D
Ammonia 10% Aq.	A	Acetone	D
Sodium carbonate	B	Ethers	D
Triethanolamine	B-D	Diethyl ether	D
Strong bases	B	Esters	D
Sodium hydroxide, 10%	B	Ethyl acetate	D
Oxidizing agents	B-C	Methyl acetate	D
Hydrogen peroxide, 1-3%	B	Freon 12	A-C
Chromic acid	C	Vegetable Oils	A-B

A: Excellent - No Effect B: Good - Little Effect
C: Fair - Moderate Effect D: Unacceptable

k) Figure 12 - Typical Physical Properties – Metric & Imperial[(1)]

Property[(2)]		XL	SXL	HPSXL		COMPAC	RiverTough/ Composite (GM2401)
Ultimate Tensile Strength ASTM D-638	MPa psi	35 5,000	37.5 5,450	40 5,800		37.5 5,450	17 2,500
Nominal Hardness Value Shore D - ASTM D-2240		73	67	76		67	92[(3)]
% Elongation - ASTM D-638		70	150	70		150	265
Young's Modulus (tensile)	MPa psi	850 123,000	605 88,000	925 134,000		605 88,000	- -
Poisson Ratio		~ 0.45	~ 0.45	~ 0.45		~ 0.45	~ 0.45
Izod Impact - notched Avg. - ASTM D-256	Joules/m ft-lb/in	~150 ~3	~500 ~9	- -		~500 ~9	{ sample not broken
Specific Gravity		1.21	1.16	1.28		1.16	1.10
Thermal Conductivity	W/m-k Btu/hr-ft-F		~0.25 ~0.14	~0.25 ~0.14		~0.25 ~0.14	~0.25 ~0.14
Thermal Capacity	KJ/kg-k @ 30°C Btu/lbm-F @86°F	~1.5 ~0.36	~1.5 ~0.36	~1.5 ~0.36		~1.5 ~0.36	~1.5 ~0.36
Coefficient of Thermal Expansion Strain	$\times 10^{-5}$ (°C^{-1}) or (°F^{-1})			(-20°C < T < 80°C) (-4°F < T < 176°F) 12 x 10^{-5} °C^{-1} or 6.7 x 10^{-5} °F^{-1}			
	T < 0°C 0°C < T < 30°C T > 30°C T < 32°F 32°F < T < 86°F T > 86°F	10.2 14.8 18.1 5.7 8.2 10.1	10.9 15.1 21.1 6.1 8.4 11.7			10.9 15.1 21.1 6.1 8.4 11.7	~10.2 ~14.8 ~18.1 ~5.7 ~8.2 ~10.1
Volumetric Swell (%) @20°C (68°F) **- Water** **- Oil/Grease**		1.3 1.3	1.3 1.3	1.3		1.3	~1.3
Compression Set (%) Ref. ASTM D395 method B		-	-	-		-	27%
Coefficient of Friction				< 200 Bar < 3000 psi	> 200 Bar > 3000 psi		
Dry	static dynamic	0.35 - 0.45 0.30 - 0.40	0.25 - 0.35 0.10 - 0.20	~0.35 0.28 - 0.35	0.09 - 0.15 0.07 - 0.12	0.25 - 0.35 0.10 - 0.20	- -
Wet	static dynamic	0.30 - 0.40 0.20 - 0.25	0.25 - 0.35 0.10 - 0.20	0.30 - 0.40 0.25 - 0.35	0.08 - 0.15 0.06 - 0.12	0.25 - 0.35 0.10 - 0.20	0.40 0.15 - 0.20
Flammability - ASTM D-635-56T		SE[(4)]	SE	SE		SE	SE
Operating Temperature (Min./Max.)							
Dry[(5)]	°C °F	-60/107 -76/225	-60/107 -76/225	-60/107 -76/225		-60/107 -76/225	
Wet	°C °F	-7/60 20/140	-7/60 20/140	-7/60 20/140		-7/60 20/140	-7/60 20/140
Oil/Grease	°C °F	/75 /167	/75 /167			/75 /167	

Notes:

(1) Appearance of '~' is indicative of interpolated or estimated values based on in-house testing of this or similar materials.

(2) All tests to develop the above data were done under carefully controlled conditions in our own laboratory to ensure the most accurate relative data possible. Bear in mind that comparison of tensile strength is less meaningful for non-metallic materials compared with metals. This is especially true of non-metallic bearings loaded in compression.

(3) Shore A.

(4) SE – self extinguishing

(5) Material used at dry temperatures exceeding 60°C (140°F) must be retained by suitable positive means. Please review these applications with Thordon Engineering.

4) DESIGN GUIDE

a) APPLICATION ANALYSIS

In order to perform any analysis of an application, all the appropriate information must be reviewed and correctly evaluated.

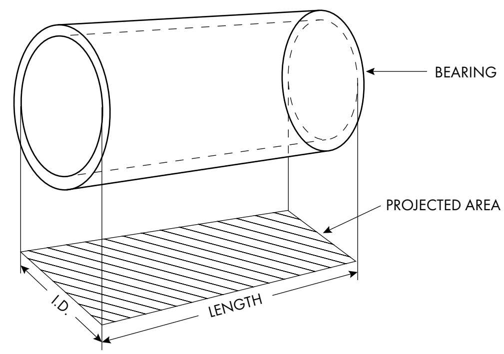
The following list covers the general subject headings which have been discussed in previous sections or will be covered in this section.

- Operating Environment
  i) Temperature
  ii) Abrasive or Clean
- Pressure
- Sliding Velocity
- Type of Lubrication
- Size
- Method of Retention
- Previous material used & problems associated with it.
- Mating Surface
- Life Requirements
- Duty Cycle
- Initial Clearance Requirements

b) BEARING PRESSURE

Bearing pressure is calculated by dividing the radial load by the projected or cross sectional area. The projected area is determined by multiplying the inside diameter of the bearing by the bearing length, as in Figure 13. The use of inside diameter multiplied by bearing length is a bearing industry norm for calculating the projected area for bearing pressure. Dividing the load by the projected area gives the approximate pressure. This assumes that the pressure is uniform across the bearing area. In reality, the pressure is greatest at the 6 o'clock position and decreases in a parabolic curve to zero where the shaft starts to have clearance with the bearing. It is therefore advantageous, considering load carrying capacity, to keep running clearances to a minimum.

FIGURE 13 - BEARING PRESSURE



Radial load needs to be defined as maximum design load, normal operating load or a combination of static and impact loads. Is the load constant or cyclic? These factors all need to be analyzed in the grade selection process as noted in sub-section 4 a).

$$\text{Bearing Pressure} = \frac{\text{Radial Load}}{\text{Projected Area}} = \frac{\text{Load}}{\text{Length x I.D.}}$$

c) VELOCITY

The sliding velocity or the peripheral shaft speed is an important design factor. Velocity is an essential consideration when evaluating frictional heat generation.

It is calculated by the following equation for rotating shafts.

$$V\ (\text{m/s}) = \frac{\pi dN}{60 \times 1000} \quad \text{or} \quad \frac{dN}{19{,}100} \qquad \text{(metric)}$$

$$V\ (\text{fpm}) = \frac{\pi dN}{12} \quad \text{or} \quad .262\ dN \qquad \text{(imperial)}$$

where:

V = Sliding Velocity
d = Shaft Diameter (mm or in.)
N = RPM of the shaft
π = pi constant 3.1416

d) PVT GRAPHS

Any sliding bearing analysis is always based on three factors. Pressure, Velocity and Time (PVT) are individual factors that are impossible to separate when selecting a bearing material because the heat generated is proportional to all three as shown in the following relationship:

$$H \sim PV\mu T$$

where:

- H = Heat or Temperature Rise
- P = Pressure
- V = Velocity
- μ = Coefficient of Friction
- T = Time

In order to evaluate an application, it is necessary to know the duty cycle of the equipment. How long per day does it run, i.e. 8 hours, 24 hours or stop and start? Is there full rotation, which is normally specified in RPM, or does it cycle or oscillate through a limited angle? Through what angle and how frequently does movement occur and how many hours a day (Duty Cycle)? These factors all play a role in determining the amount of frictional heat that will be generated under defined pressures.

However, if the frictional heat generated is removed by a sufficient flow of cooling lubricant such as water, oil or process liquid, Thordon bearings will perform well at velocities far outside the limits shown on the PVT graphs (see page 18-20). Typical applications where this occurs include marine propeller shaft and vertical pump or turbine shaft bearings where a constant flow of cool water is provided. The minimum recommended cooling water flow rate is 0.15 litres/minute/mm (1 US Gal/ minute/inch) of shaft diameter.

The PVT graphs - Figures 14A to F - have been developed by Thordon Bearings Inc. as a guide for the design engineer in the selection of the correct grade of Thordon for specific operating pressures, sliding velocities and times. The curves have been developed using the pressure step technique, where the material is tested at one pressure under various velocities with the limiting factor being bearing temperature. The arbitrarily imposed temperature limit for all of the Thordon grades during the tests was 82°C (180°F), measured at the outside diameter of the bearing, except when tested in water. The limit in water was set at 60°C (140°F) to avoid hydrolysis. When the limiting temperature was reached during the test, the test was stopped and the time recorded. The test sample temperature was then allowed to return to ambient before the test was repeated for another velocity. The tests were conducted using bearings with a shape factor of 4.

To use the graphs, select the type of lubrication that is closest to your application. Locate the sliding velocity value for your application. Where the sliding velocity makes contact with the curve closest to your pressure, read the time required to reach the operational temperature limit. If the time required for your application is less than this value, then this application will likely be suitable. If not, then either a different Thordon grade needs to be selected, or improved lubrication or cooling provided.

The PVT graphs for oil and water were developed using a bath of oil or water with no liquid flow or cooling. If the system can be designed to incorporate a forced flow of cool lubricant instead of a bath, much of the frictional heat will be dissipated by the flow of lubricant. Once the bearing is operating under hydrodynamic conditions, no additional frictional heat is developed as the speed is increased, except for a slight increase in frictional drag of the lubricant. This increase is so low that it does not affect the bearing operation.

Under the forced cool lubricant flow conditions, the limits on the graphs are not applicable. The propeller shaft of a ship using a flow of water or oil lubrication is typical of this situation.

The PVT graphs are provided as a guide only. Thordon elastomeric materials have been successfully specified in many applications with PVT's falling outside the range on the graphs. For example, Thordon SXL has been incorporated into a number of vertical pump designs where it runs dry for periods of over a minute at velocities higher than indicated on the curves.

NOTE 1: For guidance on potential applications that fall outside the PVT graphs contact your Thordon distributor or Thordon Bearings Inc.

NOTE 2: PV values are given by many non-metallic material manufacturers and are often published with several incorrect assumptions. The first is that the individual P and V values have little importance, as long as they are within the product value range. The second, and perhaps the most dangerous assumption is the limited amount of test time used to develop the P and V values. No formal consideration is given to the time factor. The Thordon XL and SXL PVT graphs illustrated in Figure 14 show that frictional heat takes time to be generated.

NOTE 3: These graphs are based on laboratory results. Actual results in applications may vary.

NOTE 4: These guideline values are supplied for reference only. PV limits for any material vary with different combinations of pressure and velocity as well as with other test conditions.

FIGURE 14A - PVT GRAPH FOR XL

Lubrication: Dry

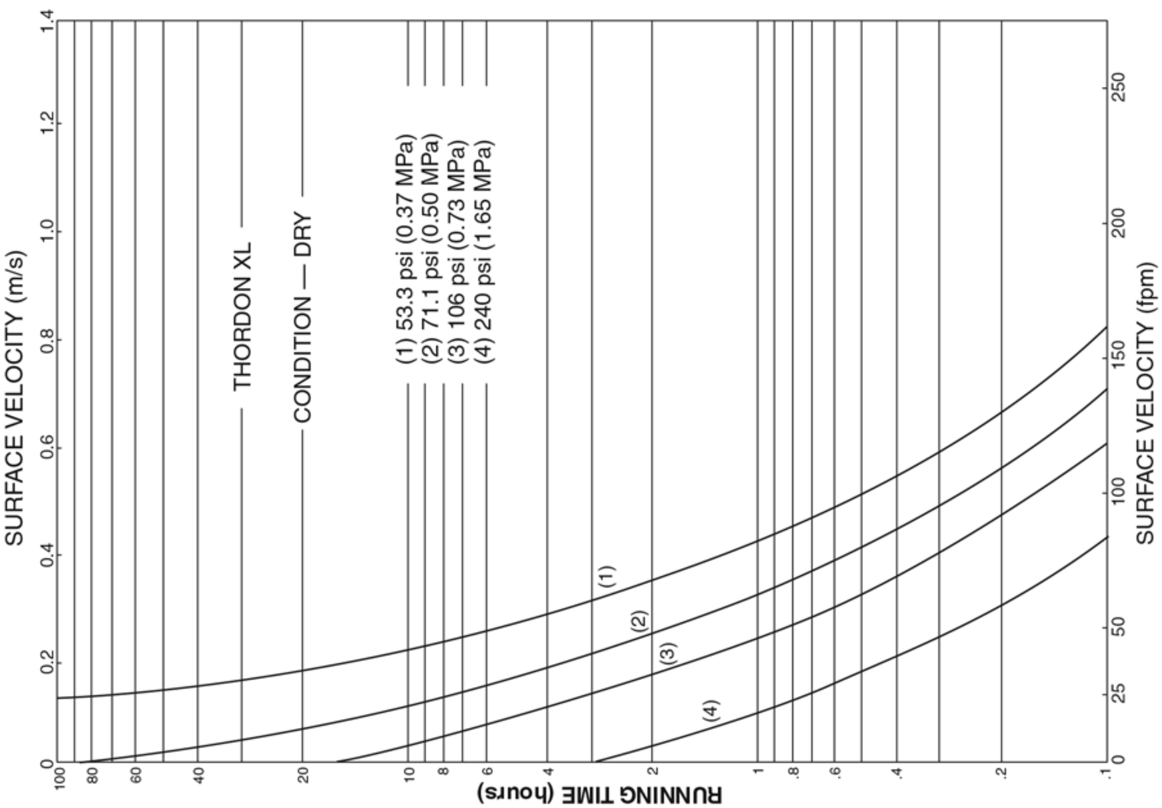
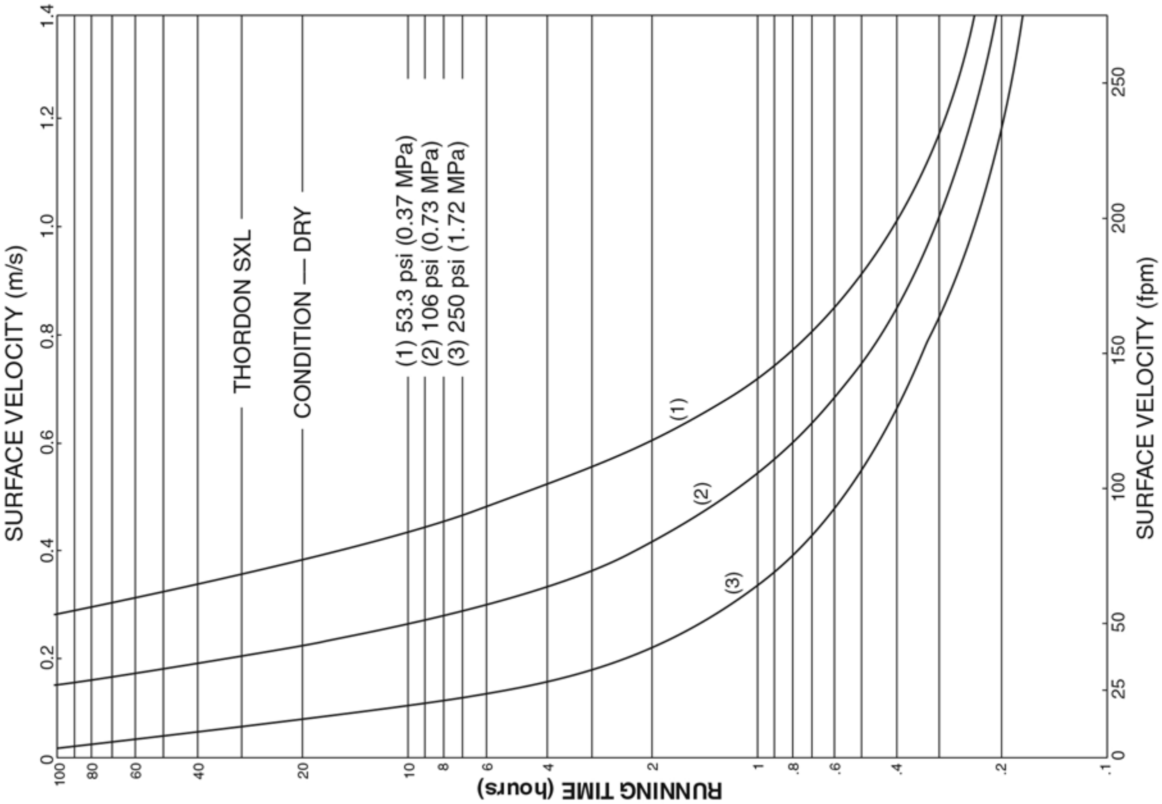


FIGURE 14B - PVT GRAPH FOR SXL

Lubrication: Dry



NOTE: These tests were conducted using a bearing with a shape factor of 4.

FIGURE 14C - PVT GRAPH FOR XL

Lubrication: Water Bath

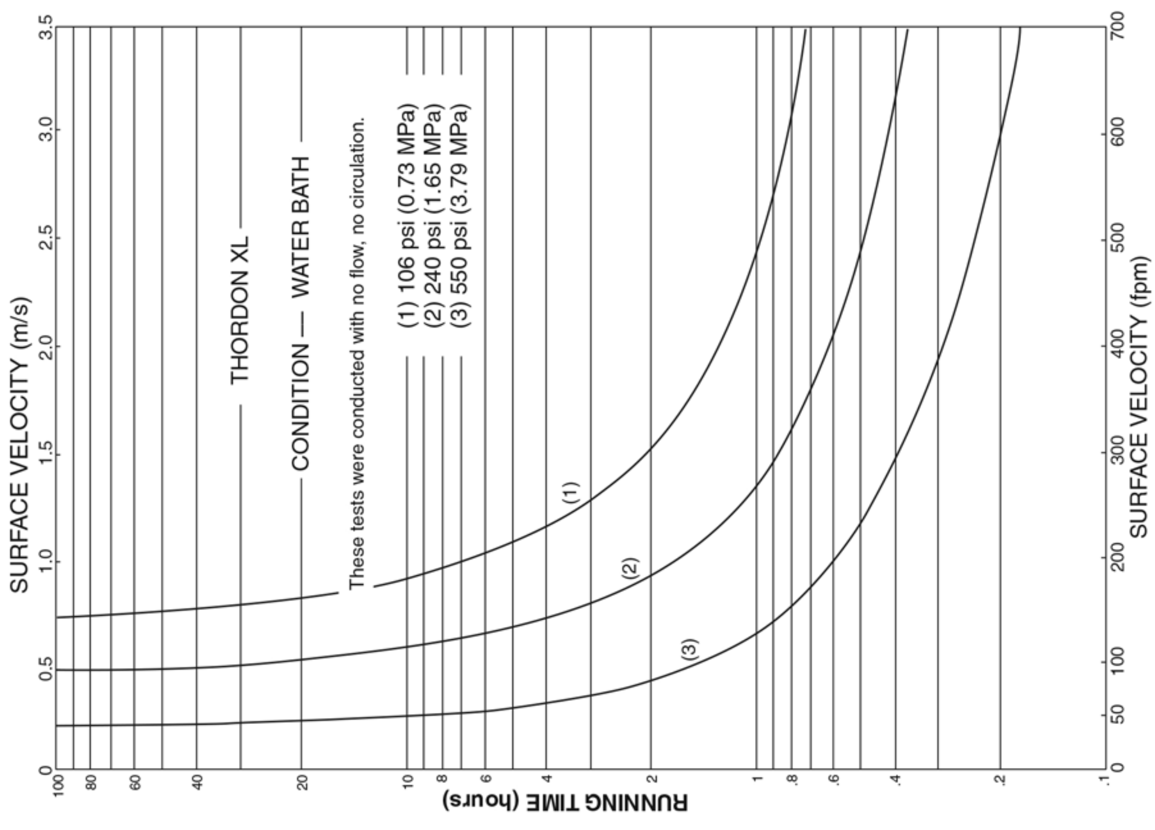
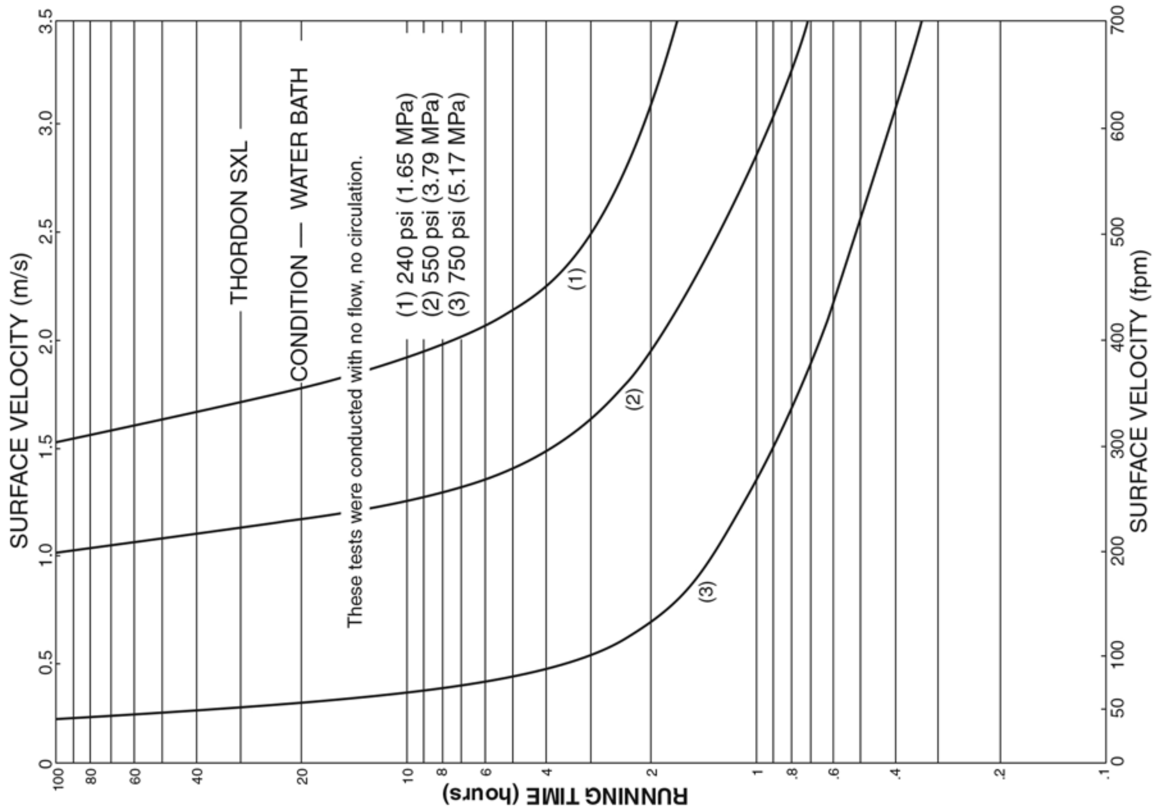


FIGURE 14D - PVT GRAPH FOR SXL

Lubrication: Water Bath



NOTE: These tests were conducted using a bearing with a shape factor of 4.

