For individual balls that are sometimes called "ball bearings", see Ball (bearing).

Working principle for a ball bearing.

A 4 point angular contact ball bearing

A ball bearing with a semi transparent cage.

Wingquist's and SKF's self-aligning ball bearing.

A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the moving parts of the bearing.

The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. Usually one of the races is held fixed. As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were rotating on each other.

Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. However, they can tolerate some misalignment of the inner and outer races.

Compared to other rolling-element bearings, the ball bearing is the least expensive, primarily because of the low cost of producing the balls used in the bearing.[dubious – discuss]

Contents [hide]

1 Common designs

1.1 Angular contact

1.2 Axial

1.3 Deep-groove

2 Construction types
There are several common designs of ball bearing, each offering various trade-offs. They can be made from many different materials, including: stainless steel, chrome steel, and ceramic (silicon nitride (Si3N4)). A hybrid ball bearing is a bearing with ceramic balls and races of metal.
Angular contact

An angular contact ball bearing uses axially asymmetric races. An axial load passes in a straight line through the bearing, whereas a radial load takes an oblique path that tends to want to separate the races axially. So the angle of contact on the inner race is the same as that on the outer race. Angular contact bearings better support "combined loads" (loading in both the radial and axial directions) and the contact angle of the bearing should be matched to the relative proportions of each. The larger the contact angle (typically in the range 10 to 45 degrees), the higher the axial load supported, but the lower the radial load. In high-speed applications, such as turbines, jet engines, and dentistry equipment, the centrifugal forces generated by the balls changes the contact angle at the inner and outer race. Ceramics such as silicon nitride are now regularly used in such applications due to their low density (40% of steel). These materials significantly reduce centrifugal force and function well in high temperature environments. They also tend to wear similarly way to bearing steel—rather than cracking or shattering like glass or porcelain.

Most bicycles use angular-contact bearings in the headsets because the forces on these bearings are in both the radial and axial direction.

Axial

An axial ball bearing uses side-by-side races. An axial load is transmitted directly through the bearing, while a radial load is poorly-supported, tends to separate the races, and anything other than a small radial load is likely to damage the bearing.

Deep-groove

In a deep-groove radial bearing, the race dimensions are close to the dimensions of the balls that run in it. Deep-groove bearings have higher load ratings for their size than shallow-groove, but are also less tolerant of misalignment of the inner and outer races. A misaligned shallow-groove bearing may support a larger load than the same sized deep-groove bearing with similar misalignment.

Construction types

Conrad

A Conrad bearing is assembled by placing the inner and outer races radially offset, so the races touch at one point and have a large gap on the radially opposite side. The bearing is then filled by placing balls in to the large gap, then distributing them around the bearing assembly. The act of distributing the balls causes the inner and outer races to become concentric. If the balls were left free, the balls could resume their offset locations and the bearing could disassemble itself. Thus, a cage is inserted to hold the balls in their distributed positions. The cage supports no bearing load; it serves to keep the balls located. Conrad bearings have the advantage that they take both radial and axial loads, but the disadvantage they cannot be filled to a full complement and thus have reduced load-carrying capacity compared to a full-complement bearing. The Conrad bearing is named for its inventor, Robert Conrad, who got British patent 12,206 in 1903 and U.S. patent 822,723 in 1906. Probably the
most familiar industrial ball bearing is the deep-groove Conrad style. The bearing is used in most of the mechanical industries.

[edit]Slot-fill

In a slot-fill radial bearing, the inner and outer races are notched so that when they are aligned, balls can be slipped in the slot to fill the bearing. A slot-fill bearing has the advantage that the entire groove is filled with balls, called a full complement. A slot-fill bearing has the disadvantages that it handles axial loads poorly, and the notches weaken the races. Note that an angular contact bearing can be disassembled axially and so can easily be filled with a full complement.

[edit]Split-race

The outer race may be split axially or radially, or a hole drilled in it for filling. These approaches allow a full complement to be used, but also limit the orientation of loads or the amount of misalignment the bearing can tolerate. Thus, these designs find much less use.

[edit]Rows

There are two row designs: single-row bearings and double-row bearings. Most ball bearings are a single-row design, which means there is one row of bearing balls. This design works with radial and thrust loads.[1]

A double-row design has two rows of bearing balls. Their disadvantage is they need better alignment than single-row bearings.

[edit]Flanged

Bearings with a flange on the outer ring simplify axial location. The housing for such bearings can consist of a through-hole of uniform diameter, but the entry face of the housing (which may be either the outer or inner face) must be machined truly normal to the hole axis. However such flanges are very expensive to manufacture. A more cost effective arrangement of the bearing outer ring, with similar benefits, is a snap ring groove at either or both ends of the outside diameter. The snap ring assumes the function of a flange.

[edit]Caged

Cages are typically used to secure the balls in a Conrad style ball bearing. In other construction types they may decrease the number of balls depending on the specific cage shape, and thus reduce the load capacity. Without cages the tangential position is stabilized by sliding of two convex surfaces on each other. With a cage the tangential position is stabilized by a sliding of a convex surface in a matched concave surface, which avoids dents in the balls and has lower friction. Caged roller bearings were invented by John Harrison in the mid 18th century as part of his work on chronographs.[2] Caged bearings were used more frequently during wartime steel shortages for bicycle wheel bearings married to replaceable cups.

