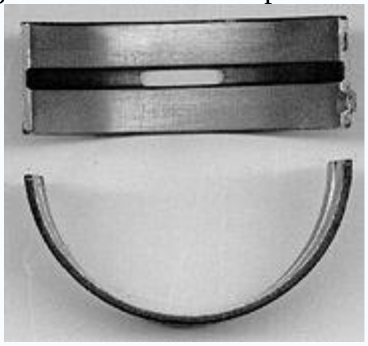
Rennilegur: (Plain bearings)

A typical plain bearing is made of two parts. For example, a rotary plain bearing can be just a shaft running through a hole. A simple linear bearing can be a pair of flat surfaces designed to allow motion (for example, a drawer and the slides it rests on).

Plain bearings may carry load in one of several ways depending on their operating conditions, load, relative surface speed (shaft to journal), clearance within the bearing, quality and quantity of lubricant, and temperature (affecting lubricant viscosity). If full-film conditions apply, the bearing's load is carried solely by a film of fluid lubricant, there being no contact between the two bearing surfaces. In this condition, they are known as fluid bearings. In mix or boundary conditions, load is carried partly by direct surface contact and partly by a film forming between the two. In a dry condition, the full load is carried by surface-to-surface contact.

Plain bearings are relatively simple and hence inexpensive. They are also compact, light weight, straightforward to repair and have high load-carrying capacity. However, if operating in dry or boundary conditions, plain bearings may wear faster and have higher friction than rolling element bearings. Dry and boundary conditions may be experienced even in a fluid bearing when operating outside of its normal operating conditions, e.g., at startup and shutdown.

A common plain bearing design utilizes a hardened and polished steel shaft and a soft bronze bushing. In such designs the softer bronze portion can be allowed to wear away, to be periodically renewed.



Plain 'self-lubricating' bearings utilize porous journals within which a lubricant is held. As the bearing operates and lubricant is displaced from the bearing surface, more is carried in from non-wear parts of the bearing. Dry plain bearings can be made of a variety of materials including PTFE (Teflon), graphite, graphite/metal (Graphalloy, Lubrite and ceramic. The ceramic is very hard, and sand and other grit which enter the bearing are simply ground to a fine powder which does not inhibit the operation of the bearing.

Kúlulegur: (Ball bearings)

There are many types of rolling-element bearings, each tuned for a specific kind of load and with specific advantages and disadvantages. For example:

A ball bearing

Ball bearings use balls instead of cylinders. Ball bearings can support both radial (perpendicular to the shaft) and axial loads (parallel to the shaft). For lightly-loaded bearings, balls offer lower friction than rollers. Ball bearings can operate when the bearing races are misaligned.

Typical rolling-element bearings range in size from 10 mm diameter to a few metres diameter, and have load-carrying capacity from a few tens of grams to many thousands of tonnes.

A particularly common kind of rolling-element bearing is the ball bearing. The bearing has inner and outer races and a set of balls. Each race is a ring with a groove where the balls rest. The groove is usually shaped so the ball is a slightly loose fit in the groove. Thus, in principle, the ball contacts each race at a single point. However, a load on an infinitely small point would cause infinitely high contact pressure. In practice, the ball deforms (flattens) slightly where it contacts each race, much as a tire flattens where it touches the road. The race also dents slightly where each ball presses on it. Thus, the contact between ball and race is of finite size and has finite pressure. Note also that the deformed ball and race do not roll entirely smoothly because different parts of the ball are moving at different speeds as it rolls. Thus, there are opposing forces and sliding motions at each ball/race contact. Overall, these cause bearing drag.

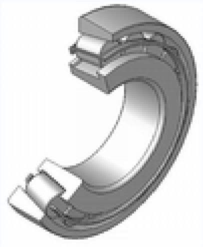
Most rolling element bearings use *cages* to keep the balls separate. This reduces wear and friction, since it avoids the balls rubbing against each other as they roll, and precludes them from jamming. Caged roller bearings were invented by John Harrison in the mid 1700s as part of his work on chronometers.[1]

Rúllu- / Keflalegur: **Roller bearings**

A roller bearing

Common roller bearings use cylinders of slightly greater length than diameter. Roller bearings typically have higher radial load capacity than ball bearings, but a low axial capacity and higher friction under axial loads. If the inner and outer races are misaligned, the bearing capacity often drops quickly compared to either a ball bearing or a spherical roller bearing.

Roller bearings are the earliest known type of rolling-element-bearing, dating back to at least 40 BC.



Tapered roller bearings

[edit] Tapered roller bearing

Main article: Tapered roller bearing

Tapered roller bearings use conical rollers that run on conical races. Most roller bearings only take radial loads, but tapered roller bearings support both radial and axial loads, and generally can carry higher loads than ball bearings due to greater contact area. Taper roller bearings are used, for example, as the wheel bearings of most cars, trucks, buses, and so on. The downsides to this bearing is that due to manufacturing complexities, tapered roller bearings are usually more expensive than ball bearings; and additionally under heavy loads the tapered roller is like a wedge and bearing loads tend to try to eject the roller; the force from the collar which keeps the roller in the bearing adds to bearing friction compared to ball bearings.