FIGURE 14E - PVT GRAPH FOR XL & SXL

Lubrication: Oil Bath

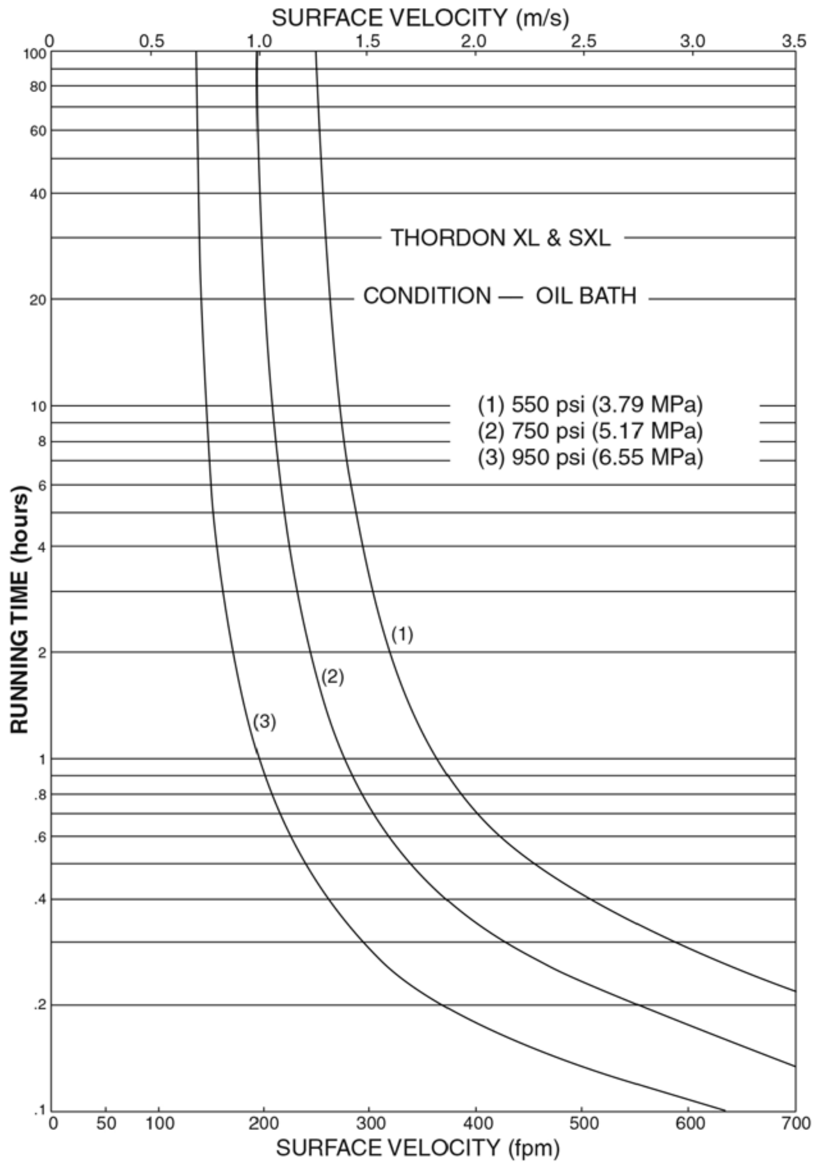
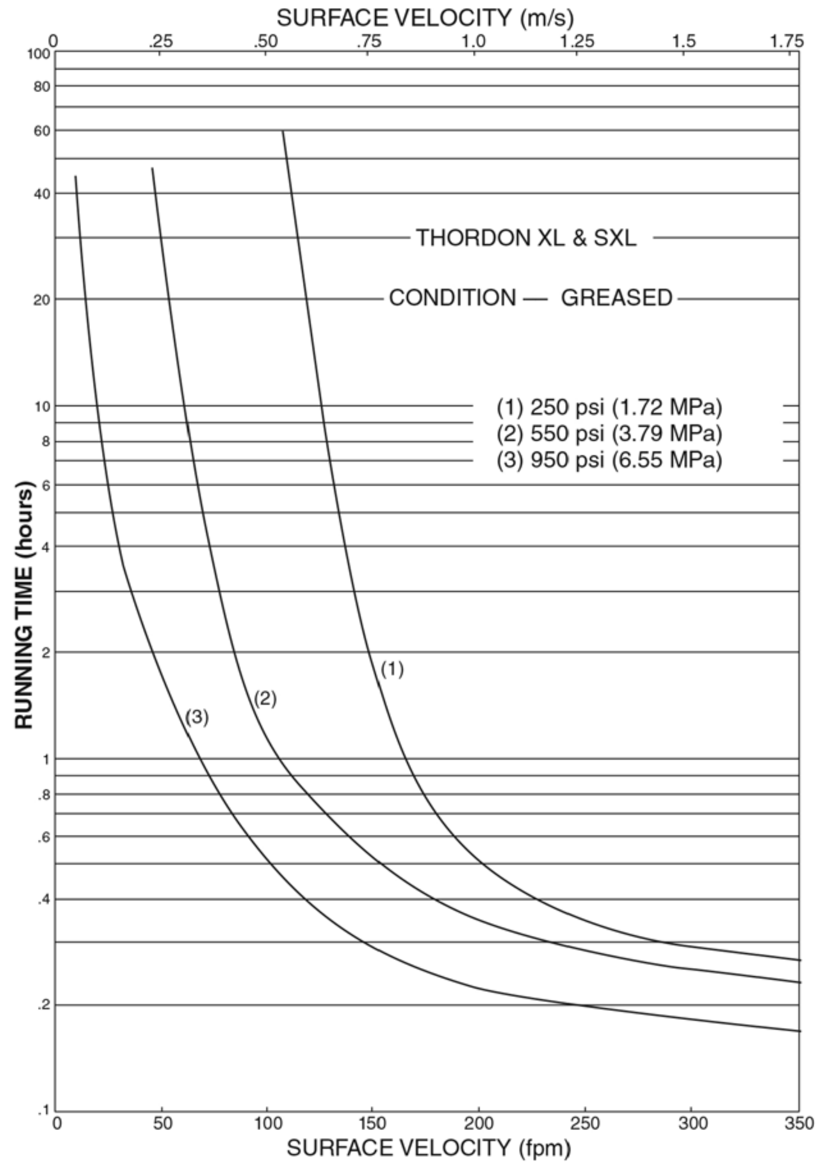


FIGURE 14F - PVT GRAPH FOR XL & SXL

Lubrication: Grease



NOTE: These tests were conducted using a bearing with a shape factor of 4.

e) LENGTH/DIAMETER (L/D) RATIO

The L/D ratio for a typical industrial sleeve bearing varies from 1:1 to 1.5:1. This is an optimum proportion permitting ease of alignment in the assembly.

In water lubricated propeller shaft bearing applications, the L/D ratio has historically been 4:1 in order to keep the bearing pressure low, i.e. 0.25 MPa (36.25 psi). However, because of the overhung load of the propeller, the pressure tends to be highest nearer the propeller and almost zero at the forward end. In operation, the high L/D ratio tends to create higher friction or drag on the shaft. This is because the forward part of the bearing is not supporting the shaft and creates unnecessary shearing of the water. There may even be contact between the shaft and bearing at the top of the bearing at the forward end. A 2:1 L/D ratio Thordon propeller shaft bearing was tested under the same conditions as the 4:1 and was found to generate less frictional force. The results of these tests in conjunction with encouragement from the marine Classification Societies resulted in the development of the Thordon COMPAC bearing system.

In most applications, where the loading of the bearing is uniform, higher L/D ratios will reduce the pressure and improve the life of the bearings. Alignment is more difficult, but if the pressure is high, an increase in the L/D ratio may be necessary. For COMPAC propeller shaft bearings, the L/D ratio is typically 2:1 and should not be more than 3:1. This limit is established because of concerns about the supply of adequate cooling water to very long bearings rotating at relatively high speeds. Rubber bearings are typically 4:1 L/D ratio.

For high pressure limited rotation applications, Thordon HPSXL TRAXL or ThorPlas bearings should be considered.

f) WALL THICKNESS

In an application where Thordon elastomeric materials are being specified as a replacement bearing, the existing configuration of the equipment usually governs the wall thickness of the bearing.

If the wall thickness of the Thordon bearing is excessive, the bearing can be used in conjunction with a metal sleeve in the housing or a liner on the shaft. Either of these methods will allow a reduction in the wall thickness of the bearing. If a shaft liner or sleeve is used, a further benefit results - as the effective diameter of the shaft and the I.D. of the bearing increase, the pressure decreases.

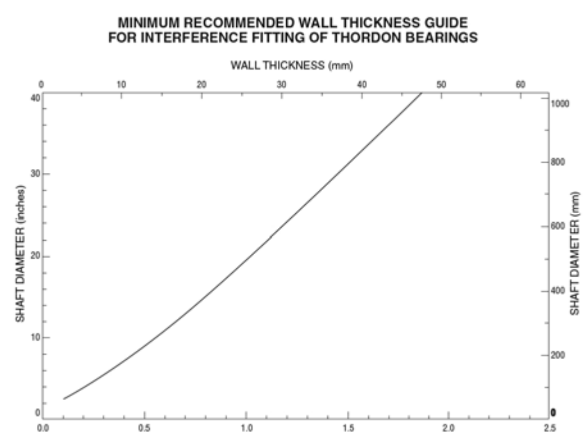
The degree of **Permissible Wear Down** before a bearing is 'worn out' is also a factor in determining wall thickness. Maximum allowable clearance and other external factors also enter into this consideration. For grooved bearings, maximum allowable wear should be less than the groove depth.

Due to the elastomeric nature of the material, a Thordon bearing must be supported along its entire length. An unsupported bearing will carry virtually no load. If wall thickness can be specified in the design, it is generally preferable to use a thinner wall. The overall clearances and tolerances can be reduced, heat dissipation is improved and the maximum permissible load is greater. There are some applications, however, such as those with low frequency impact loads where the cushioning effect of a thicker wall bearing will improve performance. Please contact your Thordon distributor or Thordon Bearings for further guidance on wall thickness, if required. Given application details, Thordon Bearings can recommend an optimum wall thickness. The Thordon Bearing Sizing Calculation program can also provide this information.

Minimum Recommended Wall Thickness Guide for Interference Fitting

The minimum recommended wall thickness of a Thordon bearing is specified in Figure 15. The values shown are based on the interface pressure between the bearing and the housing. Increasing either the wall thickness or the amount of interference will increase the interface pressure. In both grooved and ungrooved bearings, the thickness of the bearing wall that forms a continuous layer in the housing is the only material considered for interference fitting purposes. With grooved bearings, the minimum wall thickness will be greater than that of an ungrooved bearing by the amount of the depth of the groove as only the thickness behind the groove is considered when calculating the interface pressure. For Thordon RiverTough/Composite bearings, only the thickness of the yellow outer shell material should be considered when determining the minimum wall thickness. The bearing running surface material (GM2401) is too soft to contribute to the interface pressure.

FIGURE 15 - WALL THICKNESS GUIDE



NOTE: For grooved bearing, wall thickness is measured from bottom of groove to the OD.

If a Thordon bearing is replacing another bearing and the wall thickness will be below the recommended minimum there are two options. The bearing can be bonded in, or the interference can be increased to raise the amount of interface pressure to an acceptable level. Please contact your Thordon distributor or Thordon Bearings for further guidance if the level of interference is to be increased.

NOTE 1: The above information applies to Thordon XL, SXL and COMPAC. It does not apply to HPSXL. ***Thordon HPSXL is not recommended for interference fitting. It should be bonded.***

g) LUBRICATION GROOVES

For applications involving a flow of liquid across the bearing surface, such as vertical pump or propeller shaft bearings, lubrication grooves are machined or moulded into the bearing to aid in the flow of lubricant through the bearing. The grooves also provide a channel to allow abrasives to pass. The number of grooves as well as their depth and width change with the size of the bearing, its configuration and the available wall thickness. Water grooves are typically 7mm (0.27") deep for shaft diameters of 400mm (16") or larger, but should not be more than half of the wall thickness. The width of the groove is typically the same as the depth, but can be increased when grooves are very shallow to ensure sufficient water flow. The Thordon Bearing Sizing Calculation Program provides details of depth and number of grooves for any grooved bearing application, based on shaft and housing dimensions.

Please contact Thordon Bearings for further information on lubrication grooves.

FIGURE 16 - HARDNESS OF COMMONLY USED MATING MATERIAL[1]

MATERIAL	HARDNESS			REMARKS
	Rockwell C	Rockwell B	Brinell[5]	
Stainless Steel[2] 316	(16)[4]	95	(205)	Annealed
Stainless Steel Duplex 2205 (S 31803)	30.5	(105)	290	
Stainless Steel S41000	(1) 26 to 43	82 (103 to 113)	(156) (258 to 400)	Annealed Oil quenched from 1010°C & Tempered
Stainless Steel S17400	31 33 to 44	(106) (108 to 114)	(294) (311 to 409)	Annealed Water quenched from 1038°C & Tempered
Stainless Steel S30400	N/A	81	(153	Annealed
Gunmetal (G1)[3] C90500	N/A	N/A	70 to 95	
Leaded Gunmetal (LG4) C92200	N/A	N/A	70 to 85	
70/30 Copper – Nickel C96600	N/A	74	(135)	
Inconel® 625	(21)	98	(228)	Annealed
Inconel® 600	N/A	75	(137)	Annealed
Nickel-Chrome-Boron (NiCrB)	> 60	N/A	> 654	Surface coating

Notes:
1 The purpose of listed hardness value is for quick hand-on reference. Refer to Hardness Material textbooks for more details if necessary.
2 See "Stainless Steel, ASM Specialty Handbook" edited by J.R. Davis, 1994, ISBN:0-87170-503-6 for stainless steel details.
3 See "Standards Handbook", Cast Copper and Copper Alloy Products, published 1996 by Copper Development Association Inc. 260 Madison Ave., New York, NY 10016 for bronze details.
4 The number in brackets was converted from the unbracketed using conversion tables and is for comparison purposes only.
5 BRINELL scale used in this table is BHN 3000kg.

h) MATING SURFACE

Most common metallic mating surfaces will perform well when used in conjunction with Thordon bearings. Figure 16 indicates the hardness of commonly used mating materials. If corrosion is not a problem, carbon steel is commonly used, but if corrosion is a concern, such as a water lubricated propeller shaft bearing, then a bronze shaft liner should be used. Common bronzes that work well include Gunmetal (88% Cu, 10% Sn and 2% Zn) or 70-30 Copper Nickel. Nickel Aluminum Bronze is not recommended because experience has shown that it can lead to high wear rates. Aluminum and titanium are also not recommended.

Stainless steel is also widely used as a shaft liner working with a Thordon bearing. If abrasion is present, softer stainless grades like 304 should be avoided. Similarly, the softer grades of Aquamet® shafting should be avoided if the shafts will be exposed to significant abrasion. Harder grades of stainless steel, or Inconel® 625 are preferred. In lieu of a liner, some manufacturers use spiral welded stainless steel or Inconel® 625 over the whole length of the shaft, or in way of the journals.

In a heavily abrasive journal bearing application, the theoretical optimum mating surface is the hardest practical surface on the shaft in conjunction with a durable compliant bearing material. For severe abrasives, a Thordon RiverTough/Composite bearing and a mating surface with a hardness of at least 40 Rockwell C is recommended. Thordon grades cause minimal shaft wear. In general, softer bearing materials such as Thordon tend to wear the shaft less and exhibit less combined bearing and shaft wear.

The hardest shaft and softest bearing materials are the extremes to achieve minimum combined wear in a severe abrasive environment. If the shaft were changed to a softer material or if the bearing were changed to a harder material, the combined wear would increase. Should the environment contain fewer abrasives, then the need to have the hardest shaft material or softest bearing material would decrease. Other factors such as low friction requirements may then become significant in bearing selection.

In a clean environment with a lubricant (which only occurs in theory) any combination will do. However, the old principle of a bearing softer than the mating shaft is always a good guide. Running similar materials together should be avoided. Thordon elastomeric materials should not be run against a Thordon elastomeric material shaft liner.

The **Surface Finish** of the mating shaft should be as smooth as practical to limit the initial bedding-in wear. Thordon testing has shown that less frictional heat is generated with a smoother shaft, increasing the PVT limit. Thordon will perform satisfactorily with a normal machined finish on the shaft. For optimum performance, a final machined mating surface finish of 0.4 to 0.8 micro-metres (16 to 32 micro-inches) Ra is recommended. Mating shaft surface finishes up to 1.6 micro-metres (63 micro-inches) Ra will perform satisfactorily.

i) FITTING

Thordon XL, SXL, COMPAC and RiverTough/Composite bearings are usually fitted using an interference fit. Installation is quick and easy, especially when freeze fitting is used. Thordon bearings can also be bonded in place.

Bonding, using a Thordon approved adhesive, is appropriate in the following circumstances:

- where a thin walled bearing is used and retention force is not sufficient for an interference fit
- when the housing I.D. is not machined, or when it does not provide adequate support along the full length of the bearing.
- when bearings are subjected to high temperatures that may cause them to "stress relieve" and lose the retention force of an interference fit.
- when Thordon HPSXL is used.
- when the housing is not round or is damaged by corrosion, etc.

The final dimensions of a Thordon bearing will depend on how it is to be fitted. The selection of the best method of fitting is extremely important and is dependent on application requirements.

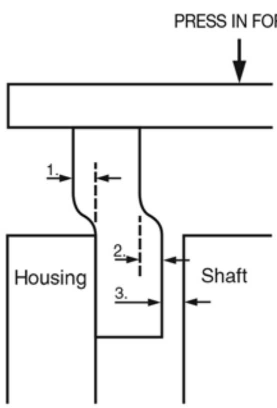
An interference fit is sufficient to prevent bearing rotation under normal operating conditions, but a forward stop and bolted end keeper ring are required to ensure that axial movement of the bearing does not occur. The keeper rings must be of adequate size and have an inside diameter approximately 3mm (1/8") larger than the groove diameter or 3mm (1/8") larger than the bearing I.D. for a non-grooved bearing. Stops and keeper rings are not mandatory when a bearing is bonded in place but are recommended in critical applications as a safety precaution. In cases where the orientation of the bearing is critical such as off-centre bored bearings or COMPAC, it is recommended that an anti-rotation device be fitted.

(i) Interference

Most applications use an interference fit assuming all the relevant design factors are taken into account. It is necessary, however, that the L/D ratio of the bearing be at least 0.5:1. Practical experience has shown that small bearings can be easily pressed into the housing, while larger bearings fit easier when they are shrunk using dry ice or liquid nitrogen. **The housing should never be heated to facilitate fitting, nor should grease or oil be used to assist when press fitting.**

In cases where the bearing is being installed with an interference fit as in Figure 17, the effect of the interference on the bearing inside diameter must also be considered. This effect, known as bore closure, is explained in Section 5 - Application Design.

