Bearings and Bearing Surfaces

Friction between rotating elements is a major source of loss in mechanical systems. In gear box design, it was seen that friction at the bearings is the primary source of lost torque.

Bearings are generally split into two categories: roller bearings and bushings.

A roller bearing is a sometimes sealed package which contains many roller surface elements (such as spheres and cylinders) the roll in between an inner race (which is designed to fit over one shaft) and an outer race (which is designed to fit into a bearing cup. Either the inner race or the outer race or both can move.

A bushing is a low friction material which has precisely controlled inner diameter, outer diameter, and thickness. It is designed to fit into a hole, usually with a loose fit, but a press fit can be used if desired. My favorite bushing material is the oilite bronze bushing. This material is a sintered bronze (ie it has holes embedded in it) which is filled with a light oil. This bushing self-lubricates (at least for a while).

Roller bearings are typically used when speeds are high (above 1000 rpm) or when thrust or radial loads are significant.

Bushings are much less expensive than bearings and allow for a more compact mounting scheme.

An example of when a bushing was used (against my recommendation, I might add) when a bearing should have been occured in the encoder section of the Think Tank. The expected speed of the system was below the 1000 rpm threshhold, although the maximum speed of the system was considerably higher. A graduate student was the first to test the system. Naturally, he hooked a battery directly to the motor and ran the system in a no load configuration. The bushing friction welded the shaft in place when the motor stopped.

Bushing Materials

Machinery's Handbook has an extensive section on Bushing Materials on pages 2237-2245.

I have used aluminum, steel, copper, brass, bronze in various designs.

I prefer brass or bronze, because it has good bearing surface characteristics and excellent strength.

Aluminum is my least favorite material for a bearing surface. It tends to gall, which deposits a layer of aluminum on the mating surface. This both opens up the hole or reduces the shaft (depending on what is aluminum).

Using the same material as both the shaft and the hub is a very bad idea. When the two mating surfaces consist of the same material, the two materials have a tendency to want to "become as one." This creates very high friction. Note: lubrication can be used to avoid this problem.

For example, Johannsen Blocks (or gage blocks) are used to create precisely measured lengths, by stacking different sized blocks into one length. Jo-blocks are ground and polished steel. When two blocks are placed upon each other, the surface tension is so great that the blocks must be slid apart in order to break the bond.

I will leave it to the interested reader to peruse Machinery's Handbook on bushing materials when the need for bushing materials arises.

Examples of bearing surfaces include the wedge of doom pins (brass pins in steel or aluminum links), the Phoenix's scissor lift (steel pins in aluminum links), the gear axles in the drive motor gear box's (steel on steel with lubrication or steel on a brass bushing). Oilite bushings are used in Buford's Lift-o-matic III and the Phoenix's Lift-o-matic I.

Anti-Friction Bearings

Bearings come in a variety of packages and styles. Non-custom bearings are made to a standard (some of this information is in Machinery's Handbook). A bearing can be bought from a variety of manufacturers; however, the OD, ID, thickness, etc. will conform to the standard. Thus, bearings from different manufacturers can be interchanged. Thrust and load ratings may not conform.

They are generally divided into single row and double row.

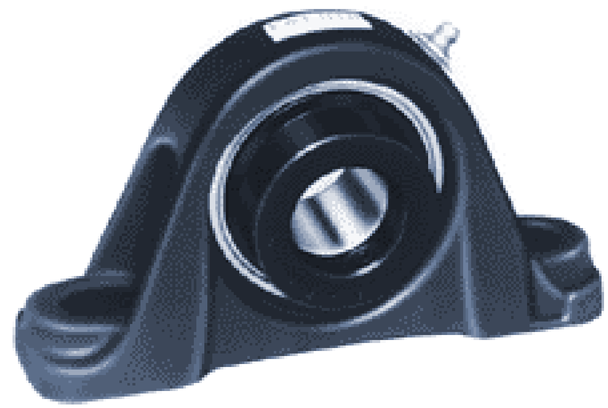
Other considerations include the type of rolling element (e.g. balls, cylinders, conic section) and the method for arranging the inner and outer races (radial or angular contact).

Bearings have different mounting packages.

For instance, the mounting can be flanged or unflanged.

The inner race can be cylindrical or spherical.

Some bearings have lubrication ports.