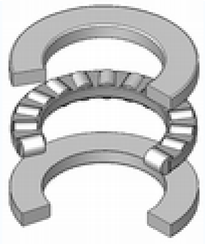
Spherical roller bearings

Spherical roller bearings

Main article: Spherical bearing

Spherical roller bearings use rollers that are thicker in the middle and thinner at the ends; the race is shaped to match. Spherical roller bearings can thus adjust to support misaligned loads. However, spherical rollers are difficult to produce and thus expensive, and the bearings have higher friction than a comparable ball bearing since different parts of the spherical rollers run at different speeds on the rounded race and thus there are opposing forces along the bearing/race contact.

Þrýstilegur: Thrust bearings



Thrust bearing

Main article: Thrust bearing

Thrust bearings are used to support axial loads, such as vertical shafts. Spherical, conical or cylindrical rollers are used; and non rolling element bearings such as hydrostatic or magnetic bearings see some use where particularly heavy loads or low friction is needed.

Nálalegur / Prjónalegur: **Needle bearing**

A needle roller bearing

Main article: Needle bearing

Needle roller bearings use very long and thin cylinders. Often the ends of the rollers taper to points, and these are used to keep the rollers captive, or they may be hemispherical and not captive but held by the shaft itself or a similar arrangement. Since the rollers are thin, the outside diameter of the bearing is only slightly larger than the hole in the middle. However, the small-diameter rollers must bend sharply where they contact the races, and thus the bearing fatigues relatively quickly.

[edit] Aerospace bearings

Aerospace bearings are installed in aircraft and aerospace systems in order to ensure a high precision aeronautical or aerospace system. Precision miniature ball bearings are found in fuel control systems, commercial airplanes, military guidance systems, and other types of aerospace systems.

[edit] Axles

These bearings are often used for axles due to their low rolling friction.

[edit] Other

Most rolling-element bearing designs are for rotating or oscillating loads, but there are also linear bearing designs. A common example is drawer-support hardware. Another example is a bearing for a shaft which moves axially in a hole. Axial-motion bearings often work like the stone-and-log example, with a pathway so rolling elements that fall off the end are pushed around to the other end, and the load rolls on to it. These are called **recirculating** bearings and were used in automotive steering units before the extensive introduction of the rack and pinion unit.

[edit] Bearing failure

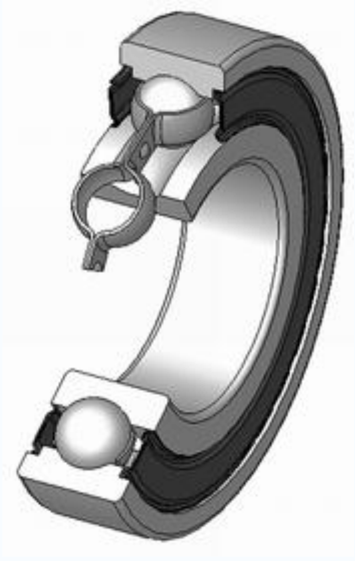
A prematurely failed rear bearing cone from a mountain bicycle, caused by a combination of pitting due to wet conditions, improper lubrication, and fatigue from frequent shock loading.

Rolling-element bearings often work well in non-ideal conditions, but sometimes minor problems cause bearings to fail quickly and mysteriously. For example, with a stationary (non-rotating) load, small vibrations can gradually press out the lubricant between the races and rollers or balls (false brinelling). Without lubricant the bearing fails, even though it is not rotating and thus is apparently not being used. For these sorts of reasons, much of bearing design is about failure analysis.

There are three usual limits to the lifetime or load capacity of a bearing: abrasion, fatigue and pressure-induced welding. Abrasion is when the surface is eroded by hard contaminants scraping at the bearing materials. Fatigue is when a material breaks after it is repeatedly loaded and released. Where the ball or roller touches the race there is always some deformation, and hence a risk of fatigue. Smaller balls or rollers deform more sharply, and so tend to fatigue faster. Pressure-induced welding is when two metal pieces are pressed together at very high pressure and they become one. Although balls, rollers and races may look smooth, they are microscopically rough. Thus, there are high-pressure spots which push away the bearing lubricant. Sometimes, the resulting metal-to-metal contact welds a microscopic part of the ball or roller to the race. As the bearing continues to rotate, the weld is then torn apart, but it may leave race welded to bearing or bearing welded to race.