FIGURE 17 - INTERFERENCE FIT PARAMETERS



Where:
1. is interference, 2. is Bore Closure, 3. is Installed Running Clearance.

Note: Minimum Installed Clearance = Running Clearance
+ Thermal Expansion Allowance (if applicable)
+ Water Absorption Allowance (if applicable)

All interference fit bearings that are fully machined before installation are subject to a build up of tolerances which can create additional installed clearance. For example, when a bearing is designed with minimum clearance, its actual clearance will be dependent on the accumulated machining tolerances of the bearing wall thickness, plus tolerances on the shaft and housing. This tolerance build up can be reduced by machining only the O.D. of the bearing prior to fitting and then machining the I.D. up to a maximum of 5% of the wall thickness after it is installed. This will eliminate the tolerance build up associated with bore closure, bearing wall and housing I.D.

Bore Closure is the most variable of the factors affecting Thordon bearing installed dimensions.

There can be situations where, in practice, the bore closure varies from that predicted by our tests, and can result in additional clearances. If it is not possible to machine the bearing I.D. after installation, a test bearing can be fitted into a machined "dummy" housing to determine the exact bore closure for that application. The finish on the I.D. of the "dummy" housing should be the same as that on the actual housing. Corresponding adjustments if required, can then be made. Alternatively, bearings can be machined in the "dummy" housing, removed and fitted into the actual housing. This approach is sometimes used for vertical pump or turbine bearings where there is a requirement to keep the initial installed clearance as small as possible.

(ii) Freeze Fitting

Freeze fitting is the easiest way to install Thordon bearings which have been designed with an interference fit. Thordon contracts significantly when cooled, because of its high coefficient of thermal contraction/expansion, facilitating easy fitting without expensive jacking or other equipment. Liquid nitrogen is the optimum cooling agent but dry ice can also be used for most installations if liquid nitrogen is not available. **When freeze fitting Thordon RiverTough/ Composite Bearings, dry ice should be used and not liquid nitrogen.**

Liquid nitrogen should only be used in a tight container to prevent leakage. The bearing should be completely immersed in, or evenly coated with, liquid nitrogen. When vapour stops boiling off the liquid nitrogen the bearing has reached a temperature of -196°C (-320°F) and can be easily installed (approximately 5 to 30 minutes depending on the surface area of the bearing). For large or thick-wall bearings, it may be necessary to check the bearing dimensions to see if the bearing has shrunk sufficiently to allow easy installation. If dry ice is used as the cooling medium it should be supplied in pellets or broken into small pieces, if supplied in block form. The dry ice must be packed tightly around the O.D. of the bearing with some clearance around the I.D. of the bearing, making contact with both the inside and outside surfaces. After 3 hours packed in dry ice the bearing dimensions can be checked to see if the bearing has shrunk sufficiently to allow easy installation. If not, the bearing should be re-packed for another hour.

CAUTION: Use of liquid nitrogen or significant quantities of dry ice in closed or poorly ventilated areas should be avoided. The boiled off gases tend to displace existing oxygen and can be fatal.

The approximate amount of shrinkage that can be expected can be estimated as follows:

Each 10°C decrease in temperature will result in an approx. decrease in diameter of 0.0014mm/mm of diameter.

(Each 10°F decrease in temperature will result in an approx. decrease in diameter of 0.0008 in./in. of diameter).

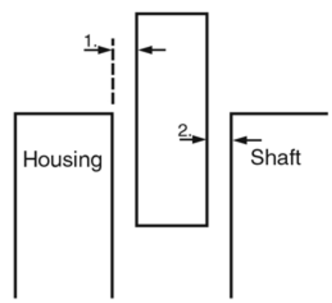
(iii) Bonding

As indicated previously, bonding is an acceptable alternative to interference fit in selected circumstances. The thickness of the layer of adhesive must be considered when dimensioning the O.D. of the bearing. When bearings are bonded into housings, there is no bore closure effect on the bearing I.D. (see Figure 18).

To hold the accumulation of tolerances to a minimum, the bearing should be machined on the O.D. and then bonded into the housing. The I.D. should then be machined. This method is used in pump applications where the impeller clearance must be held to a minimum.

To ensure good results, the procedures for bonding using Thordon approved adhesives must be followed, as outlined in Section 7. Bonding should be done at a consistent temperature throughout the adhesive curing process. Temperature variations during curing can have a negative effect on the bond integrity. Combining freezing and bonding does not work well because the moisture/frost on the frozen bearing will have a significant negative impact on the bond strength.

FIGURE 18 - BOND FIT PARAMETERS



Where:
1. is Bond Thickness, 2. is Installed Running Clearance.

Note: Minimum Installed Clearance = Running Clearance
+ Thermal Expansion Allowance (if applicable)
+ Water Absorption Allowance (if applicable)

(iv) Bearing Housing

The housing into which a Thordon bearing is to be installed must be round, aligned, and not tapered or bell-mouthed. The maximum allowable housing ovality is 1/3 the initial (normal) designed running clearance. The housing must also provide support to the Thordon bearing along its full length. Gaps in the housing or other abnormalities must be filled or corrected by machining, installing a sleeve, bonding the bearing [for gaps up to 3mm (0.125")] or chocking with a Thordon approved chocking compound.

If the housing is misaligned, or if there is a need for slope boring, then the misalignment or slope should be corrected in the housing. Offset boring of Thordon bearings after fitting is not recommended because of the possible adverse effect this could have on the interference hoop stresses. Alternatives are to align a machined bearing and then bond or chock it in place, or to align a "dummy" bearing, pour chocking compound around the "dummy" bearing and then remove the "dummy" bearing leaving a round aligned housing of chocking material into which a Thordon bearing can be installed using a press or freeze fit.

j) MINIMIZING INITIAL INSTALLED CLEARANCE

Initial installed clearance for Thordon bearings is usually larger than final running clearance, mainly because the initial clearance includes absorption and thermal expansion allowances. These allowances will disappear during operation of the equipment, but this will take time.

In some applications, there is a requirement to keep the initial installed clearance as small as possible. A typical example would be a vertical pump bearing. Final running clearance may be acceptable, but when absorption allowance, thermal expansion and tolerance build-up are considered, the accumulated initial clearance may be beyond design requirements. In such cases it is necessary to consider ways to reduce the initial clearance.

There are several options:

1. Thinner bearing - Absorption and thermal expansion both vary according to the wall thickness of the bearing. By reducing the wall thickness, the allowances for these factors become smaller, so the initial clearance is reduced. Reducing the wall thickness is usually accomplished by reducing the housing diameter. The Thordon Bearing Sizing Calculation program can be useful in this exercise – it calculates "Minimum Installed Clearance". It can be used to determine what wall thickness will yield the required initial clearance. The wall may become too thin for an interference fit, so bonding may be required.
2. Minimize bore closure variations – The bore closure calculation (effect of interference on the I.D. of the bearing) is the least precise aspect of the Thordon dimension calculations. Actual bore closure will depend on a number of factors including machined finish on the bearing and housing. There are several ways to minimize variations in bore closure:
   a. Reducing the length/diameter ratio of the bearing will reduce variations in bore closure over the length.
   b. Final machining of the bearing bore after it is installed. Machining after fitting into the housing eliminates the effect of bore closure because it has already happened. It also eliminates the effect of tolerance build-up on the bearing wall. This method however removes stressed material that is developing the "grip" of the bearing within its housing so only minimum material must be removed.
      - For ungrooved bearings, this machining stage must not remove more than 5% of the wall thickness.
      - For grooved bearings, it is not as important because the bore material is much less stressed.

      However, machining should be limited to 10% of the wall thickness or 25% of the groove depth, whichever is less. Lubrication grooves must always be machined before fitting the bearing into the housing.
   c. Fitting the bearing into a dummy housing before machining the I.D. This method is a variation of "b" above which can be used when it is not practical to install the bearing in its final housing for I.D. machining. The dummy housing should have the exact dimensions and machining finish as the final housing. This method is less precise because it does not eliminate machining tolerance variations on the housing. The same restrictions on the amount of material that can be removed mentioned in "b" above still apply.

k) MATERIAL SELECTION PROCESS

In any bearing application the primary consideration is to ensure that the frictional heat developed in the sliding action is either absorbed and dissipated by the surrounding mechanism or that it is conducted away by a flow of lubricant or coolant. There must be a balance in the system where temperature equilibrium is reached, and this must be below the temperature limit of the material. If not, bearing failure will result.

The secondary consideration is the type of environment that the bearing is operating in, e.g. very abrasive or clean, as this will affect material selection.

NOTE: The General Material Selection Guide for Industrial Applications (Figure 19) has been compiled to select the correct Thordon grade for various application parameters, and should be used in conjunction with the PVT graphs.

The Material Selection Guide does not consider any heat generation. If the peripheral velocity is high enough to generate frictional heat, then the maximum pressure will be significantly less. For example, in marine propeller shafts with Thordon COMPAC, SXL and XL shaft bearings, maximum pressure is limited to 0.6 MPa (87 psi).

For high pressure applications where the frictional heat generated is not a factor due to either oscillating motion or very slow speeds, the bearing needs to be designed with a very high shape factor, e.g. above 100, as in the Thordon HPSXL TRAXL bearing.

THORDON GRADES

Thordon XL (Black) is used in a variety of industrial and marine applications.

- low coefficient of friction (typically 0.20-0.25)
- high resistance to abrasion in dry applications
- high resistance to shock loading and vibration

Thordon SXL (Off-White) has superior dry running capability, a lower coefficient of friction and similar abrasion resistance compared to XL.

- lower coefficient of friction (typically 0.10-0.20) than XL
- higher dry PV (Pressure Velocity) rating than XL
- higher resistance to abrasion than XL in wet applications; good abrasion resistance operating dry
- dry start-up capability as a vertical pump bearing
- high resistance to shock loading and vibration

NOTE: When SXL is used in vertical pumps where dry startup is a consideration, consult with Thordon Bearings regarding bearing design. Thordon will recommend a maximum dry running time based on the peripheral velocity of the shaft and the load on the bearing.

Thordon COMPAC (Orange) is a high performance grade of Thordon that is used in open water lubricated propeller shaft bearing systems. Specially formulated with a low coefficient of friction to reduce startup friction and reduce stick-slip, COMPAC's unique configuration is designed to promote early formation of a hydrodynamic film at lower shaft rpm.

The COMPAC bearing system is Class-approved for 2:1 L/D ratios. COMPAC's design properties are quite similar to SXL.

Thordon RiverTough/Composite (yellow outer shell, black inner shell - known as GM2401) is a two-component marine and pump bearing formulated specifically for use in very abrasive environments.

- used in rotating applications in abrasive water conditions such as pump and dredge bearings
- outstanding abrasion resistance - two or more times that of rubber
- significantly lower coefficient of friction than rubber
- higher resilience and stiffness than rubber
- available with either yellow polymer or metal bearing shells

Thordon HPSXL (Grey) is designed for higher pressure applications, either as a homogeneous material or as the bearing component in HPSXL TRAXL bearings (HPSXL bonded in a metallic shell).

- maximum dynamic working pressure to 15.0 MPa (2175 psi) in limited motion
- HPSXL TRAXL has maximum dynamic working pressure to 55.0 MPa (8000 psi) in limited motion
- lowest coefficient of friction (typically 0.06-0.12)
- moderately abrasion resistant (lower abrasion resistance than XL or SXL)
- high resistance to shock loading and vibration
- TRAXL is also available with XL and SXL for extreme pressure applications, with slightly less compressive load capability

ThorPlas-Blue & ThorPlas-White are non-elastomeric materials developed by Thordon specifically as a homogeneous high pressure bearing.

- max dynamic design pressure to 45 MPa (6527 psi)
- low coefficient of friction (typically 0.10-0.17)
- very low wear in non-abrasive environments
- reasonable abrasion resistance (less than Thordon elastomer grades) but, better than bronze, epoxy phenolics and many other non-metallic bearing materials

ThorPlas is outside the scope of this manual.
For more information, please contact your Thordon distributor or Thordon Bearings to obtain the ThorPlas Bearings Engineering Manual.

FIGURE 19 - GENERAL MATERIAL SELECTION GUIDE FOR INDUSTRIAL APPLICATIONS

	THORDON GRADES				
Parameter	**SXL**	**RiverTough/ Composite (GM2401)**	**XL**	**ThorPlas- Blue**	**ThorPlas-White**
Description	Elastomeric Polymer Alloy	Elastomeric Polymer Alloy	Elastomeric Polymer Alloy	Engineered Thermoplastic	Engineered Thermoplastic
Temperature Limit	60°C (140°F)	60°C (140°F)	60°C (140°F)	80°C (176°F)	80°C (176°F)
Suitable for Dry Start-up	YES**	NO	NO	YES**	YES**
Resistance to Acids	Limited	Limited	Limited	Limited	Good
Resistance to Alkalies	Limited	Limited	Limited	Limited	Fair
Suitable for Hydrocarbons	YES	YES	YES	YES	YES
Abrasion Resistance	Very Good	Excellent	Good	Acceptable	Acceptable
Installation Clearance	Medium to Low	Higher	Medium	Lowest	Lowest
Shaft Sleeve Material	Bronze, Stainless Steel	Ni-Cr-B Recommended	Bronze, Stainless Steel	Bronze, Stainless Steel	Bronze, Stainless Steel
Lubrication	Water, Seawater, Most Fluids (pH 5-10)	Water, Seawater, Most Fluids (pH 5-10)	Water, Seawater, Most Fluids (pH 5-10)	Water, Seawater, Most Fluids (pH 3-11)	Potable Water
Remarks	Low friction. Suitable for dry start-up. Good abrasion resistance.	For use in highly abrasive operating environments.	Good balance between abrasion resistance and medium level of friction.	Lowest friction. Good for low abrasion applications. For use at temperatures and in chemical solutions unsuitable for Thordon elastomers.	NSF International Certification for NSF/ANSI 61 Drinking Water System Components. Accepted Material by CFIA. WRAS Material Approval

** *For dry start-up times longer than 30 seconds, please contact Thordon Engineering for grade selection.*

Note: *For Nuclear use, Quality Control certificates including certified test reports can be supplied. Thordon Bearings Inc. operates under the provision of 10 CFR21.*

This is a general guide for technical reference only. Critical applications that are close to pressure or temperature limits, or subjected to non-standard environments should be reviewed and approved by Thordon Engineering.

FIGURE 20 - LUBRICATION/OPERATING PRESSURE MATERIAL SELECTION GUIDE FOR INDUSTRIAL APPLICATIONS

	RECOMMENDED THORDON GRADES		
Lubrication / Operating Pressure	★★★★★ **Excellent**	★★★★ **Good**	★★★ **Fair**
Dry (sealed or minimal abrasives)			
0-10 MPa (0-1450 psi)	SXL	ThorPlas-Blue	-
10-15 MPa (1450-2175 psi)	HPSXL	ThorPlas-Blue	-
15-45 MPa (2175-6525 psi)	ThorPlas-Blue	HPSXL TRAXL	-
45-55 MPa (6525-8000 psi)	HPSXL TRAXL	-	-
Dry (abrasives present)			
0-5.5 MPa (0-800 psi)	XL	SXL	ThorPlas-Blue
5.5-10 MPa (800-1450 psi)	SXL	ThorPlas-Blue	-
10-15 MPa (1450-2175 psi)	HPSXL	ThorPlas-Blue	-
15-45 MPa (2175-6525 psi)	ThorPlas-Blue	-	-
Wet (sealed or minimal abrasives)			
0-10 MPa (0-1450 psi)	SXL	ThorPlas-Blue	-
10-15 MPa (1450-2175 psi)	HPSXL	ThorPlas-Blue	-
15-45 MPa (2175-6525 psi)	ThorPlas-Blue	HPSXL TRAXL	-
45-55 MPa (6525-8000 psi)	HPSXL TRAXL	-	-
Wet (abrasives present)			
0-3 MPa (0-500 psi)	GM2401	SXL	ThorPlas-Blue
3-10 MPa (500-1450 psi)	SXL	ThorPlas-Blue	-
10-15 MPa (1450-2175 psi)	HPSXL	ThorPlas-Blue	-
15-45 MPa (2175-6525 psi)	ThorPlas-Blue	-	-
Potable Water (wet or near dry)			
0-3 MPa (0-500 psi)	ThorPlas-White	-	-
3-10 MPa (500-1450 psi)	ThorPlas-White	-	-
10-15 MPa (1450-2175 psi)	ThorPlas-White	-	-
15-45 MPa (2175-6525 psi)	ThorPlas-White	-	-
Note: The maximum pressures given for the various products are based on maximum dynamic working pressures for intermittent, limited motion. For applications involving continuous rotary motion, PV limits of the materials will significantly reduce the maximum allowable pressures stated above.			

This is a general guide for technical reference only. Critical applications that are close to pressure or temperature limits, or subjected to non-standard environments should be reviewed and approved by Thordon Engineering.

I) PROBLEMS & CAUSES OF BEARING FAILURE

	PROBLEM	CAUSE	SOLUTION
A	A bearing becomes loose in the housing when subjected to a quick reduction in temperature, even when it is designed to operate at that temperature.	When a bearing is installed with an interference fit and then subjected to a quick reduction in temperature, it contracts faster than the material's ability to recover its interference fit.	When Thordon bearings are likely to be subjected to this type of "Thermal Shock", the bearing should be bonded into the housing and mechanically retained.
B	A bearing becomes loose in the housing when subjected to long periods when the temperature is greater than 60°C (140°F) for XL, SXL, COMPAC and RiverTough/Composite (GM2401).	The material has stress relieved itself and adequate interference fit is no longer present. When the temperature is then reduced, the bearing will shrink and come loose in the housing.	The bearing should be bonded into the housing and mechanically retained.
C	A bearing 'walks' or moves axially out of the housing.	This normally occurs where the pressure along the length of the bearing is not uniform and cyclic, and the component of forces produces an axial load.	Ensure that the bearing is retained axially with a keeper ring, or step in the housing or that the bearing is bonded into the housing.
D	A bearing seizes onto the shaft causing interface melting.	Either insufficient clearance was allowed or the combined PVT value is too high.	Ensure that the correct clearance is calculated allowing for running clearance, water absorption and thermal expansion where applicable. Also ensure that the correct bore closure allowance is used for bearings installed with an interference fit. Check the PVT requirements to see if auxiliary lubricant or coolant is required.
E	A water lubricated bearing wipes and takes on a glazed appearance either covering the whole inside diameter or only in the loaded area. The bearing may have a crazed or cracked appearance.	The bearing has been operating in water at elevated temperatures, i.e. over 60°C (140°F) or in steam. The bearing has failed due to hydrolysis, causing a softening or cracking of the material.	Provide a cool water flush to the bearing and do not use steam for cleaning or flushing the bearing.
F	The bearing material separates as if it has delaminated. The separation takes place half way through the wall thickness.	Internal heat build-up from high frequency, high load impact has caused the material to fail from hysteresis.	The wall thickness of the bearing must be reduced to limit deflection and reduce the recovery time between impacts. Review Thordon PVT Charts.
G	A bearing shows signs of having softened. Bulges on the ends of the bearing or material flows into the grooves.	The bearing does not have enough lubrication to keep it cool. Frictional heat generation is greater than what can be dissipated through the lubricant.	Improve lubrication flow: • for water lubricated bearings ensure that the flow is adequate and that the water is cool. • for other lubrication ensure that there is sufficient lubricant and adequate facilities for keeping it cool.
H	An adequately lubricated bearing wears quickly and shows signs of melting.	Bearing is overloaded.	Check load on bearing relative to pressure limits for Thordon Bearings as indicated in Figure 20.
I	A water lubricated bearing wears more rapidly than expected and shaft liner is covered with a white coating.	The white powder is cathodic chalk that can be deposited on the shaft liner when the ship's cathodic protection system is stronger than necessary.	Clean shaft liner and reduce level of cathodic protection. If ship spends a lot of time in one specific port, investigate cathodic protection of the dock that may be adding to the problem.
J	A water lubricated propeller shaft bearing is worn prematurely after few running hours.	Marine growth on the shaft.	Where a vessel is idle for periods lasting longer than two days, good marine practice is to slowly rotate the shaft on turning gear for 2 revolutions every 1-2 days to dislodge marine growth and salt deposits on journal surfaces. When seawater temperature exceeds 25°C (77°F) it is recommended that shafts are rotated at least daily.

5) APPLICATION DESIGN

a) APPLICATION DESIGN

The final dimensions of a Thordon bearing will depend on how it is to be fitted. The selection of the best method of fitting is extremely important and is dependent on application requirements.

Thordon bearings are usually fitted either by installing with interference or by bonding. In certain applications mechanical keeper strips or keys are used to assist interference fits. If a bearing is to be press fitted, then interference and bore closure need to be considered in the calculation along with running clearance, water absorption and thermal allowances. However, if it is to be bonded into a housing, then only the latter three factors need to be considered.