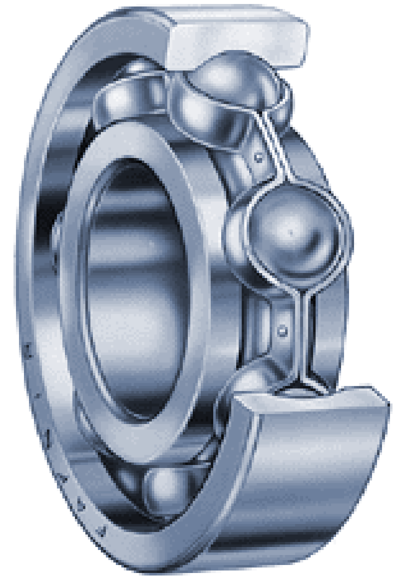


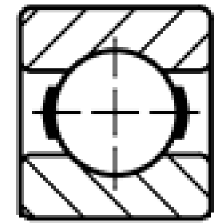
Pillow Block (from Torrington)

A special, easy mount bearing is the pillow block, which has a bolt down flange to allow shafts to be mounted with some fit-up but little machining.

Bearing companies include Stock Drive Products, PIC Design, Torrington, and Fafnir. If you want to see the true variety of available bearing options, visit the various web sites.

Ball Bearings





Drawn Cup Needle Bearing
from Torrington

Ball bearings use a spherical rolling element (or a ball).

They have an inner race and an outer race with a cage holding the rolling elements. The cage keeps the elements uniformly spaced.

The inner and outer races have grooves in which the balls roll.

Ball bearings support radial loads and a much lower thrust load.

The consequence of exceeding the radial load rating is that the balls and grooves will wear excessively. This will result in failure of the bearing. The bearing will begin to exhibit higher and higher friction until it seizes.

Exceeding the thrust load will increase friction and hasten failure. In the extreme limit, the balls can be pushed out of the groove.

Imminent bearing failure can be heard, usually as a high-pitched whining or a low frequency growling. (The noise depends on the speed of the rotating shaft.) It can also be felt. If the shaft does not turn smoothly in the bearing, something is wrong. Diagnostic algorithms have been developed to analyze the acoustic signature of bearings under load to predict failure. The science of predicting failure through acoustic signal processing is called Mechanical Diagnostics.

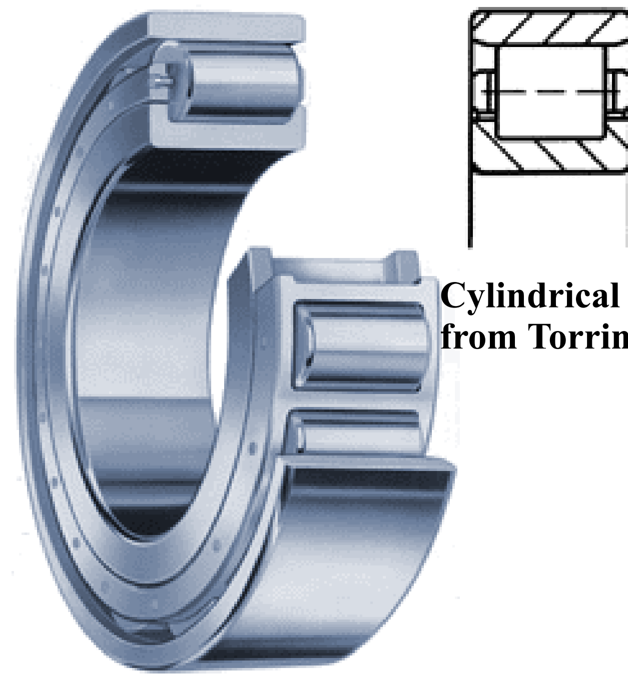
The classic folk tale is the old mechanic who can listen to an aircraft engine for a few moments and then proclaim, “Mmmm, the number two bearing is about to fail.”

Cylindrical Bearings

Cylindrical bearings use a cylindrical rolling element. They provide higher radial load bearing capacity to ball bearings, at the expense of higher friction. They cannot perform at speeds as high as a ball bearing.

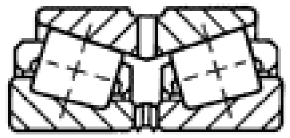
They can support thrust loads; however, these loads should be kept as low as possible.

The failure modes are the same as in ball bearings.