[edit]Ceramic hybrid ball bearings using ceramic balls
Ceramic bearing balls can weigh up to 40% less than steel bearing balls, depending on size and material. This reduces centrifugal loading and skidding, so hybrid ceramic bearings can operate 20% to 40% faster than conventional bearings. This means that the outer race groove exerts less force inward against the ball as the bearing spins. This reduction in force reduces the friction and rolling resistance. The lighter ball allows the bearing to spin faster, and uses less energy to maintain its speed.

Ceramic hybrid ball bearings use these ceramic balls in place of steel balls. They are constructed with steel inner and outer rings, but ceramic balls; hence the hybrid designation.

Self-aligning ball bearings are constructed with the inner ring and ball assembly contained within an outer ring that has a spherical raceway. This construction allows the bearing to tolerate a small angular misalignment resulting from deflection or improper mounting.

Ball bearings are produced in various series, independent of the manufacturer:[1]

Series 100: Extra light series
Series 200: Light series
Series 300: Medium series
Series 400: Heavy series

The ball size increases as the series increases, for any given inner diameter or outer diameter (not both). The larger the ball the greater the load carrying capacity. Series 200 and 300 are the most common.[1]

Operating conditions

Lifespan

The calculated life for a bearing is based on the load it carries and its operating speed. The industry standard usable bearing lifespan is inversely proportional to the bearing load cubed. Nominal maximum load of a bearing (as specified for example in SKF datasheets), is for a lifespan of 1 million rotations, which at 50 Hz (i.e., 3000 RPM) is a lifespan of 5.5 working hours. 90% of bearings of that type have at least that lifespan, and 50% of bearings have a lifespan at least 5 times as long.[3]

The industry standard life calculation is based upon the work of Lundberg and Palmgren performed in 1947. The formula assumes the life to be limited by metal fatigue and that the life distribution can be described by a Weibull distribution. Many variations of the formula exist that include factors for material properties, lubrication, and loading. Factoring for loading may be viewed as a tacit
admission that modern materials demonstrate a different relationship between load and life than Lundberg and Palmgren determined.[3]

[edit]Failure modes

If a bearing is not rotating, maximum load is determined by force that causes non-elastic deformation of balls. If the balls are flattened, the bearing does not rotate. Maximum load for not or very slowly rotating bearings is called "static" maximum load.[3]

If that same bearing is rotating, that deformation tends to knead the ball into roughly a ball shape, so the bearing can still rotate, but if this continues for a long time, the ball fails due to metal fatigue. Maximum load for rotating bearing is called "dynamic" maximum load, and is roughly two or three times as high as static maxload.[3]

If a bearing is rotating, but experiences heavy load that lasts shorter than one revolution, static maxload must be used in computations, since the bearing does not rotate during the maximum load.[3]

[edit]Maximum load

In general, maximum load on a ball bearing is proportional to outer diameter of bearing times width of bearing (where width is measured in direction of axle).[3]

[edit]Lubrication

For a bearing to have its nominal lifespan at its nominal maximum load, it must be lubricated with a lubricant (oil or grease) that has at least the minimum dynamic viscosity (usually denoted with the Greek letter ν) recommended for that bearing.[3]

The recommended dynamic viscosity is inversely proportional to diameter of bearing.[3]

The recommended dynamic viscosity decreases with rotating frequency. As a rough indication: for less than 3000 RPM, recommended viscosity increases with factor 6 for a factor 10 decrease in speed, and for more than 3000 RPM, recommended viscosity decreases with factor 3 for a factor 10 increase in speed.[3]

For a bearing where average of outer diameter of bearing and diameter of axle hole is 50 mm, and that is rotating at 3000 RPM, recommended dynamic viscosity is 12 mm²/s.[3]

Note that dynamic viscosity of oil varies strongly with temperature: a temperature increase of 50-70°C causes the viscosity to decrease by factor 10.[3]

If the viscosity of lubricant is higher than recommended, lifespan of bearing increases, roughly proportional to square root of viscosity. If the viscosity of the lubricant is lower than recommended, the lifespan of the bearing decreases, and by how much depends on which type of oil being used. For oils with EP ('extreme pressure') additives, the lifespan is proportional to the square root of dynamic viscosity, just as it was for too high viscosity, while for ordinary oil's lifespan is proportional to the square of the viscosity if a lower-than-recommended viscosity is used.[3]
Lubrication can be done with a grease, which has advantages that grease sticks to the bearing and protects bearing metal from environment, but has disadvantages that this grease must be replaced periodically, and maximum load of bearing decreases (because if bearing gets too warm, grease melts and runs out of bearing). Time between grease replacements decreases very strongly with diameter of bearing: for a 40 mm bearing, grease should be replaced every 5000 working hours, while for a 100 mm bearing it should be replaced every 500 working hours.[3]