Thordon Bearings has developed a software program for calculating the dimensions of Thordon bearings. This program greatly simplifies the dimensioning process. Using the Thordon Bearing Sizing Calculation Program is the preferred method of calculating dimensions for Thordon bearings.

The explanations below are provided mainly to facilitate understanding of the calculation parameters.

The following parameters should be considered:

- Housing Size and Tolerance
- Shaft Diameter and Tolerances
- Length of Bearing
- Operating Temperatures
- Machine Shop Temperature
- Type of Lubrication
- Retention Method

b) INTERFERENCE

One of the basic and important differences between Thordon and other bearing materials is that Thordon requires more interference. This is due to the nature of the material. The larger interference does not cause any significant problems, but it must be taken into consideration to ensure that Thordon bearings have adequate retention in their housings.

Thordon elastomeric bearings shrink on the O.D. and I.D. as the temperature decreases. Due to the high coefficient of thermal expansion (or contraction), compared to metal, it is necessary to allow for this factor when the operating environment drops below ambient. For calculation purposes, we assume ambient (machine shop) temperature to be 21°C (70°F). The Thordon Bearing Sizing Program calculates dimensions at 21°C (70°F) ambient temperature and then provides adjustments to the dimensions to suit actual ambient temperature in the machine shop at time of machining.

In the Housing Interference graphs (Figures 21 and 22), the required cold temperature interference has been calculated for XL & SXL increments of 10°C for metric sizes and 20°F for imperial sizes, below machine shop ambient temperatures.

Thordon bearings installed with an interference fit can be done with either a press fit or a freeze fit. An entry chamfer on the bearing and/or a rounded corner on the housing will facilitate press fitting.

The bearing press in force can be estimated as follows:

Press force (kg) =

$$\frac{\text{Interference (mm)} \times \text{wall thickness (mm)} \times \text{length (mm)} \times 85}{\text{Housing bore (mm)}}$$

Press force (N) =

$$\frac{\text{Interference (mm)} \times \text{wall thickness (mm)} \times \text{length (mm)} \times 850}{\text{Housing bore (mm)}}$$

Press force (lbs) =

$$\frac{\text{Interference (inch)} \times \text{wall thickness (inch)} \times \text{length (inch)} \times 120000}{\text{Housing bore (inch)}}$$

NOTE: These are estimations, using a 0.3 friction co-efficient and a nominal Compression Modulus to suit all grades of Thordon elastomeric polymer bearings.

When freeze fitting a Thordon bearing, the selection of a suitable cooling agent depends on the temperature differential for which the bearing's interference fit is designed. [Temperature differential is the difference between ambient machine shop temperature and the coldest temperature to which the installed bearing will be exposed during operation.] If the differential is 40°C (100°F) or less, then dry ice can be used. If the differential is greater than 40°C (100°F), the use of Liquid Nitrogen is recommended. The amount of shrinkage that can be expected can be estimated using the following information:

- Each 10°C decrease in temperature will result in an approximate decrease in diameter of 0.0014mm/mm of diameter.
- Each 10°F decrease in temperature will result in an approximate decrease in diameter of 0.0008 inches/inch of diameter.
- On the removal of an interference fit bearing from the housing, it will recover a portion of its total deflection almost immediately, and then it will slowly recover the balance of the interference except for the compression set portion. In tests, recovery based on standard interference is over 90% of initial deflection over a period of several weeks.

NOTE: Interference fit is not recommended for Thordon HPSXL. This material should be bonded in place.

FIGURE 21 - HOUSING INTERFERENCE: XL BEARINGS

Imperial

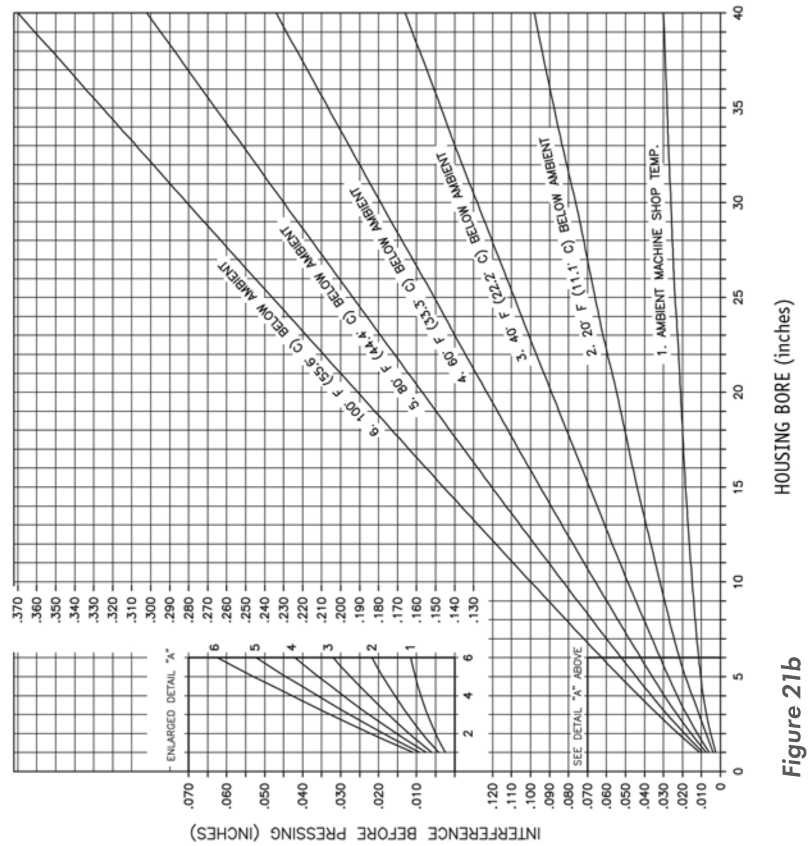


Figure 21b

Metric

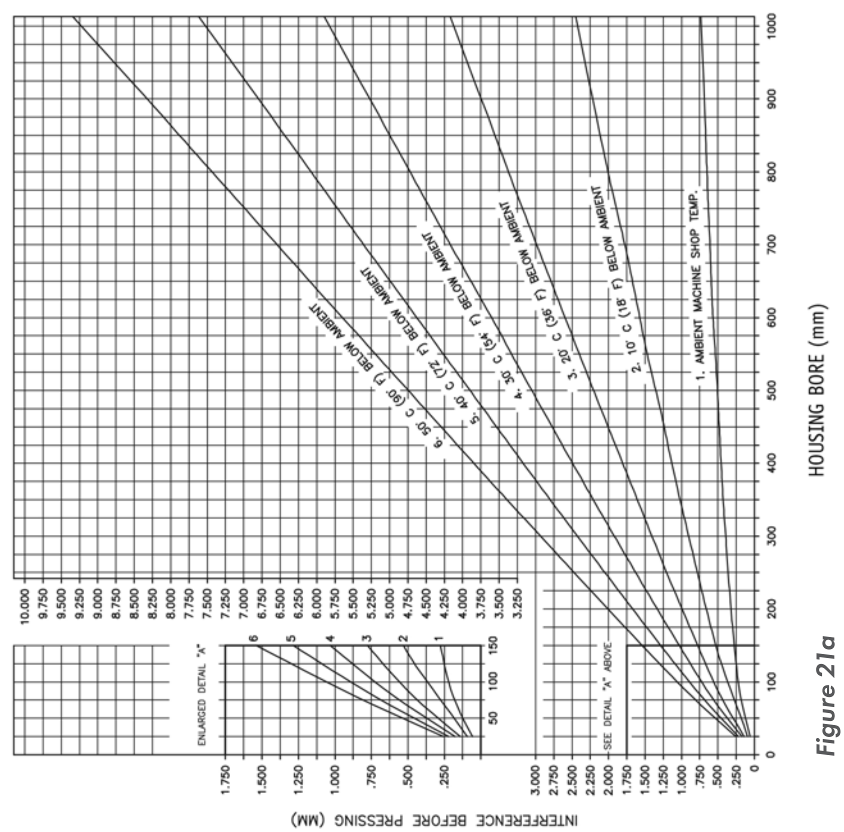


Figure 21a

NOTE: These tests were conducted using a bearing with a shape factor of 4.

FIGURE 22 - HOUSING INTERFERENCE: SXL BEARINGS

Imperial

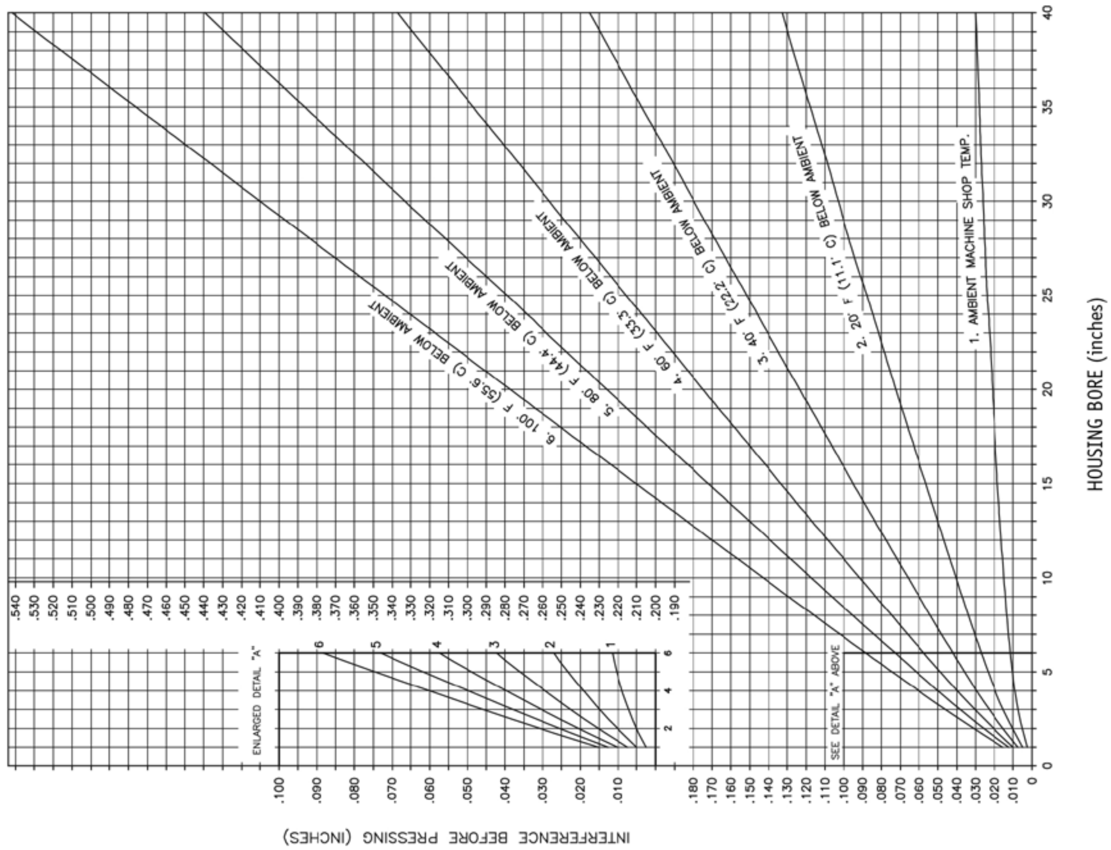


Figure 22b

Metric

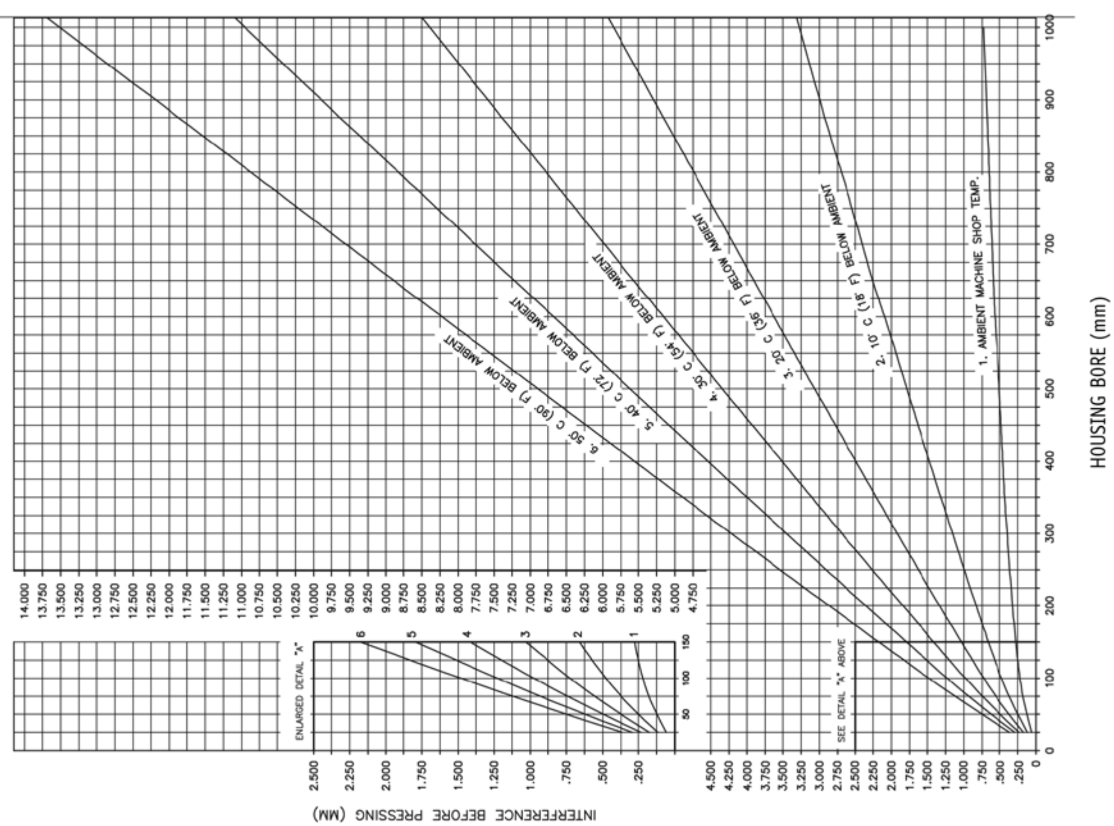


Figure 22a

APPLICATION DESIGN

c) BONDING

As indicated in Section 4(i)-iii, bonding is an alternative to interference fitting. Interference fit is not used when bearings are bonded in place. The O.D. of the bearing should be the housing diameter less an allowance for the thickness of the bonding agent. The Thordon Bearing Sizing Calculation program provides detailed dimension calculations for bond fit bearings.

To ensure good results are achieved, the procedures for bonding using Thordon approved adhesives must be followed, as outlined in Section 7.

d) BORE CLOSURE

When a Thordon bearing is installed with an interference fit, the inside diameter reduces due to volumetric displacement. The actual bore closure value varies depending on the surface finish on the outside diameter of the bearing and the inside diameter of the housing.

Both can influence axial compression. It also depends on the coefficient of friction of the bearing material. Thordon Bearings Inc. has extensively studied two bore closure theories. Theory A does not allow for axial movement in the calculations (constrained) and Theory B does allow for axial movement. Figure 23 shows typical test results. For dimensioning Thordon bearings, Theory A has been selected as the safest way of estimating bore closure because it offers a greater running clearance.

The field results have been mixed, with most being close to Theory A. Figures 24a & 24b reflect Theory A with a maximum bore closure factor of 1.45 for Thordon XL and RiverTough/Composite and 1.25 for Thordon SXL and COMPAC. If required, actual testing in a given application can develop more precise figures. The Thordon Bearing Sizing Calculation program also uses Theory A for calculating bore closure. The bore closure factor, determined from Figures 24a or 24b, is multiplied by the average interference (minimum interference plus 50% of housing tolerance and 50% of machining tolerance on bearing O.D.) to give the bore closure allowance.

Bore closure is expressed as a factor which is applied to the average interference. It is added to the bearing I.D.