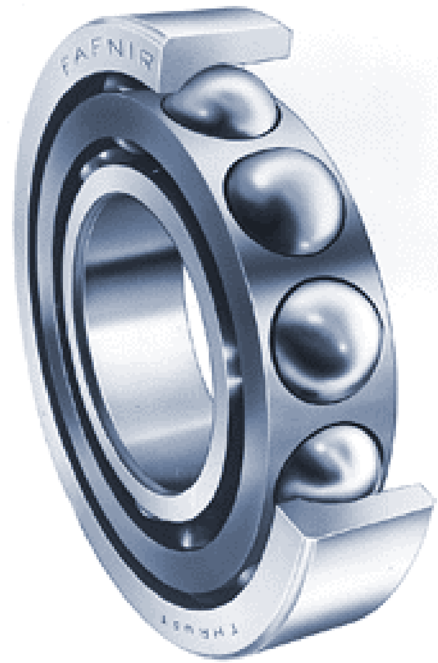


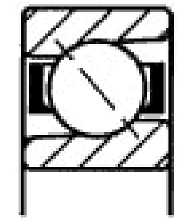
Cylindrical Bearing from Torrington

Angular Contact Bearings



Radial Tapered Cylindrical Bearing
from Torrington



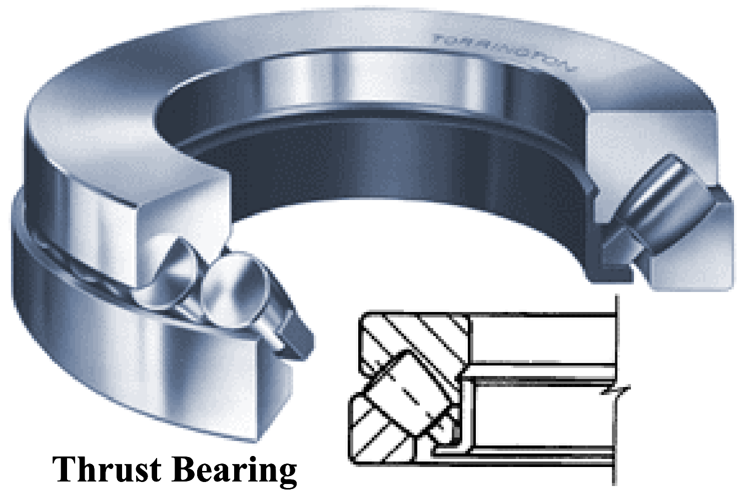


Angular Contact Ball Bearing
from Torrington

Angular contact ball bearings and rad tapered cylindrical bearings shape the races so that the thrust and radial loads are redirected at an angle. Single row bearings can only support thrust in one direction. If you are in the habit of double bearing supporting shafts (a very good design practice), then you would support the shaft on one end with a single row AC bearing and the other with a similar bearing oriented oppositely to the first bearing.

Thrust Bearings

Thrust bearings orient the rollers at an angle such that they can support large thrust loads. They have minimal radial load capacity.



Thrust Bearing
from Torrington

A thrust bearing will usually be used in conjunction with a roller bearing. The roller bearing will support the axial load and the thrust bearing will support the thrust load. An example of this arrangement can be seen in the Bosch drill motor output shaft.

Failure modes in thrust bearings are a little different than for roller bearings. The races can be pushed apart in the radial direction.

The other failure mode of a thrust bearing (siezing) is the same as for radial bearings.