Lubrication can also be done with an oil, which has advantage of higher maximum load, but needs some way to keep oil in bearing, as it normally tends to run out of it. For oil lubrication it is recommended that for applications where oil does not become warmer than 50 °C, oil should be replaced once a year, while for applications where oil does not become warmer than 100 °C, oil should be replaced 4 times per year. For car engines, oil becomes 100 °C but the engine has an oil filter to continually improve oil quality; therefore, the oil is usually changed less frequently than the oil in bearings.[3]

[edit]Direction of load

Most bearings are meant for supporting loads perpendicular to axle ("radial loads"). Whether they can also bear axial loads, and if so, how much, depends on the type of bearing. Thrust bearings (commonly found on lazy susans) are specifically designed for axial loads.[3]

For single-row deep-groove ball bearings, SKF's documentation says that maximum axial load is circa 50 % of maximum radial load, but it also says that "light" and/or "small" bearings can take axial loads that are 25 % of maximum radial load.[3]

For single-row edge-contact ball bearings, axial load can be circa 2 times max radial load, and for cone-bearings maximum axial load is between 1 and 2 times maximum radial load.[3]

If both axial and radial loads are present, they can be added vectorially, to result in total load on bearing, which in combination with nominal maximum load can be used to predict lifespan.[3]

[edit]Avoiding undesirable axial load

The part of a bearing that rotates (either axle hole or outer circumference) must be fixed, while for a part that does not rotate this is not necessary (so it can be allowed to slide). If a bearing is loaded axially, both sides must be fixed.[3]

If an axle has two bearings, and temperature varies, axle shrinks or expands, therefore it is not admissible for both bearings to be fixed on both their sides, since expansion of axle would exert axial forces that would destroy these bearings. Therefore, at least one of bearings must be able to slide.[3]

A 'freely sliding fit' is one where there is at least a 4 um clearance, presumably because surface-roughness of a surface made on a lathe is normally between 1.6 and 3.2 µm.[3]

[edit]Fit
Bearings can only withstand their maximum load if the mating parts are properly sized. Bearing manufacturers supply tolerances for the fit of the shaft and the housing so this can be achieved. The material and hardness may also be specified.[3]

Fittings that are not allowed to slide are therefore made to have diameters that make sure they can not slide, for whatever real diameter of mating surface of bearing is, and consequently these mating surfaces can not be brought into position without using considerable force. For small bearings this can be done by using a press (because tapping with a hammer to press-fit the bearing pre-damages both the bearing and the shaft), while for large bearings forces are so large that there is no alternative to heating one part before fitting, so thermal expansion causes a (temporary) sliding fit.[3]

[edit]Avoiding torsional loads

If an axle is supported by two bearings, and center-lines of rotation of these bearings are not same, then large forces are exerted on the bearing that destroy it. Some very small amount of misalignment is acceptable, and how much depends on type of bearing. For bearings that are specifically made to be ‘self-aligning’, acceptable misalignment is between 1.5 and 3 degrees of arc. Bearings that are not designed to be self-aligning can accept misalignment of only 2–10 minutes of arc.[3]

[edit]Applications

Today the ball bearing is used in numerous everyday applications. Ball bearings are used for dental and medical instruments. In dental and medical hand pieces, it is necessary for the pieces to withstand sterilization and corrosion. Because of this requirement, dental and medical hand pieces are made from 440C stainless steel, which allows smooth rotations at fast speeds.[4]

Hard drive bearings used to be highly spherical, and were said to be the best spherical manufactured shapes, but this is no longer true, and more and more are being replaced with fluid bearings.

German ball bearing factories were often a target of allied aerial bombings during World War II; such was the importance of the ball bearing to the German war industry.[5]

In horology, the company Jean Lassale designed a watch movement that used ball bearings to reduce the thickness of the movement. Using 0.20 mm balls, the Calibre 1200 was only 1.2 mm thick, which still is the thinnest mechanical watch movement.[6]

Aerospace bearings are used in many applications on commercial, private and military aircraft including pulleys, gearboxes and jet engine shafts. Materials include M50 tool steel (AMS6491), Carbon chrome steel (AMS6444), the corrosion resistant AMS5930, 440C stainless steel, silicon nitride (ceramic) and titanium carbide-coated 440C.

Skateboarding. The wheels in a skateboard contain two bearings in each of the four wheels.
Agricultural Equipment. The many moving parts in a piece of farm machinery depend on several different types of bearings to operate. Under the heavy loads and dusty conditions, these bearings need to be lubricated, repaired, or replaced often.

[edit]History

Main article: History of bearings

Although roller bearings had been developing since ancient Egyptian times, the first recorded patent on ball bearings was awarded to Jules Suriray, a Parisian bicycle mechanic, on 3 August 1869. The bearings were then fitted to the winning bicycle ridden by James Moore in the world's first bicycle road race, Paris-Rouen, in November 1869.[7]

Ball bearings were first produced in Europe so they were standardized to metric dimensions. American manufacturers came along later so they produced ball bearings in metric dimensions prior to the early-1990s.[1]

[edit]See also

Ball screw
Bearing Specialists Association
Brinelling, a common failure mode
Linear bearing
Thrust bearing
Thrust ball bearing