FIGURE 23 - THORDON BORE CLOSURE TEST RESULTS

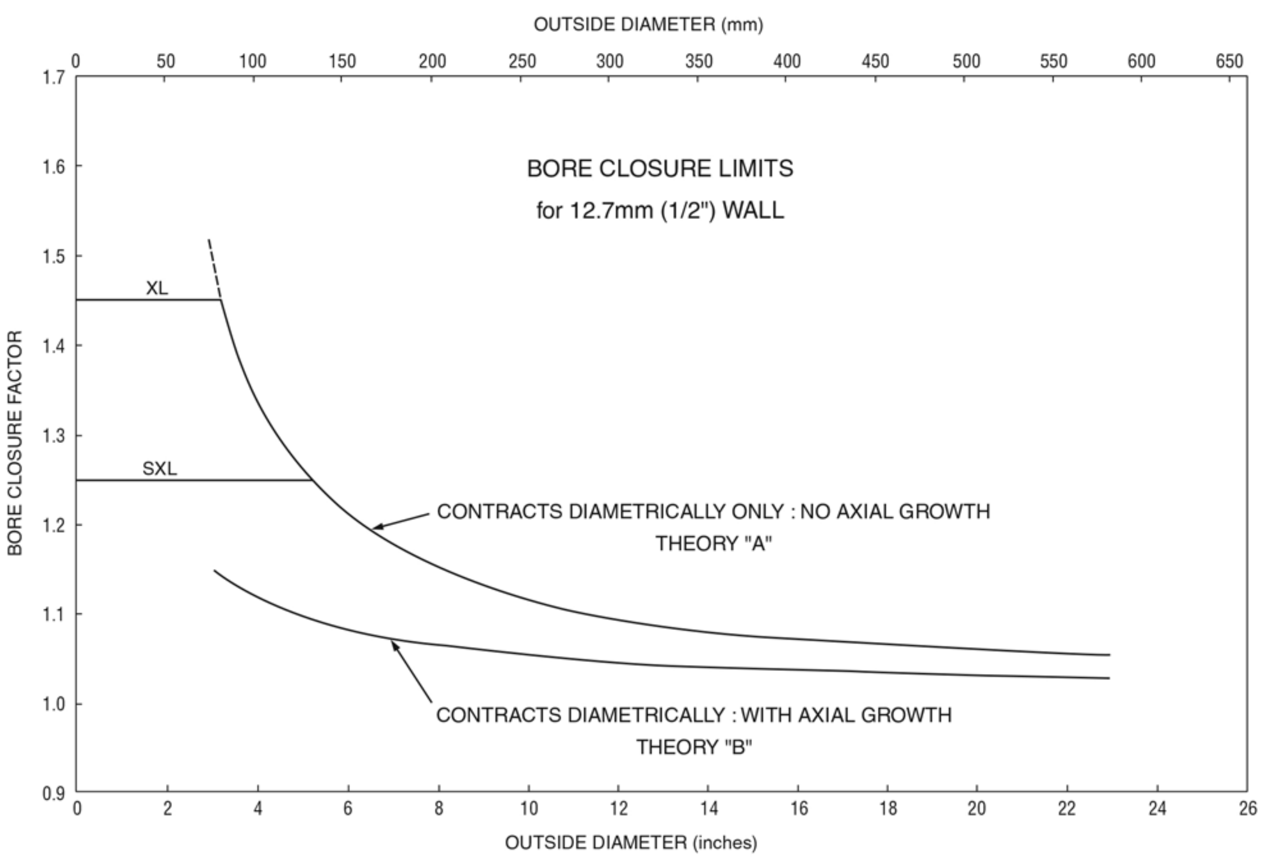


FIGURE 24 - BORE CLOSURE FACTOR FOR VARIOUS WALL THICKNESSES

Metric

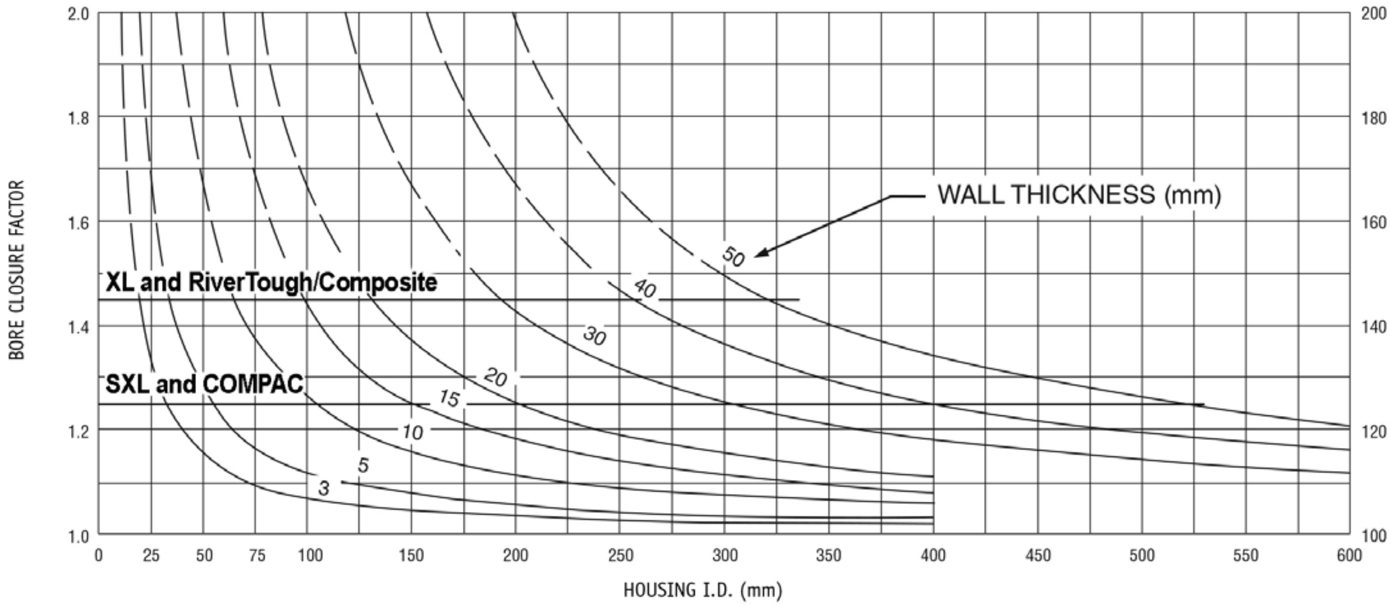


Figure 24a

Imperial

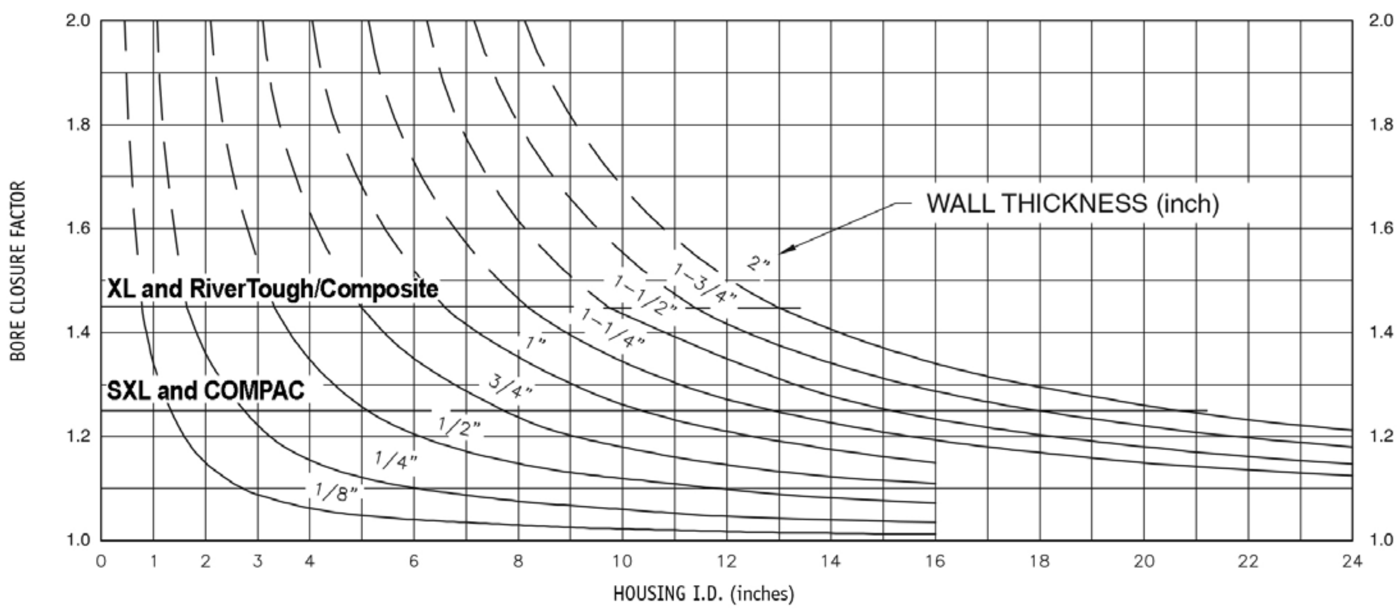


Figure 24b

Note: This graph has been limited for use up to a maximum bore closure factor of 1.25 for SXL and COMPAC, and a maximum of 1.45 for XL and RiverTough/Composite.

APPLICATION DESIGN

FIGURE 25 - MINIMUM RUNNING CLEARANCE FOR THORDON BEARINGS RELATED TO SHAFT DIAMETER

Metric

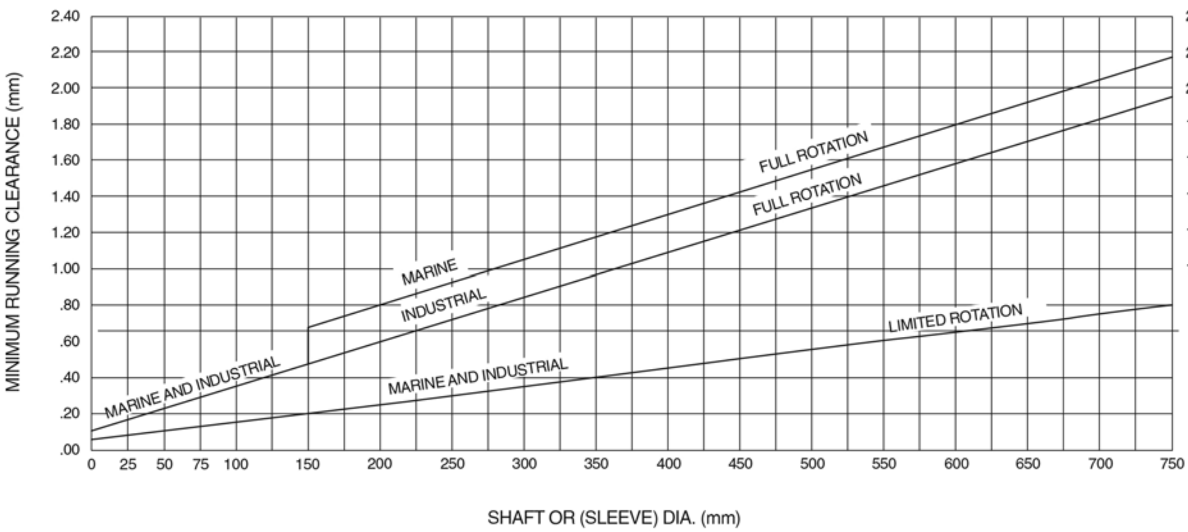


Figure 25a

Imperial

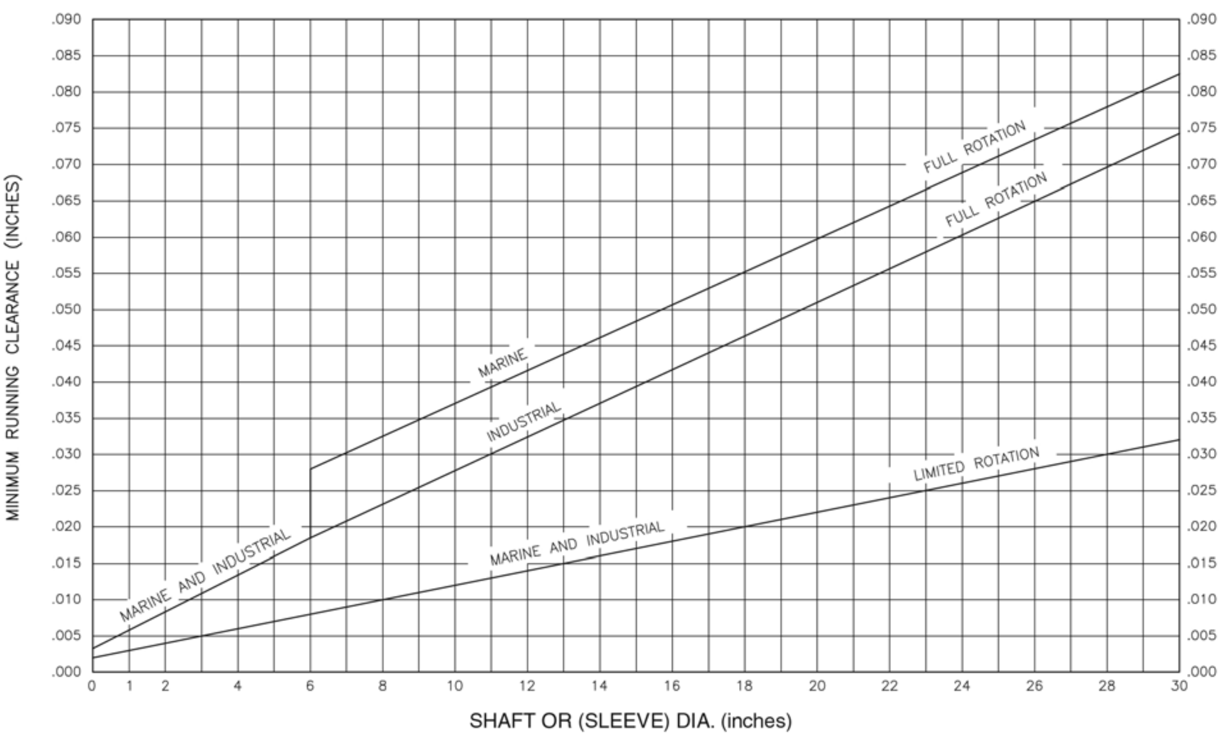


Figure 25b

Note: Small bearing clearances reflect industrial standards. Larger marine bearings, 150mm (6") and above are given greater clearance to reflect Class Society requirements.

Note: Where applicable, additional allowances must be made for thermal expansion and water swell. Refer to Steps 5/6 in Calculation Procedures.

e) RUNNING CLEARANCE

Recommended running clearances for Thordon bearings, as well as all other non-metallic materials, are usually more generous than those specified for metallic bearings.

Running clearance is necessary for the establishment of a satisfactory liquid lubricant film. It also includes a margin of safety to allow for bore reduction as a result of frictional heating of the bearing during operation. Figures 25a and 25b illustrate the diametrical running clearance requirements for industrial and marine applications.

Diametrical running clearance is the total difference in dimension between the final installed inside diameter of the bearing after accounting for the effects of temperature and water absorption, and the outside diameter of the shaft.

In oscillating motion applications, where heat build up is not as likely to occur, running clearances can be reduced as shown in Figures 25a and 25b.

Inadequate running clearances result in bearing failure characterized by a "smeared" or "wiped" bearing I.D.

Typical example of a wiped bearing.

NOTE 1: In certain bearing configurations, where there is no unidirectional load such as vertical pumps and vertical hydro turbines, reduced running clearances are possible. In these configurations, bearings can be designed with running clearances of 0.075% to 0.1% of shaft diameter. Bearing designs with tighter running clearances are possible. Please contact Thordon Bearings for more detailed information.

f) THERMAL EXPANSION ALLOWANCE

Thermal Expansion Allowance (C_t) is an additional clearance that must be taken into account when the bearing will operate at temperatures above ambient (machine shop) temperature. The diametrical C_t is calculated based on the coefficient of thermal expansion of Thordon using the following formula.

C_t (diametrical) = 2 W.T. $\propto (T_o - T_a)$

$\propto$ = Coefficient of Thermal Expansion for Thordon as follows:

For a temperature range of 0°C to 30°C (32°F to 86°F)

XL and RiverTough/Composite:
$\propto = 0.000148°C^{-1}$ ($0.000082°F^{-1}$)

SXL and COMPAC:
$\propto = 0.000151°C^{-1}$ ($0.000084°F^{-1}$)

NOTE: A Directory of symbols used is found on the inside front cover.

This clearance (C_t) is then added to the minimum running clearance as determined from Figure 25a or 25b.

In applications where the bearing is being axially retained and is operating at temperatures above ambient, an axial thermal expansion allowance must be deducted from the bearing length to allow room for the axial expansion before encountering the retainers. The axial thermal expansion allowance is calculated using the following formula.

C_t (axial) = L $\propto (T_o - T_a)$

NOTE 1: If sufficient axial thermal expansion clearance is not provided, the bearing will still expand. It will either dislodge the bearing retainers or, instead of expanding axially, it will expand more diametrically, reducing the running clearance of the bearing. This can result in bearing failure.

g) ABSORPTION ALLOWANCE

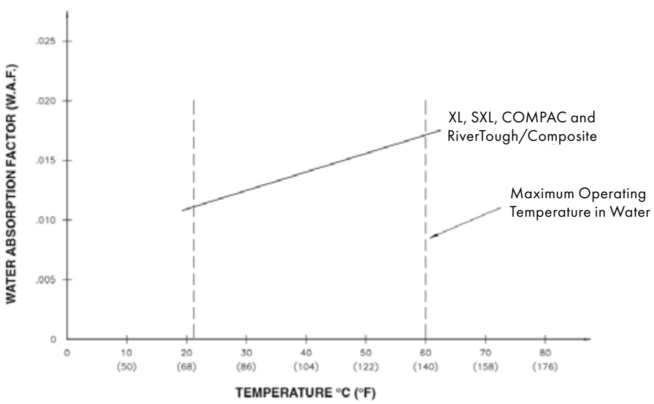
Thordon normally absorbs liquid at a rate of 1.3% by volume, although in warmer liquids the expansion by volume can reach a rate of 2%. Although considerably less than most other non-metallic products, this expansion must be taken into account because it results in bore reduction as well as a slight increase in interference fit.

The diametrical (bore closure) effect of the Absorption Allowance (Cs) is calculated using the following formula.

C_s (diametrical) = W.A.F. x W.T.

where W.A.F. is the Water Absorption Factor determined from Figure 26 for the approximate maximum operating temperature. W.T. is wall thickness.

FIGURE 26 - WATER ABSORPTION FACTOR (W.A.F.) FOR VARIOUS WATER TEMPERATURES



GRAPH DATA BASED ON TESTS AT 21°C (70°F) and 60°C (140°F)

For example: if the highest operating temperature is 21°C (70°F), the W.A.F. is 0.011. This clearance is then added to the minimum running clearance obtained from Figure 25a or 25b.

In applications where the bearing is being operated in a liquid and axially retained, an axial absorption allowance must be deducted from the machined bearing length to allow room for the axial expansion before encountering the retainers.

The **axial absorption allowance** for an interference fit bearing is calculated using the following formula.

C_s (axial) = .005 x Length of Bearing

NOTE: If sufficient axial absorption clearance is not provided, the bearing will still expand, dislodging the bearing retainers or, instead of expanding axially, it will expand more diametrically reducing the running clearance of the bearing. This can result in bearing failure.

h) MINIMUM INSTALLED CLEARANCE

As indicated in the following examples, the ID of a bearing is calculated by adding the bore closure (if applicable), running clearance, thermal expansion allowance and absorption allowance to the maximum shaft diameter. When the bearing is fitted into the housing, the bore closure (if applicable) happens, so the allowance is not a factor. What is left is running clearance, thermal expansion allowance and absorption allowance. The sum of these three factors is what is called "Minimum Installed Clearance". This is clearly indicated in the Thordon Bearing Sizing Calculations. When the bearing is operating, the thermal expansion allowance will disappear when the maximum operating temperature is reached, and the absorption allowance will disappear as the bearing gradually absorbs the lubricating liquid. Running clearance will be the only clearance left.

Minimum Installed Clearance is used as an important final check before putting the bearing into service. If the measured clearance after fitting is less than the Minimum Installed Clearance, then there is a high probability that the bearing will fail. The problem should be anticipated before the bearing enters service.

i) USING THE THORDON BEARING SIZING CALCULATION PROGRAM

A software program is available to calculate the sizing of Thordon bearings. It takes into account all of the factors covered in the application design section of this manual and greatly simplifies the calculation process. The program is available from your Thordon distributor or Thordon Bearings Inc.

The Thordon Bearing Sizing Calculation Program is only as reliable as the information entered. Care must be taken to ensure that all inputs are correct. The current program is the result of more than 30 years of work with computer-based Thordon dimension calculations.

Detailed help screens are available throughout the program if you have questions regarding a specific topic.

The following are examples of the Sizing Program used to calculate typical bearing dimensions:

1. SAMPLE CALCULATION USING THORDON BEARING SIZING CALCULATION PROGRAM (MARINE PROPELLER SHAFT APPLICATION)

a) METRIC EXAMPLE

FIT: Interference **MATERIAL:** XL

Given Data

1. Type of Operation	Marine Propeller Shaft
2. Shaft Diameter	100 +0.00/-0.04 mm
3. Bearing Housing	150 +0.04/-0.00 mm
4. Housing Length	400mm
5. Operating Temp.	Min. -2°C Max. 45°C
6. Ambient Temp.	21°C
7. Environment	Water

The Bearing Sizing Program Gives the Following Results:

Machined Bearing Outside Diameter:
150.96 +0.13/+0.00 mm

Machined Bearing Inside Diameter:
102.28 +0.13/+0.00 mm

Minimum Installed Diametrical Clearance: 0.89 mm
Machined Bearing Length: 396.26 +0.00/-0.50 mm
Bearing Wall Thickness: 24.34 mm

b) IMPERIAL EXAMPLE

FIT: Interference **MATERIAL:** XL

Given Data

1. Type of Operation	Marine Propeller Shaft
2. Shaft Diameter	4 +0.00/-0.002 in.
3. Bearing Housing	6 +0.001/-0.00 in.
4. Housing Length	16 in.
5. Operating Temp.	Min. 28°F Max. 113°F
6. Ambient Temp.	70°F
7. Environment	Water

The Bearing Sizing Program Gives the Following Results:

Machined Bearing Outside Diameter:
6.038 +0.005/+0.00 in.

Machined Bearing Inside Diameter:
4.091 +0.005+0.00 in.

Minimum Installed Diametrical Clearance: 0.035 in.
Machined Bearing Length: 15.850 +0.00/-0.020 in.
Bearing Wall Thickness: 0.974 in.

The Thordon Bearing Sizing Calculation Program can be used to do the following calculations quickly and accurately. The program will provide machining dimensions for the bearing O.D., for either interference or bond fit. For the machined bearing I.D., run the appropriate calculation for an interference or bonded fit, and then add the "Minimum Installed Clearance" to the shaft diameter to obtain the required bearing I.D. for machining.

2. SAMPLE CALCULATION USING THORDON BEARING SIZING CALCULATION PROGRAM (INDUSTRIAL VERTICAL PUMP APPLICATION)

a) METRIC EXAMPLE:

Bearing machined after fitting into housing

FIT: Interference Fit, machined after fitting in housing
MATERIAL: SXL

Given Data

1.	Type of Operation	Ind. Vertical Pump
2.	Shaft Diameter	100 +0.00/-0.04 mm
3.	Bearing Housing	150 +0.03/-0.00 mm
4.	Housing Length	200mm
5.	Operating Temp.	Min. -2°C Max. 30°C
6.	Ambient Temp.	21°C
7.	Environment	Water

The Bearing Sizing Program gives the following results:

Machined Bearing Outside Diameter:
151.03 +0.13/+0.00 mm

Machined Bearing Inside Diameter:
101.85 +0.13/+0.00 mm

Minimum Installed Diametrical Clearance: 0.53 mm

Machined Bearing Length: 198.62 +0.00/-0.50 mm

Bearing Wall Thickness: 24.59 mm

Step 1: Bearing O.D. is machined to 151.03 mm as per Bearing Sizing Calculation Program

Step 2: Fit bearing into the housing

Step 3: Machine the bearing I.D. to maximum shaft diameter plus minimum installed clearance = 100 + 0.53 = 100.53 mm.

(The Thordon Bearing Sizing Calculation Program will calculate minimum installed clearance. The difference between the value in Step 3 and machined bearing is bore closure.)

When final machining of the bearing bore is done after it is installed in the housing, care must be taken because this method removes stressed material that is developing the "grip" of the bearing within its housing. Only minimum material must be removed.

For ungrooved bearings, this machining stage must not remove more than 5% of the wall thickness.

For grooved bearings, it is not as important because the bore material is much less stressed, however machining should be limited to 10% of the wall thickness or 25% of the groove depth, whichever is less.

Lubrication grooves must always be machined prior to fitting the bearing into the housing.

b) IMPERIAL EXAMPLE:

Bearing machined after fitting into housing

FIT: Interference Fit, machined after fitting in housing
MATERIAL: SXL

Given Data

1.	Type of Operation	Ind. Vertical Pump
2.	Shaft Diameter	4 +0.00/-0.002 in.
3.	Bearing Housing	6 +0.001/-0.00 in.
4.	Housing Length	8 in.
5.	Operating Temp.	Min. 28°F Max. 86°F
6.	Ambient Temp.	70°F
7.	Environment	Water

The Bearing Sizing Program gives the following results:

Machined Bearing Outside Diameter:
6.041 +0.005/+0.00 in.

Machined Bearing Inside Diameter:
4.074 +0.005+0.00 in.

Minimum Installed Diametrical Clearance: 0.021" in.

Machined Bearing Length: 7.945 +0.00/-0.020 in.

Bearing Wall Thickness: 0.983 in.

Step 1: Bearing O.D. is machined to 6.041 in. as per Bearing Sizing Calculation Program

Step 2: Fit bearing into the housing

Step 3: Machine the bearing I.D. to maximum shaft diameter plus minimum installed clearance = 4 + 0.021 = 4.021 in.

(The Thordon Bearing Sizing Calculation Program will calculate minimum installed clearance. The difference between the value in Step 3 and machined bearing is bore closure.)