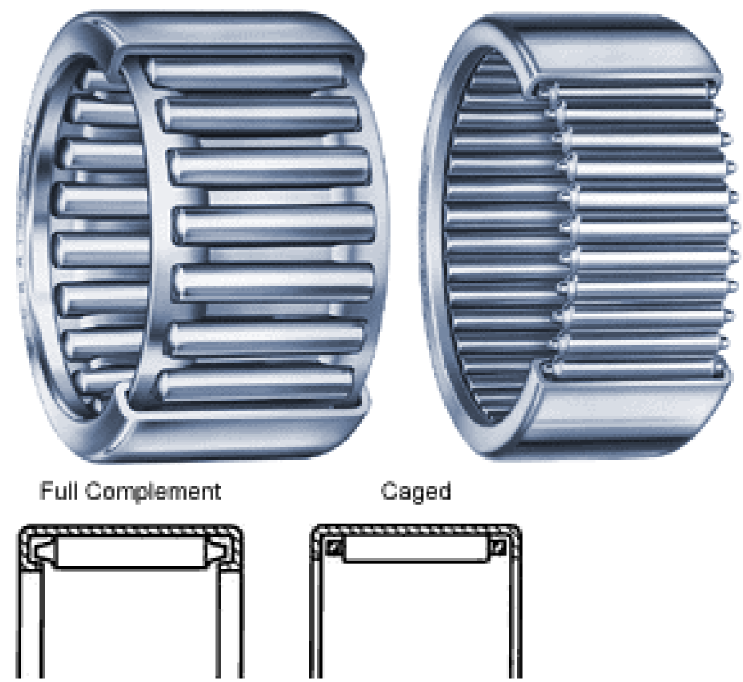
Needle Bearings

Needle bearings are similar to cylindrical bearings. However, the roller has a small axle on either end. This reduces the contact friction relative to cylindrical bearings.

They can function at higher speeds than regular cylindrical bearings.

The other primary difference between a needle bearing and a cylindrical bearing is that the rollers are usually small diameter and long.

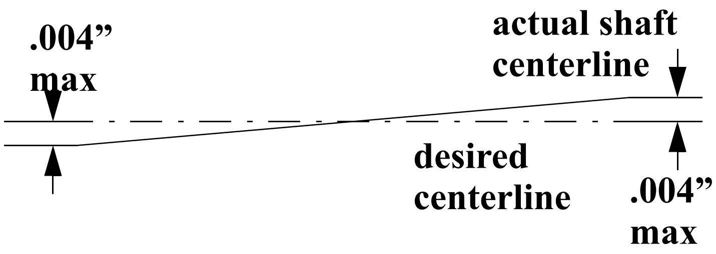
In the figure, one bearing has a cage, the other is loose.



Drawn Cup Needle Bearing from Torrington

Mounting Anti-Friction Bearings

Bearings are usually mounted by machining a bearing cup. The tolerance on this cup affects axial alignment of the shaft.



Shafts which are used with bearings (actually, shafts in general) are usually ground. This keeps the tolerance on the shaft diameter minimal.

The things which must be controlled are: shaft diameter, inner race diameter. These should be specified so as to achieve a tight fit between the two. No more than .002” difference should be tolerated.

On the other side of the bearing, the bearing cup diameter and depth and the outer race diameter must be tightly controlled. Again, .002” oversize at most can be tolerated. Note: sometimes bearings can be press fit, using a light press fit. The down side to this operation is that the disassembly to replace the bearing is more complicated.

At the worst case, this would allow the shaft to flex off center by at most .004” at the location of the bearing. If a double bearing arrangement were used, this might allow one end of the shaft to be .004” high and the other to be .004” low. This net tolerance would probably not be acceptable. However, it is a maximum and some tolerance can be a good thing. I.e. if things fit up too tightly, the whole system might bind up.

On a side note, in the FIRST kick-off speech, Woodie Flowers said, “Never use three bearings in a row!” This is generally good philosophy. If, for some reason, you plan to use three bearings in a row, tolerances must be held very strictly. It might be a good idea to leave a little extra room in the middle bearing, as well.

More probably, you would be coupling two shafts. In this case, simply use an alignment device in the coupling.

Bearing Seats for Unflanged Bearings

A bearing seat is a close fit on the outer diameter of the bearing. Usually, the bearing OD will be quoted as a tolerance which is +.000 and -.001. The close fit would require that the hole have a similar tolerance, usually .001" greater than the bearing OD, -.000" and +.001".

The bearing seat hole would be made by a boring head (if done on the mill) or by a boring tool (if done on the lathe).

The diameter bore is measured using a internal snap gage or an internal bore micrometer. The boring tool is advanced in the bore until the desired accuracy is reached.

For unflanged bearings, the depth of the bore must also be controlled. The bearing thickness is also tightly regulated, usually with an under tolerance (ie. +.000", -.002"). The bearing seat depth must likewise be controlled, so that the bearing does not protrude from its seat.

The depth of the bore is measured by a depth micrometer. Final depth would be achieved after the bore diameter has been completed.

Bearing Seats for Flanged Bearings

The bore for flanged bearings is accomplished similarly to the unflanged bearing. However, the depth is not critical. As second, larger diameter is machined to contain the flange. The depth of this seat is critical. However the diameter is not.

Therefore, a flanged bearing allows the bore diameter to be set separately from the bore depth. This makes the machining of the bearing seat easier.