When final machining of the bearing bore is done after it is installed in the housing, care must be taken because this method removes stressed material that is developing the "grip" of the bearing within its housing. Only minimum material must be removed.

For ungrooved bearings, this machining stage must not remove more than 5% of the wall thickness.

For grooved bearings, it is not as important because the bore material is much less stressed, however machining should be limited to 10% of the wall thickness or 25% of the groove depth, whichever is less.

Lubrication grooves must always be machined before the bearing is fitted into the housing.

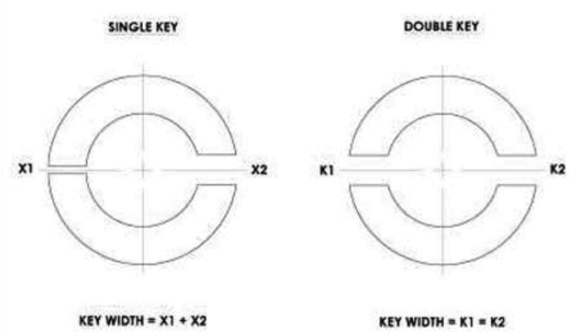
j) KEYED TUBULAR BEARING CALCULATIONS

Thordon bearings are often installed with both an interference fit and one or two sets of locking keys.

To size the Thordon bearings and split gap widths to obtain the correct interference for a keyed bearing application, the following procedure should be used.

1. Calculate the bearing dimensions based on a normal tube and an interference fit. The calculations can be done using the Thordon Bearing Sizing Calculation Program.
2. Machine the bearing according to the calculated dimensions.
3. Measure the circumferential width of the key(s) and measure or approximate the width of the cut on the side opposite the key in the case of a single key. See Figure 27.

FIGURE 27 - MEASURING KEY WIDTHS



4. Cut the slot(s) in the bearing so the total width of material removed equals the width of the keys / keyset. Ensure that the combined circumferential interference of bearing and key(s) is the same as for a non-split bearing.
5. If more than one key or keyset is fitted, then the bearing is slotted accordingly, the slots logically positioned to suit the keys and the material removed in each slot equal to the width of the corresponding keys.

Note: The same approach should be taken when working with a split bearing that will be interference fitted with no keys. It is important to maintain the circumference after splitting. The easiest approach is to fully machine the bearing as a tube and then split it. Use the Thordon Bearing Sizing Calculation Program to calculate the bearing dimensions as if it were not split. Then add to the O.D. and I.D. the circumferential effect of the thickness of the splitting cuts – total thickness of cuts/π.

k) HIGH PRESSURE BEARINGS

Thordon has two grades for high pressure bearing applications. The first is ThorPlas, a homogeneous non-elastomeric material. **Details on ThorPlas are provided in a separate manual.** The other grade for high pressure bearing applications is Thordon HPSXL TRAXL, which is specified in many industrial and marine applications. HPSXL TRAXL bearings are ideally suited to applications where the loads are high and conventional lubrication is not used.

Typical applications include hydro-turbine wicket gates and linkages, lock gate supports, stern rollers, cranes and construction equipment pivot points.

Thordon HPSXL TRAXL bearings are a composite design consisting of a thin layer of Thordon HPSXL bonded in a metallic shell.

As outlined in **l) Material Selection Process** of the Design Guide, it is possible to achieve operating pressures up to 55.0 MPa (8,000 psi) with permissible peak static pressures up to 70.0 MPa (10,000 psi) or higher, with HPSXL TRAXL bearings.

These pressure ratings are achieved through the combination of several factors. The applications are either oscillating or very slow speed operation so that frictional heat build up is not a consideration.

The bearing is designed with a very high shape factor (typically over 100). This means that the wall thickness of the bearing is very thin (usually 1.5mm (0.060") or less).

Optimum high pressure results are obtained using Thordon HPSXL TRAXL in which HPSXL is bonded directly into a specially grooved metallic shell. This bearing with HPSXL as the wear surface is then press fit into the bearing housing. Lower pressure applications can be done by cold bonding a thin wall Thordon tube into a shell. The pressure range for each method is illustrated in Figure 28.

FIGURE 28 - PRESSURE RANGE FOR DIFFERENT MANUFACTURING METHODS

	Pressure			
Manufacturing Method	Normal Operation		Peak Static	
	MPa	psi	MPa	psi
TRAXL	27.5-55.0	4,000-8,000	70.0	10,000
Cold Bonded	13.7-20.6	2,000-3,000	27.5	4,000

NOTE: Thordon bearings can be designed to operate at higher pressures for specific applications. Please contact Thordon Bearings for further information.

APPLICATION DESIGN

The cold bonding process is used when the application requires a combination of relatively high pressure capability and thicker (greater than 1.5mm or 0.060") wall. The pressure rating decreases, however, as the wall thickness increases, due to the decreasing shape factor.

Much tighter running clearances can be achieved with HPSXL TRAXL bearings compared to Thordon sleeve bearings. There are a number of factors that contribute to this:

1. All machining is performed after the Thordon material is bonded into the bearing shell. Therefore, tolerance build up is minimized.
2. Due to the rigid metal shell, and the support that it provides to HPSXL, both the O.D. and I.D. can be machined to tighter tolerances.
3. Design running clearance is reduced because rotation is limited (frictional heat build up is not a concern). Similarly, due to the thin wall, the thermal expansion and absorption allowances are not significant.

The following design parameters should be considered in the design of a Thordon high pressure bearing application:

- Interference
- Bore Closure
- Running Clearance
- Housing and Shaft Dimensions
- Bearing Dimensioning and Tolerances

NOTE 1: Absorption Allowance and Thermal Allowance are normally assumed to be insignificant because the Thordon wall thickness in a HPSXL TRAXL bearing is usually 1.5mm (0.060") or less. If the thickness of HPSXL is greater than this, then the Absorption Allowance and Thermal Expansion should be considered.

NOTE 2: The calculations for HPSXL TRAXL bearings are different from those for full form Thordon bearings because the relatively thin HPSXL is fitted into a metallic shell. Calculations such as interference and bore closure are based on the properties of the metallic shell rather than on the properties of the Thordon.

i) Interference:

The amount of interference between the Thordon HPSXL TRAXL bearing and the housing is dependent on the operating conditions. As the pressure increases so must the interference. The normal recommended interference fit ranges from 0.025% to 0.100% of the O.D. depending upon the size of the bearing. For larger bearings, the percent interference is decreased.

Note: HPSXL TRAXL bearings should not be freeze fitted. There is a significant risk that freezing, with dry ice or liquid nitrogen, could damage the bond between the Thordon HPSXL and the metallic shell.

ii) Bore Closure:

From practical experience the bore closure from an interference fit between two metals is normally in the range of from 75 to 95% of the interference. To ensure that running clearance is adequate, an assumed bore closure factor of 1 is recommended for calculation purposes.

iii) Running Clearance:

The normal recommended running clearance is 0.1% of shaft diameter with a minimum recommendation of 0.075mm (0.003").

In applications where tighter tolerances are required please contact your Thordon distributor or Thordon Bearings for guidance.

iv) Housing and Shaft Dimensions:

To obtain the optimum installed running clearance it is necessary to control tightly the tolerances of not only the bearing but also of the housing and the shaft. Excessive housing bore or shaft tolerances translate directly into additional running clearance requirements. If a project involves a series of bearings as in a wicket gate assembly, each position can be measured and numbered so that the bearings can be specifically dimensioned for each position.

v) Bearing Dimensioning and Tolerances:

The O.D. and I.D. of a Thordon HPSXL TRAXL bearing are calculated as follows:

Bearing O.D. = Housing Diameter (maximum) + Normal Interference

Bearing I.D. = Shaft Diameter (maximum) + Bore Closure (maximum bearing O.D. - minimum housing diameter) + Running Clearance

The standard machining tolerances of Thordon High Pressure bearings are:

Bearing O.D.:	+0.025mm/-0.000mm	(+0.001"/-0.000")
Bearing I.D.:	+0.075mm/-0.000mm	(+0.003"/-0.000")

I) VERTICAL PUMP BEARINGS: DRY START-UP

Thordon SXL and ThorPlas are widely used in vertical pumps because of its ability to run dry on start-up. The length of time that SXL can run dry in a vertical pump configuration usually meets the requirements of the pump designer for dry start-up. The Thordon Bearing Sizing Calculation Program will automatically adjust the clearances when a dry start-up vertical pump application is selected.

For further information regarding dry start-up, please contact Thordon Bearings.

6) MACHINING & MEASURING

a) GENERAL MACHINING

Thordon XL, SXL, COMPAC and RiverTough/Composite are hard, tough elastomeric polymer products that can be easily machined. It is necessary, however, to remember that Thordon elastomers are non-metallic materials, and must be machined differently than metal. Due to the elastomeric nature of Thordon elastomeric materials they have a tendency to “move away” from anything that exerts pressure on it, including machine tools of all types. Thordon elastomeric materials cannot be burnished or chipped; they must be cut with a sharp tool. **The importance of sharp cutting tools cannot be overemphasized if Thordon elastomeric materials are to be successfully machined.**

NOTE: Machining videos are available from Thordon Bearings Inc., or from your local distributor. This is an excellent tool for understanding the requirements for machining Thordon bearings.

www.youtube.com/ThordonBearings

When thin wall bearings are being machined it is important to recognize that the exertion of excess pressure may actually deform the bearing. In some situations it may be necessary to use modified chuck jaws, to support the tube using a spider, plug or a mandrel or to mount the tube using screws to fix it to a faceplate. For large, thin-walled tubular bearings, it is recommended to machine them on a vertical boring mill.

Cutting speeds are also important. Low feed rates combined with too low a turning speed tend to produce a rough cut due to the toughness and elastomeric nature of Thordon elastomeric materials. High speeds combined with a low feed rate may produce excessive frictional heat, resulting in a gummygalled finish. The most suitable speed/feed combinations are similar to those used when machining aluminum.

Clearances, as specified using the design information in this manual, may seem excessive in comparison to metals. Thordon elastomeric materials, however, expand from temperature change and submersion in liquids. Thordon elastomeric materials also exhibit bore closure shrinkage at a rate greater than 100% of interference. This is due to the incompressible nature of Thordon elastomeric materials. **The minimum installed clearance takes all of these factors into account.** As well, clearance for a liquid lubrication film if the bearing is water or oil lubricated and safety clearance for frictional heat build up are also accounted for. The recommended running clearance should not be decreased without first consulting your Thordon distributor or Thordon Bearings Inc.

NOTE: If adequate running clearance is not provided, bearing failure is almost certain.

Virtually all operations that can be performed on metal, including machining, drilling, tapping, shaping, routing, sawing, milling and bonding, can be performed on Thordon elastomeric materials. Thordon elastomeric materials can also be worked or shaped with conventional hand tools, keeping in mind that carbide tipped cutting blades should be used to prevent heat build up when sawing.

MACHINING

b) MACHINING XL, SXL AND COMPAC

i) Cutting Tool

To machine Thordon elastomers, it is critical that the correct cutting tool be used. The tool must be designed to slice the material and project it away from the machined surface. When machining Thordon properly, a continuous streamer is projected from the cutting tool. **The cutting tool must be sharp.** Carbide cutting tools currently available provide excellent results machining Thordon. They are extremely sharp initially and hold their edge very well.

Thordon Bearings recommends a tool bit manufactured by Kennametal® that is available worldwide. The tool bit is Titanium Nitride PVD coated carbide and is Kennametal® part number: CPGT3251HP-KC730 as shown below. The tool holder is part number: SCMPN-083V. There are a number of tool bits and holders offered in the Kennametal® KC730 series.

The applicable ISO standards are M05 - M20, S15 - S25. If you have trouble locating this, or a similar product, please contact Thordon Bearings or your local Thordon Distributor.

Kennametal® Tool Bit

It is important when machining Thordon and particularly when boring, to ensure that the machining streamer is removed from the work. If this is not done, it will interfere with the cutting tool and a rough finish will result.

NOTE: Due to the very elastic nature of the Thordon material, caution should be taken when removing cuttings from the work area.

The drawings in Figure 30 illustrates the proper cutting tool configuration when using conventional tool bits. High speed steel can be used for SXL and COMPAC; tungsten carbide tool bits are used with XL.

ii) Machining Speeds and Feeds

Suggested turning speeds for bearings of various diameters are provided in the chart below.

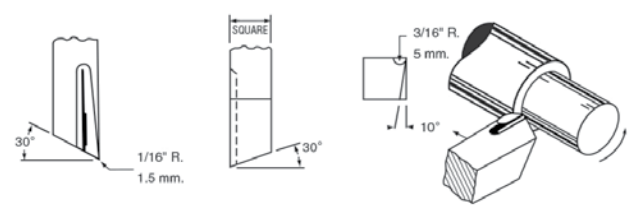
FIGURE 29 - TYPICAL SPEEDS AND FEEDS

Bearing Diameter		RPM	Coarse Feed	Fine Feed
mm	inches			
75mm	3″	600	0.6mm/rev.	0.4mm/rev.
150mm	6″	450	(0.025″/rev.)	(0.015″/rev.)
300mm	12″	300	for HSS tool	for HSS tool
450mm	18″	150	-	-
600mm	24″	120	0.3mm/rev.	0.2mm/rev.
750mm	30″	95	(0.012″/rev.)	(0.007″/rev.)
900mm	36″	80	for tipped tool	for HSS tool

NOTE 1: The turning and feed speeds are provided as a guide only. The optimum speed may vary higher or lower depending on such variables as the length of tube, the wall thickness, and how the bearing is being supported, i.e. simply chucked, spider at chuck or on a full length mandrel. As is common with all machining operations, some experimentation is required to obtain optimum results.

NOTE 2: Cutting lubricants are not required and are not recommended.

FIGURE 30 - STEP MACHINING TOOL BIT

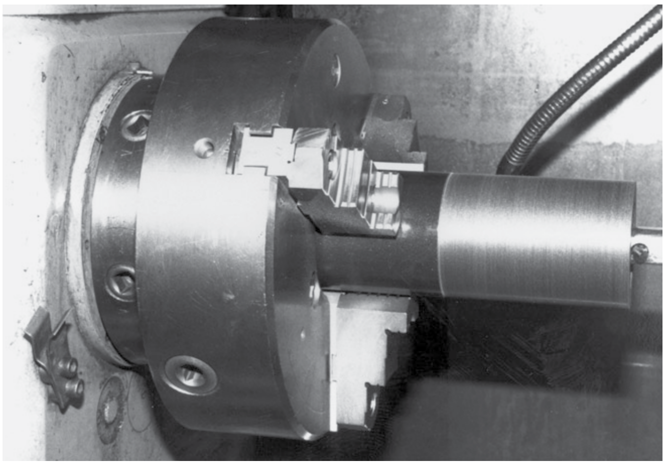


Manual vs. CNC Machining

As Thordon elastomeric materials are machined using ID, OD and Length, manual machines are most often employed.

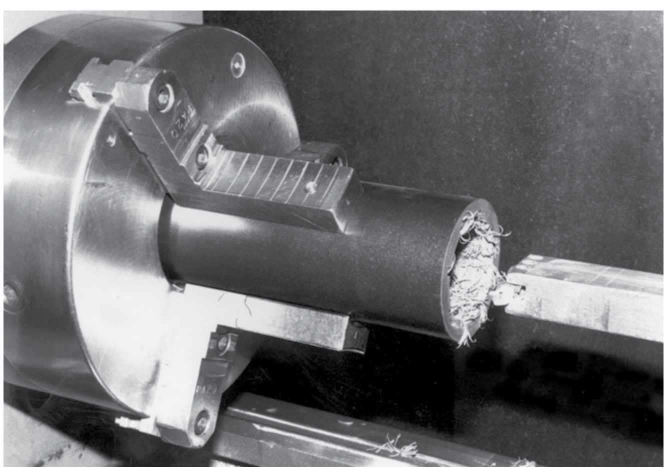
iii) Bearing Set Up

MACHINING - PARTIAL LENGTH FROM A TUBE



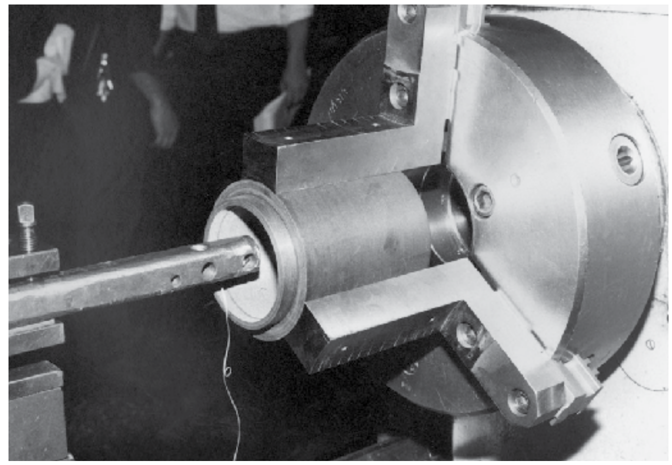
A bearing that is being made from the partial length of a tube can be chucked at one end in a normal 3 jaw chuck, the O.D. rough machined, the I.D. finish machined, the O.D. finish machined and then parted to length. Care must be taken not to over tighten the chuck and distort the tube.

MACHINING (I.D.) - THIN WALL TUBE WITH SOFT JAW CHUCK



To machine the I.D. of a thin wall tube, the O.D. should be rough machined, the tube gripped in an extended soft jaw chuck and the I.D. finish machined. The extended chuck will grip and support the tube without deforming.

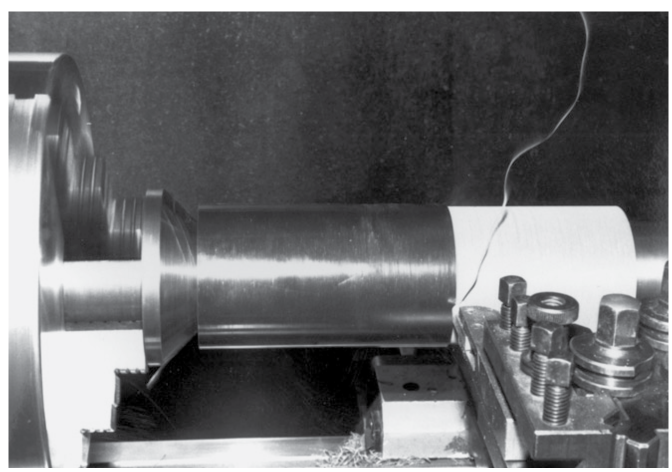
MACHINING (I.D.) - THIN WALL TUBE WITH EXTERNAL SLEEVE



A thin wall tube I.D. can also be machined by first machining the O.D. to size, lightly pressing the tube into a machined metal housing, chucking the housing and then machining the I.D. of the tube. It is possible to obtain tighter tolerances than those obtained with external soft jaws with this method but it is more complicated and typically not necessary.

MACHINING (O.D.) - FULL LENGTH OF A LUBRICATION

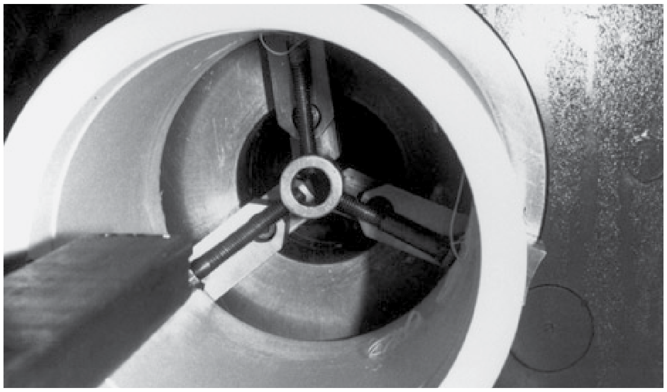
GROOVED BEARING - SUPPORTED ON CENTRES



After the I.D. of a bearing with lubrication grooves has been finish machined, the bearing can be chucked on centres, driven by a key in one of the grooves and the O.D. finish machined. This method is acceptable for propeller shaft bearings, but will not yield the tight tolerances required for pump bearings.

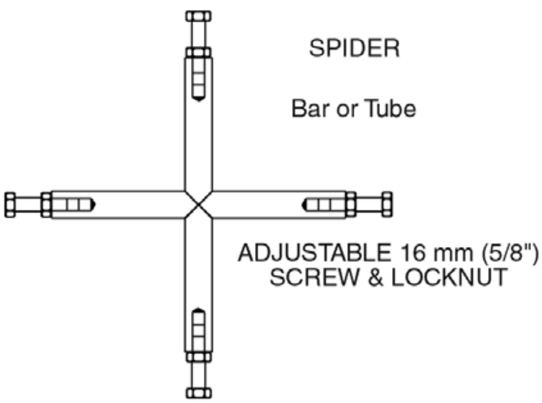
MACHINING

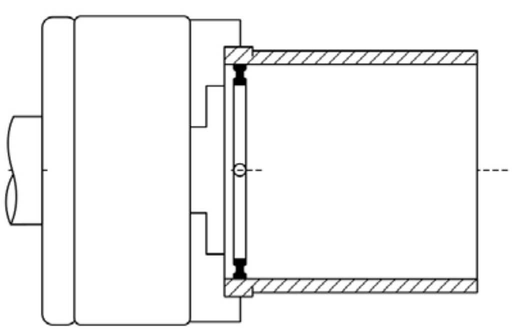
MACHINING (O.D.) - MACHINED STEEL PLUG OR ADJUSTABLE SPIDER



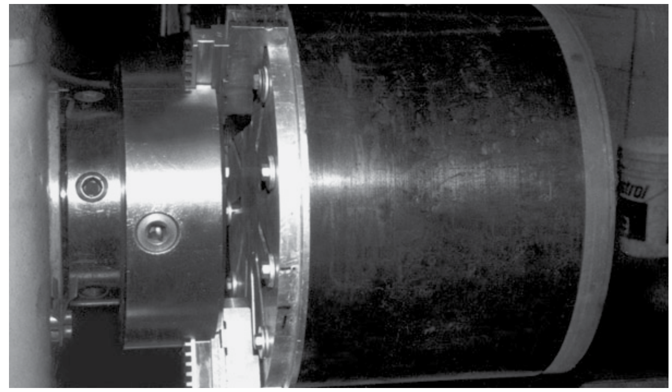
After the I.D. of a tube has been finish machined, a machined steel plug can be slip fit into the I.D. of the bearing. On larger tubes, a 3 or 4 arm spider can be set to the inside diameter of the tube and located opposite the chuck jaws. Both of these devices eliminate distortion from chuck jaw pressure. A simply constructed 4-arm spider is illustrated below. With either of these methods it is necessary to add a 50mm (2") chucking allowance to the required length of the bearing.

FIGURE 31 - ADJUSTABLE SPIDER





MACHINING (O.D.) PREFERRED MACHINING METHOD - O.D. & I.D.

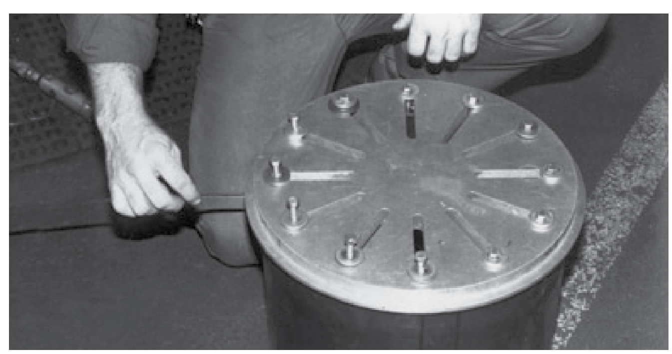


Bearings larger than 380mm (15") O.D. are most easily mounted for machining by lag screwing them to a faceplate. The faceplate can then be set up on a vertical mill, or chucked in the lathe. An additional 50mm (2") must be added to the required length of the bearing as a chucking allowance. The faceplate is centered as accurately as possible and then screwed to the tube using lag screws into predrilled holes. After mounting, the tube can be trued for machining, if required, by loosening the screws and adjusting the position of the tube using the slots in the faceplate.

The O.D. of the tube is rough machined first, then the I.D. finish machined, the O.D. finish machined and then the bearing is parted to length from the tube. If the bearing is too large to safely catch as it is parted off from the tube, the following procedure should be used. Part the tube approximately 80-90% of the way through, remove faceplate and tube from the lathe and knife cut the bearing from the tube.

If the bearing is mounted in a lathe, it should be completely machined without stopping for extended periods of time. This prevents the bearing drooping or going out of round under its own weight.

NOTE: Ensure that the tube is securely mounted to the faceplate before turning. Failure to mount the tube securely could result in the tube coming loose and causing personal injury.

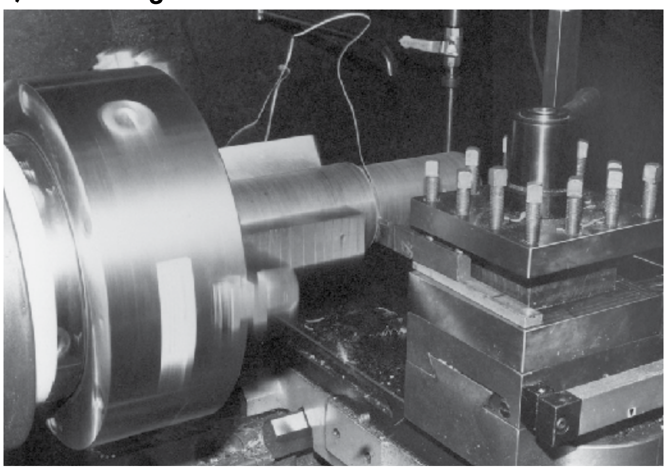


iv) Parting to Length

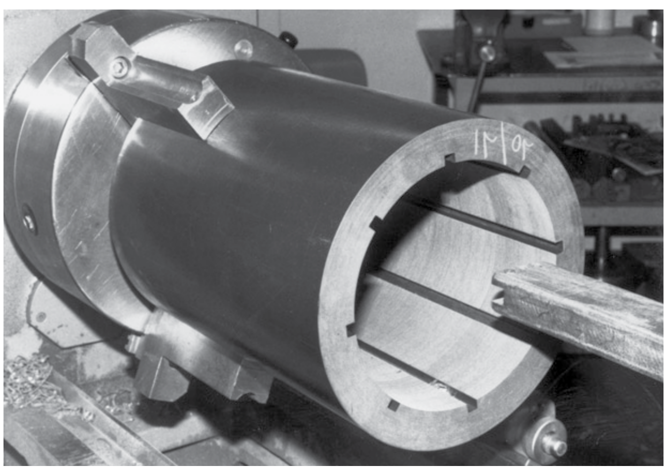
Thordon elastomeric materials can be parted to length with a standard parting tool, however, additional rake and side clearance are helpful to prevent heat generation resulting from the Thordon elastomeric materials contacting the side of the parting tool. Cuttings from Thordon elastomeric materials should be constantly removed during parting off, in order to achieve a uniform cut face.

NOTE: Due to the very elastic nature of the material, caution should be taken when removing cuttings from the work area.

v) Machining Lubrication Grooves

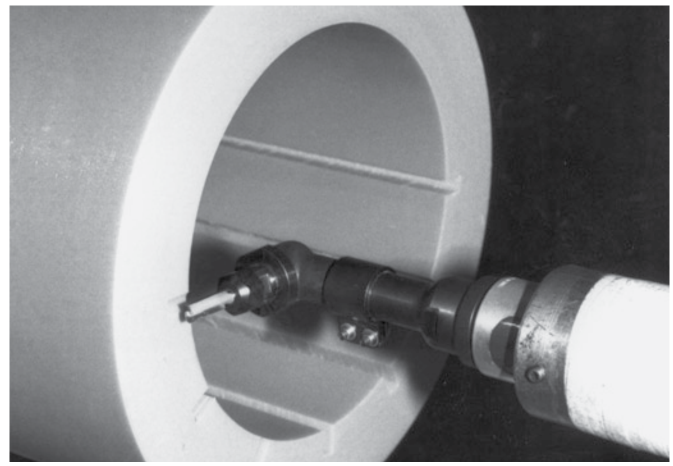


Lubrication grooves can be machined by hand or with a router.



To machine lubrication grooves by hand, a formed tool bit is mounted to the lathe boring bar and manually pushed through the bearing (broached). Several passes may be required to achieve the final groove depth.

NOTE: Lubrication grooves must always be machined before the bearing is fitted into the housing. Bearing I.D. can sometimes be machined after fitting into the housing, but grooves cannot.



The grooves can be machined much more easily by mounting a 90° pneumatic router to the boring bar and then machining to the correct depth in one pass through the bearing.

The outside diameter of the chuck can be divided and marked to act as a guide for locating the grooves in the bearing.

MACHINING

vi) General Machining Tips

1. To obtain optimum dimensional and surface finish results, the final machining cut should be 1.5mm (0.060") to 2.5mm (0.100") and the cutting tool razor sharp.
2. If machining is not done in a temperature controlled environment, the Thordon Temperature Chart must be used to adjust the machining dimensions to suit the actual temperature at the time of machining. Changes in temperature can result in significant bearing dimensional changes.
3. Due to the elastomeric nature of Thordon bearings, if a machining error is made on the I.D. and if the wall thickness is still adequate, it may be possible to recalculate the O.D. of the bearing and still use it. Contact Thordon Bearings for corrected O.D. value.
4. Before making a final machining cut, the bearing should be checked to ensure that it has not retained any heat from previous cuts. If the temperature of the bearing is higher than the machine shop ambient temperature, the resulting final cut dimensions will not be correct.

vii) Machining Large Bearings >1000mm (>40")

The easiest way to machine large Thordon elastomeric bearings is on a vertical boring mill. When machining on a vertical boring mill, the following basic steps should be followed:

1. Use a two stage machining procedure (see below) to avoid significant dimensional issues after part off,
2. Machine on a vertical boring mill,
3. Use a Pi tape for checking O.D. dimensions,
4. Use a ball micrometer to check wall thickness.

A large Thordon bearing will change dimensions significantly with changes in temperature, so it is essential to monitor the temperature of the bearing during inspection. Use an accurate temperature gun to verify temperature of the bearing for all inspections. Take care when measuring temperature. Thordon streamers and the heat generated from the chuck can be misleading.

1. FIRST STAGE MACHINING

   Rough machine O.D. and I.D. and leave overbuild on all diameters including stepping the length (flange) with a groove for final machining/clamping.

2. FINAL MACHINING

   Clamp on grooved flange step as described above. Thordon recommends machining from chuck/flange up as Thordon streamers will generate heat and will cause difficulties determining actual bearing temperatures for getting finish cuts. Also, material streamers around the cutting tool will tend to push the tool and may cause a very rough finish or issues holding tolerances.

   - Skim O.D. and I.D.
   - Finish O.D. - use temperature charts. Check O.D. at a minimum of three positions (top, middle & bottom)
   - Finish I.D. by measuring the wall thickness - use temperature charts. Check wall thickness. Machine a partial part-off, and knife cut.

   Recommend flipping and facing to length. Holding method needs to be determined by the machine shop (best method available) as part off will result in the end collapsing and clamping stress which may lead to gouging.

   Re-check O.D. at 3 positions and wall thickness at both ends.

c) MACHINING RIVERTOUGH/COMPOSITE

Machining Thordon RiverTough/Composite is different from machining Thordon XL, SXL and COMPAC because of the softer (black) bearing wear surface material, GM2401. The O.D. or yellow shell, can be machined using the same techniques as outlined in Section 6b).

The I.D. (black), however, machines differently and is covered in this section.

i) Cutting Tool

The new Kennametal® or equivalent Titanium Nitride PVD carbide coated tool bits described earlier in the section on machining XL, SXL and COMPAC are highly recommended for machining Thordon RiverTough/Composite bearings. With these tool bits, the black GM2401 I.D. of the bearing material can be finish machined to an acceptable surface finish without using a grinding hog as was recommended in the past.

When using a conventional high speed tool bit to machine the I.D. of a Thordon RiverTough/Composite bearing some extra steps must be taken. Due to the nature of the GM2401 (black) wear surface material, conventional tool bits wear very quickly. In the course of one machining pass through the I.D., the tool bit will wear enough to produce a taper along the bearing I.D. This taper must be corrected for on a second pass, so the first step is to ensure that two final passes in a range of 2.0 to 3.0mm (0.080" to 0.120") deep are required to finish machine the I.D. of the bearing. The first pass is used to measure the amount of taper that is occurring (a taper of 0.15mm (0.006") over the length of a standard Thordon tube is common) and then this taper must be corrected for on the second pass.

NOTE: It is very important to note that the final pass must be made at the same depth, speeds and feed rate as the preceding one. Otherwise the wear on the tool bit producing the taper will change and the correction that is being made by hand will not be correct.

Machining the I.D. results in a burr at the lubrication grooves that can be removed using emery cloth or a deburring tool. The surface finish of the bearing will be somewhat rough but the bearing will bed in quickly and perform well.

Deburring tool

ii) Machining Speeds and Feeds

Suggested turning speeds for RiverTough/Composite bearings of various diameters are given in the chart below.

FIGURE 32 - TYPICAL SPEEDS AND FEEDS FOR MACHINING RIVERTOUGH/COMPOSITE

Bearing Diameter			Feed	
mm	inches	RPM	HSS	Tipped Tool
150mm	6"	250	0.5mm/rev.	0.25mm/rev.
300mm	12"	100	(0.020"/rev.)	(0.010"/rev.)
450mm	18"	75	for HSS tool	for HSS tool
600mm	24"	60	-	-
750mm	30"	50	-	-
900mm	36"	40	-	-

iii) Machining Procedure - O.D. up to 250mm (10")

The procedure for machining Thordon RiverTough/Composite bearings up to 250mm (10") O.D. can be summarized in the following steps.

a. Part the bearing oversize and face to the required finished length.
b. Mount the bearing on centres and rough machine the O.D.
c. Press the bearing (light press fit) into a housing to support it and finish machine the I.D.
d. Lightly press the bearing onto a mandrel and finish machine the O.D.

iv) Machining Procedure - O.D. > 250mm (>10")

RiverTough/Composite bearings larger than 250mm (10") are best machined by mounting them to a faceplate and then machining the I.D., machining the O.D., parting oversize and facing to length.

NOTE: Ensure that the bearing is securely mounted to the faceplate before turning. Failure to mount the bearing securely could result in it coming loose and causing personal injury.

MACHINING

d) SPLITTING THORDON BEARINGS

There are two methods to split a Thordon elastomeric bearing, either using a saw blade or with a knife. Both methods are explained below.

i) Splitting a Thordon Bearing Using a Saw Blade

The O.D., I.D., bearing length, lubrication grooves, and all chamfers must be fully machined prior to initiating the procedures to split the bearing segments. A horizontal boring mill with an indexed rotating table is the best type of equipment to use to ensure proper location and accurate measurement of the splits. The pictures below illustrate the recommended process and equipment.

Depending on the length of the bearing, create two or three support disks that are the same diameter as the fully machined bearing I.D. The wooden inserts should be approximately 19.05mm or 0.75" thick. Two holes should be cut in each insert, 180° apart, to allow for two threaded rods to be placed through for securing purposes. Locate the support discs at the top and bottom (and mid section if required) of the bearing ID. These will keep the bearing "roundness" during the splitting process.

Centre the mill table and use four blocks to raise the bearing up from the surface of the mill table. Use the indicator so that the blocks are set to the centre of the table and the bearing is centered on the mill. The blocks should be positioned at approximately 90° apart from each other to support the bearing. The bearing is to be set on the blocks and oriented to place the cut on the split line shown on the Bearing Details Drawing.

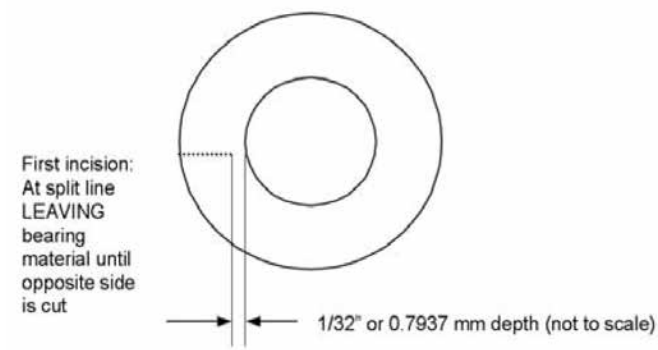
NOTE: Measure the ID of the bearings at the temperature at which they are being machined and use these numbers to create the wooden inserts. Maintain the machine shop temperature constant as the splits are being machined. If the temperature changes drastically, the bearings may shrink or expand and the woooden inserts will not fit properly.

The bearing is clamped onto the table with 2 threaded rods secured with "T" nuts located in a groove on the table. Two metal bars are placed on the top of the bearing located directly over the metal support blocks on the mill table and clamped into position using a nut threaded onto the rod. Care is to be taken to ensure the clamps are not secured too tight.

Line the spindle of the machine to the split line indicated on the drawing and square to the bearing surface. A high-speed steel metal slitting saw 203.2mm x 3mm x 31.75mm (8″ x 1/8″ x 1 1/4″) cutter is typically used by the Thordon Machine Shop (saws with side chip clearance) to do the splits. The cutting speed should be approximately 250 mm/min (10 inches/min) at 140 RPM. The blade should be positioned with its saw teeth on the opposite direction of the bearing so that the saw is cutting away from the bearing.

Begin cutting the split line. Position the spindle to make the incision from the bottom up, cutting from the O.D. towards the I.D. of the bearing. The depth of the cut should leave a 0.794mm (1/32″) section of material at the bottom of the cut for further cutting after opposite side is cut. See figure below. If the bearing is cut all the way through, the material will have a tendency to spring back losing its roundness and making it very difficult to continue with the split on the opposite side (180°).

FIGURE 33 – SPLITTING A THORDON BEARING



Rotate the table 180° and proceed with the second cut, again leaving approximately 0.794mm (1/32″) of bearing material behind as shown in Figure 33. Ensure that both halves have the same arc length. Air should be used constantly during slitting to remove shavings. If shavings are not removed, the saw blade could get stuck and break. Take the bearing off the boring mill table. Using a sharp knife cut through the 0.794mm (1/32″) gap of material that was left behind until the two segments are separated. Clean off the edges.

NOTE: Use compressed air to remove the material as it is being split away from the bearing. If the material is not removed it will tend to melt on the blade as the splitting process continues.

MACHINING

ii) Splitting A Thordon Bearing Using A Knife

The O.D., I.D., bearing length and grooves of the bearing must be fully finished before proceeding with this technique. Mark the split before splitting.

A Hydraulic Press is used to "knife" cut bearings without a gap. The knife or blade holder has been made in house to fit our press. The two holders at the bottom support the shaft used to position the bearing.

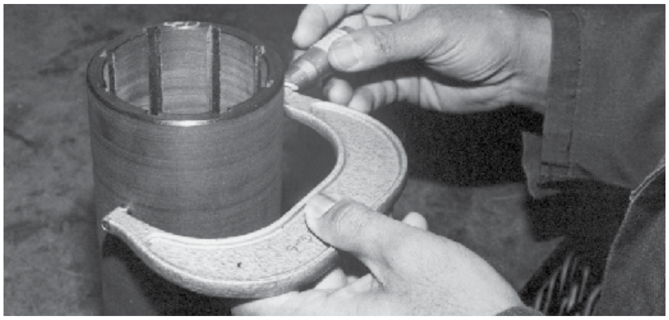
The shaft is placed inside of the bearing to be split and the assembly is located over the two stand supports.

The first cut is made. Hold the bearing so that there is no movement while the blade is being lowered.

Rotate bearing 180°, and support the bearing so that there is no movement while the second cut is being made.

e) DIMENSIONAL AND SURFACE FINISH MEASUREMENTS

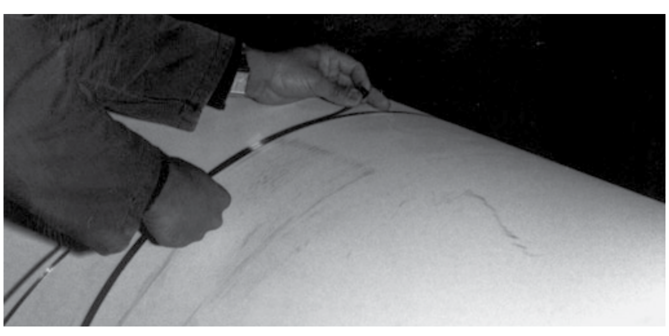
i) Dimensional Measurements



Outside micrometer

In most cases Thordon bearings can be measured using the same instruments and methods as any other material. It must be remembered that Thordon elastomeric bearings require a light touch when measuring because it is possible to deform the bearing out of round. In addition, Thordon elastomeric bearings have a high coefficient of expansion compared to metals, so measurements must be taken at machine shop temperature. If this is not possible then the dimensions must be corrected for the thermal expansion and contraction that has occurred because of the difference between the machine shop and ambient measuring temperatures.

In the case of larger diameter, relatively thin wall bearings that have been machined and removed from the lathe, it is typical to find that they show ovality. This deformation can be the result of the bearing sagging under its own weight or from being secured to a pallet for shipping. The bearing may appear to be out of tolerance due to the fact that it has become out of round. This is not a problem because when the bearing is pressed into a housing, it will conform to the shape of the housing and will be round. To accurately measure the bearing outside the housing, use a pi tape to measure the O.D. and then measure the wall thickness using a ball micrometer to obtain the correct I.D. dimension.



A pi tape is a precision steel tape calibrated to measure diameters by measuring circumference.

ii) Surface Finish and Tolerances

Thordon, due to its non-metallic elastomeric nature, cannot be machined to as smooth a surface finish as metals. This is not a problem because the bearing goes through a normal break in period during which the initial surface roughness is worn smooth. It is important, however, to strive for as good a surface finish as possible to reduce friction and initial break in wear. The mechanics of obtaining a good surface finish have been covered in the machining section but it is important to know how to measure the surface finish of a Thordon bearing.

Due to the non-metallic nature of Thordon bearings, they will tend to feel smoother to the touch in comparison to metal than they really are. To measure accurately the Thordon bearing surface finish, a stylus type of surface finish gauge should be used. Practical experience has shown that the use of a comparator will usually result in a value that is less than the actual value. This is because Thordon bearings are softer than metal and feel smoother than they actually are when measured with a stylus.

The tolerances on surface finish are as follows:

- XL, SXL, COMPAC, HPSXL:
  3.2 micro-metres (125 micro-inches) Ra
- RiverTough/Composite:
  4.2 micro-metres (175 micro-inches) Ra

NOTE: Due to the unique characteristics of Thordon bearings, compared to metals, optimal performance can still be obtained at relatively high (compared to metal) surface finishes.

MACHINING

iii) Machining Tolerances

Thordon bearings are non-metallic and consequently cannot be machined to the same tight tolerances as bronze or other rigid materials. Conversely tight metallic tolerances are not necessary to obtain optimum performance. The standard machining tolerances for Thordon elastomers is shown in Figure 34.

FIGURE 34 - MACHINING TOLERANCE

XL, SXL, COMPAC & RiverTough/Composite

Bearings up to 330mm (13.00”)		
O.D.	+0.13mm, -0.00mm	(+0.005”, -0.000”)
I.D.	+0.13mm, -0.00mm	(+0.005”, -0.000”)
Bearings between 330 and 530mm (13.00” and 21.00”)		
O.D.	+0.18mm, -0.00mm	(+0.007”, -0.000”)
Wall thickness (W.T.)	+0.00mm, -0.13mm	(+0.000”, -0.005”)
I.D. (RiverTough/Composite only)	+0.18mm, -0.00mm	(+0.007”, -0.000”)
Bearings over 530mm (21.00”)		
O.D.	+0.25mm, -0.00mm	(+0.010”, -0.000”)
W.T.	+0.00mm, -0.13mm	(+0.000”, -0.005”)
I.D. (RiverTough/Composite only)	+0.25mm, -0.00mm	(+0.010”, -0.000”)
Bearing Length Tolerance:		
For bearings shorter than 500mm (20”) long	+0.00mm, -0.50mm	(+0.000”, -0.020”)
For bearings longer than 500mm (20”) long	+0.00mm, -1.00mm	(+0.000”, -0.040”)

NOTE 1: For Thordon XL, SXL and COMPAC bearings over 330mm (13”), machined I.D. tolerance should be controlled by controlling the wall thickness of the bearing. For RiverTough/Composite bearings over 330mm (13”) only, the actual I.D. of the bearing should be controlled.

NOTE 2: If the wall thickness is less than 25mm (1”) then there may be restrictions as to the length of bearing that can be properly machined. Consult Thordon Bearings for details.

NOTE 3: If an application requires tolerances that are tighter than those outlined in this manual please contact your Thordon distributor or Thordon Bearings for guidance.

7) Bonding with TG-75

a) SURFACE PREPARATION

The metal substrate and the Thordon material need to be properly prepared. Poor substrate preparation may result in loss of bond strength and the possibility of the bearings coming loose from their housings during operation.

i) Metal Preparation

Metal surfaces should be machined not smoother than 3.0 micrometers Ra (125 microinches). The surface should be gritblasted to increase adhesion. For metals exhibiting corrosion, the surface should be clean blast to obtain a Near White Blast clean surface per Standard SSPC-SP No. 10/NACE No.2.

NOTE: Bonding should take place within 2 hours of surface preparation and cleaning. For Aluminum and Stainless Steel, reduce the exposure time to 30 minutes or less as an oxidation layer form very quickly after sandblasting in these materials.

The surface to be bonded needs to be cleaned after sandblasting with an organic solvent/degreaser such as Methyl Ethyl Ketone (MEK), isopropyl alcohol, or other equivalent non-residue degreaser, to remove any contamination prior to applying the TG-75 adhesive. Allow the degreaser to completely evaporate without further contamination before bonding. Do not touch the cleaned parts – if the parts need to be handled, use NEW latex gloves to protect the clean surface from contamination caused by oil in skin.

ii) Thordon Bearing Preparation

The surface finish of the Thordon bearing to be bonded should be between 3.0 to 6.0 micrometers Ra (125 to 250 microinches). Sandpaper can be used to roughen up the area to be bonded.

It is recommended that the bearing surface be wiped with a cloth or soft paper wetted with a small amount of solvent – ensure that no residue from the paper is left behind. A clean brush can also be used to clean the surface. Allow the solvent to dry completely before applying the adhesive. Note that the elastomeric bearing should NOT be soaked in the solvent.

b) MIXING ADHESIVE COMPONENTS

TG-75 adhesive is a two-part system consisting of an accelerator denoted as “TG-75A” and a resin “TG-75B”. These two components should be mixed using the following VOLUME ratio:

Part A to Part B = 1:2

Improper mixing ratios may result in failure of the adhesive to cure (too little accelerator used, adhesive does not harden) or it could cure too quickly (if too much accelerator is used) resulting in significantly reduced curing times. Using TG-75 cartridges not only ensures correct ratios, but the static mixer ensures proper mixing as well.

Temperature of the materials at the time of mixing is also very important for proper performance. For cartridges stored in at low temperatures, the cartridge should be allowed to return to room temperature (minimum overnight) PRIOR to mixing of Components A&B. See Storage guideline section for more information.

Once mixed, the adhesive offers a maximum working time of 60 minutes at 23°C (73°F) and has a viscosity of approximately 50,000cps. Increases in temperature will reduced the working time or pot life.

TG-75 adhesive is packaged in pre-measured tubes and each tube yields 450 ml (0.12 US gallons) of mixed adhesive. Typical coverage for one tube is 7000 cm2 (1085 in2) at a thickness of 0.25mm (0.010 inches). Recommended adhesive thickness ranges from 0.25mm to 0.38mm (0.010 in to 0.015 in). Exceeding the recommended adhesive thickness reduces the bond strength. Consult with Thordon Bearings if higher adhesive thickness values must be used.

i) Dispensing Procedure A – Pneumatic Gun

a. Fully retract the pistons manually: The pneumatic gun must be connected to the airline and the middle rod pulled back until the pistons are fully retracted.

b. Insert the cartridge assembly: remove the "D" shaped plugs from the cartridge, keep in a safe place for restorage. See figure 35. Place the open end of the cartridge assembly over the piston pads. Be careful to align the pads in the centre of the cartridge plungers. If the pistons are not centred, the plungers may flip or be pushed unevenly resulting in improper mixing and leaking. Snap the front end of the cartridge assembly into position at the front of the gun. Manually push the piston forward until they bottom out against the inside of the cartridge plungers. See figure 38.

Figure 35: Plugs for TG-75 cartridge

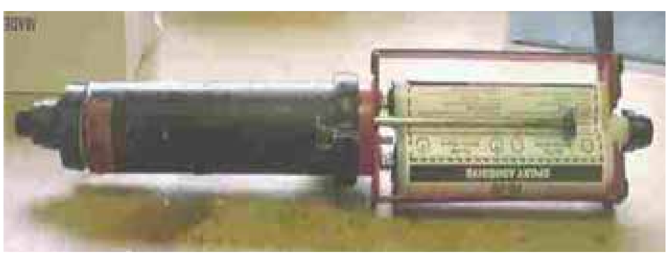


Figure 36: TG-75 cartridge properly inserted into pneumatic gun

c. Phase the cartridge: use a pneumatic gun with a maximum pressure of 0.70 MPa (100 psi), turn the regulator knob counterclockwise to the stop. Hold the cartridge tips over a disposable surface. Depress the gun trigger and slowly open (turn the regulator knob clockwise) until compound extrudes evenly from the cartridge tips. Release the trigger.

d. Dispensing: open the pressure regulator from the low pressure setting until the desired flow rate is obtained. The quantity of adhesive required should be squeezed out onto a disposable surface and thoroughly mixed until the colour of the adhesive is completely uniform.

ii) Dispensing Procedure B – Manual Gun

a. Fully depress the thumb release lever and then retract the piston carriage assembly. See figure 37.

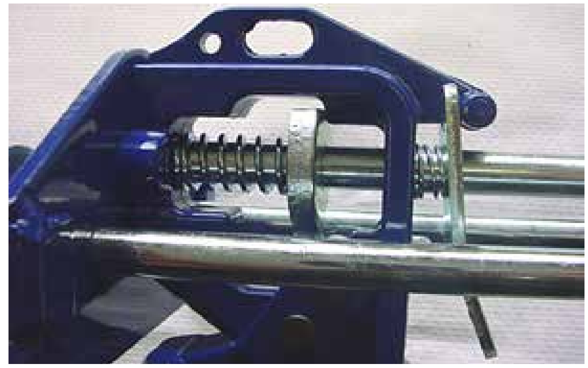


Figure 37: Thumb release lever - shown with arrow

b. Insert the cartridge assembly: remove the "D" shaped plugs from the cartridge, keep in a safe place for restorage. Place the open end of the cartridge assembly over the piston pads. Be careful to align the pads in the centre of the cartridge plungers. See figure 38.

Figure 38: Plungers in manual gun

If the pistons are not centred, the plungers may flip or be pushed unevenly resulting in improper mixing and leaking. Snap the front end of the cartridge assembly into position at the front of the gun. Manually push the piston forward until they bottom out against the inside of the cartridge plungers.

c. Place the cartridge tips over a disposable surface and squeeze the trigger handle slowly until compound extrudes from both cartridge tips. Release the trigger handle and depress the thumb release lever.

d. Maintain consistent pressure on the trigger handle as you dispense the appropriate amount of material. Depress the thumb release lever immediately after dispensing or built up pressure in the cartridge will result in additional compound extruding.

c) ADHESIVE CURING

Provided the material was mixed correctly, the cure time for TG-75 is dependent upon the temperature during the curing period. The recommended curing temperatures for TG-75 are:

- Typical: 20 to 40°C (68 to 104°F)
- Minimum: 10°C (50°F)

Contact Thordon Bearings if TG-75 is being used at temperatures outside the range shown above.

Curing Times and Temperature

Over 60% of the bond strength is attained in 8 hours at 23°C (73°F). Approximately 80% of the bond strength is achieved in 4 hours at 40°C (104°F). Full cure is reached in 5 days at 23°C (73°F).

Insufficient curing time, particularly at low temperatures, prior to water immersion will result in reduced bond strength values. Water will stop further curing of the adhesive.

Note: For bearings with large OD [250mm (9.4843 in) and up], it is important to machine the bearing AND perform the bonding installation at approximately the SAME temperature. Machining the bearing at one temperature and installing it at a different temperature may have significant effects on the optimal adhesive thickness – see example.

After application of adhesive, keep bearing and carrier assembly at a constant temperature while the adhesive cures.

EXAMPLE

An SXL bearing is machined in the afternoon at 30°C (86°F) to suit a housing ID of 250mm (9.843 in). Based on optimal adhesive thickness, the bearing OD is machined to

250mm - 2 x 0.25mm = 249.50mm
(9.843 in - 2 x 0.010 in = 9.823 in.)

The bearing is to be installed the next day but note that the shop temperature has increased to 35°C (95°F).

Using the thermal coefficient of expansion for SXL [21.1 x 10^{-5} cm/cm/°C (11.7 x 10^{-5} in/in/°F)] and the temperature difference [5°C (9°F)], the bearing OD at 35°C has increased to 249.76mm (9.833 in.)

The adhesive thickness is reduced to 0.12mm (0.005 in.) with the temperature difference. Such thermal effects are even greater with larger bearings.

d) ADHESIVE APPLICATION

As mentioned previously, for best results it is recommended to conduct the bonding installation at the SAME temperature at which the bearing was machined. In cold weather environments, it is important to maintain the temperature above 10°C (50°F) for proper curing of the adhesive.

i) Split Bearings or Flat Surfaces

a. Apply the adhesive to the prepared surface of the metal and spread evenly with a spatula or a small notched trowel. See Figures 39 and 40.

Figure 39: Adhesive being applied to split metal housing

Figure 40: TG-75 being applied to OD of split SXL bearing

b. Position the Thordon component and clamp so that a small amount of the adhesive is extruded out from the edges of the Thordon part. See Figure 41. Do not machine or handle the bonded piece for a minimum of 8 hours at 23°C or 73°F. Avoid smearing the adhesive during assembly.

Figure 41: Clamping with slight force SXL to metal housing

ii) Cylindrical Bearings

a. The bearing should be sized to allow for a 0.25 to 0.38mm (0.010 to 0.015 in) adhesive thickness. This is an allowance of 0.50 to 0.76mm (0.020 to 0.030 in) on the outside diameter. TG-75 will fill gaps up to a thickness of 3.0mm (0.125 in) but the shear strength of the adhesive decreases at thickness over 0.6mm (0.025 in).

b. Apply the adhesive to both the metal and the Thordon bearing. Spread evenly with a spatula or small notched trowel.

c. Slide the bearing into the housing. Slight rotation of the bearing can help homogenize the adhesive layer, but do not use excessive back-and-forth movements as this could induce the creation of air bubbles within the layer.

d. Spacers can be used in situations where the bearing cannot be held eccentrically with the housing and uneven adhesive thickness is an issue. Glass beads and metal shims and wire can be used to ensure an even thickness throughout the circumference – see Figure 42 for suggested set up.

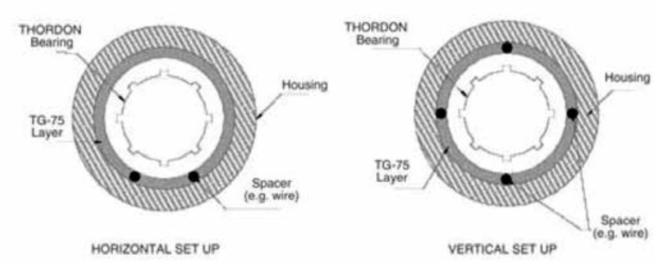


Figure 42: Wire used to keep bearing eccentric in housing (drawing not to scale)

e) TROUBLE SHOOTING

a. If compound bypasses the plungers and leaks from the backside of the cartridges, check that the plungers are seated squarely against the cartridge plungers.

b. If the compound leaks around the retaining nut, ensure that the nut is not cross-threaded and tighten it further.

c. The dispensed compound must be consistent in colour.

f) CLEAN UP

Scrape excess with a trowel then dampen a cloth with solvent and carefully remove the remainder of the adhesive from the bonded assembly edges. Do not contaminate the bond line with solvent.

g) STORAGE OF TG-75 & SHELF LIFE

TG-75 cartridges can be stored at room temperature (~20°C or 68°F) with a shelf life of 15 months from time of delivery. To increase the shelf life of the material, the cartridges can be placed in a fridge or freezer. The lower temperature increases the shelf life of the unmixed components to 30 months from time of delivery.

Storage at lower temperatures (-10°C to -20°C or 14°F to -4°F) may cause the adhesive to crystallize or solidify, giving the product the appearance of a hazy liquid or waxy semi-solid. Crystallization is not an indication of material problems and does not affect the performance of the material. However, Components A & B should not be mixed if it is suspected to be crystallized.

This crystallization phenomenon is reversible by bringing the materials back to room temperature. If time permits, allow the material to warm up naturally overnight. Gentle warming (no direct heat or flame) of the cartridge and its contents is acceptable. Bring the cartridge to 50°C (120°F) for approximately 30 minutes. Allow to cool back to room temperature prior to use.

If only a portion of a cartridge assembly is needed, it is possible to store the remainder of the cartridge for later use provided it is sealed properly. After completion of the initial bonding procedure, place the "D" shaped end plugs back into the cartridges. Store the used cartridge in a freezer to preserve components.

NOTE: TG-75 does not contain volatile photochemical reactive solvents. Produced CFC free.

LIMITED WARRANTY AND LIMITATION OF LIABILITY FOR THORDON BEARINGS INC. ('TBI')

a. Basic Terms. TBI provides a limited warranty on the Goods of its own manufacture sold by it to the Buyer thereof, against defects of material and workmanship (the "Limited Warranty").

b. Coverage. This Limited Warranty covers the repair or replacement or the refund of the purchase price, as TBI may elect, of any defective products regarding which, upon discovery of the defect, the Buyer has given immediate written notice. TBI does NOT warrant the merchantability of its product and does NOT make any warranty express or implied other than the warranty contained herein.

c. Third Party Products. Accessories, equipment and parts not manufactured by TBI are warranted or otherwise guaranteed only to the extent and in the manner warranted or guaranteed to TBI by the actual manufacturer, and then only to the extent TBI is able to enforce such warranty or guarantee.

d. Limited Liability. TBI's liability for any and all claims, damages, losses and injuries arising out of or relating to its performance or breach of any contract of sale of goods and the manufacture, sale delivery, re-sale, repair, or use of any goods, shall NOT exceed the agreed price of such Goods. The Buyer's remedy shall be at TBI's option, the replacement or repair of the Goods. This shall be the Buyer's sole, exclusive and only remedy against TBI.
IN NO EVENT SHALL TBI BE LIABLE FOR INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES, INCLUDING BUT NOT LIMITED TO LOSS OF PROFITS, BUSINESS, GOODWILL, INCURRING OF MACHINERY DOWNTIME, DESTRUCTION OR LOSS OF ANY CAPITAL GOODS, LIABILITY FOR PERSONAL INJURY, DEATH, PROPERTY DAMAGE AND ANY OTHER TYPE OF DAMAGES WHETHER SIMILAR TO OR DIFFERENT FROM THIS LISTING.

e. Latent Defects. In cases of defects in materials or workmanship or defects arising from the selection of material or processes of manufacturer, such defects must be apparent in the Goods within three (3) months, after delivery and acceptance of the Goods to the Buyer.

f. Exclusions. TBI shall, as to each aforesaid defect, be relieved of all obligations and liability under this Limited Warranty if:
   1. The Goods are operated with any accessory, equipment or part not specifically approved by TBI and not manufactured by TBI or to TBI's design and specifications, unless the Buyer furnishes reasonable evidence that such installation was not a cause of the defect; provided, that this provision shall not apply to any accessory, equipment or part, the use of which does not affect the safety of the Goods;
   2. The Goods shall not be operated or maintained in accordance with TBI's written instructions as delivered to the Buyer, at any time or from time to time, unless the Buyer furnishes reasonable evidence that such operation or maintenance was not a cause of the defect;
   3. The Goods shall not be operated or maintained under normal industry use, unless the Buyer furnishes reasonable evidence that such operation was not a cause of the defect;
   4. The Goods shall have been repaired, altered or modified without TBI's written approval or, if the Goods shall have been operated subsequent to its involvement in an accident or breakdown, unless the Buyer furnishes reasonable evidence that such repair, alteration, modification, operation, accident or breakdown was not a cause of the defect; provided, however, that this limitation insofar as it relates to repairs, accidents and breakdowns, shall NOT be applicable to routine repairs or replacements or minor accidents or minor breakdowns which normally occur in the operation of a machine, if such repairs or replacements are made with suitable materials and according to standard practice and engineering;
   5. The Buyer does not submit reasonable proof to TBI that the defect is due to a material embraced within TBI's Limited Warranty hereunder.

g. Warranty Term. This Limited Warranty made by TBI contained in these Terms and Conditions, or contained in any document given in order to carry out the transactions contemplated hereby, shall continue in full force and effect for the benefit of the Buyer, save and except, no warranty claim may be made or brought by the Buyer after the date which is twelve (12) months following delivery and acceptance of the Goods pursuant to this Contract.

h. Expiration and Release. After the expiration of this Limited Warranty's period of time, as aforesaid, TBI shall be released from all obligations and liabilities in respect of such warranty made by TBI and contained in this Contract or in any document given in order to carry out the transactions contemplated hereby.

CUSTOMER FOCUSED TO SUPPORT YOUR IMMEDIATE AND FUTURE NEEDS

Supply and Service

Geared to provide quick response to customer needs, Thordon Bearings understands the importance of fast delivery and reduced down time. Thordon marine and industrial bearings can be designed, produced to the exact requirements of the customer and shipped quickly.

Distribution

With Thordon bearings specified all around the world, an extensive distribution network has been established in over 100 countries. Inventories of common bearing sizes are stocked by local Thordon Distributors and are backed up by large regional and head office Thordon stocks.

Application Engineering

Thordon Bearings' engineers work closely with customers to provide innovative bearing system designs that meet or exceed the technical requirements of the application.

Manufacturing

Thordon's modern polymer processing facility is staffed with experienced and dedicated employees. Bearings up to 2.2 m (86") in diameter have been supplied and bearings up to 1.5 m (60") O.D. can be machined in-house.

Quality

Thordon Bearings Inc. is a Canadian company manufacturing to ISO 9001 Quality System requirements.

With over 40 years experience in polymer bearing design, application engineering and manufacturing, Thordon marine and industrial bearings are recognized worldwide for both quality and performance.

Research and Development

Thordon bearings are being continuously tested by our Bearing Test Facility. The facility evaluates new designs and applications before they are put into service. Ongoing testing not only allows for design refinements, but ensures quality and performance after installation. Our polymer laboratory evaluates new and modified polymers in a continuing quest to improve Thordon bearing performance and searches for new polymer bearing solutions.

Your Authorized Thordon Distributor

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