Although there are many other apparent causes of bearing failure, most can be reduced to these three. For example, a bearing which is run dry of lubricant fails not because it is "without lubricant", but because lack of lubrication leads to fatigue and welding, and the resulting wear debris can cause abrasion. Similar events occur in false brinelling damage. In high speed applications, the oil flow also reduces the bearing metal temperature by convection. The oil becomes the heat sink for the friction losses generated by the bearing.

[edit] Constraints and trade-offs



Caged radial ball bearings

All parts of a bearing are subject to many design constraints. For example, the inner and outer races are often complex shapes, making them difficult to manufacture. Balls and rollers, though simpler in shape, are small; since they bend sharply where they run on the races, the bearings are prone to fatigue. The loads within a bearing assembly are also affected by the speed of operation: rolling-element bearings may spin over 100,000 rpm, and the principal load in such a bearing may be momentum rather than the applied load. Smaller rolling elements are lighter and thus have less momentum, but smaller elements also bend more sharply where they contact the race, causing them to fail more rapidly from fatigue. Maximum rolling element bearing speeds are often specified in 'DN', which is the product of the diameter (in mm) and the maximum RPM. For angular contact bearings DNs over 2.1 million have been found to be reliable in high performance rocketry applications.[2]

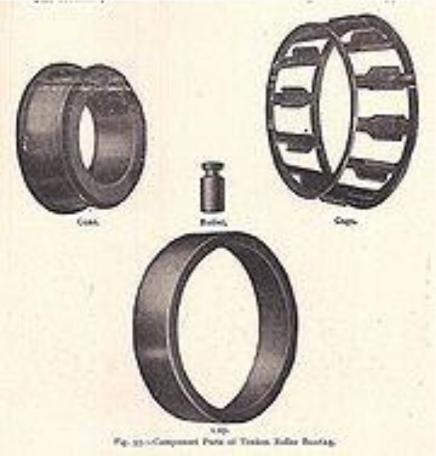
There are also many material issues: a harder material may be more durable against abrasion but more likely to suffer fatigue fracture, so the material varies with the application, and while steel is most common for rolling-element bearings, plastics, glass, and ceramics are all in common use. A small defect (irregularity) in the material is often responsible for bearing failure; one of the biggest improvements in the life of common bearings during the second half of the 1900s was the use of more homogeneous materials, rather than better materials or lubricants (though both were also significant). Lubricant properties vary with temperature and load, so the best lubricant varies with application.

Although bearings tend to wear out with use, designers can make tradeoffs of bearing size and cost versus lifetime. A bearing can last indefinitely -- longer than the rest of the machine -- if it is kept cool, clean, lubricated, is run within the rated load, and if the bearing materials are sufficiently free of microscopic defects. Note that cooling, lubrication, and sealing are thus important parts of the bearing design.

The needed bearing lifetime also varies with the application. For example, Tedric A. Harris reports in his *Rolling Bearing Analysis*[3] on an oxygen pump bearing in the U.S. Space Shuttle which could not be adequately isolated from the liquid oxygen being pumped, but all lubricants reacted with the oxygen leading to fires and other failures. The solution was to lubricate the bearing with the oxygen. Although liquid oxygen is a poor lubricant, it was adequate, since the service life of the pump was just a few hours.

The operating environment and service needs are also important design considerations. Some bearing assemblies require routine addition of lubricants, while others are factory sealed, requiring no further maintenance for the life of the mechanical assembly. Although seals are appealing, they increase friction, and a permanently-sealed bearing may have the lubricant contaminated by hard particles, such as steel chips from the race or bearing, sand, or grit that got past the seal. Contamination in the lubricant is abrasive and greatly reduces the operating life of the bearing assembly. Another major cause of bearing failure is the presence of water in the lubrication oil. Online water in oil monitors have been introduced in recent years to monitor the effects of both particles and the presence of water in oil and their combined effect.

head bearings for a motorcycle



Early Timken tapered roller bearing, with notched rollers

An early type of linear bearing uses tree trunks laid down under sleds. This technology may date as far back as the construction of the Pyramids of Giza, though there is no definitive evidence. Modern linear bearings use a similar principle, sometimes with balls in place of rollers.

Bearings saw use for holding wheel and axles. The bearings used there were plain bearings that were used to greatly reduce friction over that of dragging an object by making the friction act over a shorter distance as the wheel turned.

The first plain and rolling-element bearings were wood, but ceramic, sapphire, or glass were also used, and steel, bronze, other metals, ceramics, and plastic (e.g., nylon, polyoxymethylene, teflon, and UHMWPE) are all common today. A "jeweled" pocket watch uses stones to reduce friction, and allow more precise time keeping. Even old materials can have good durability. As examples, wood bearings can still be seen today in old water mills where the water provides cooling and lubrication.

Rotary bearings are required for many applications, from heavy-duty use in vehicle axles and machine shafts, to precision clock parts. The simplest rotary bearing is the *sleeve bearing*, which is just a cylinder inserted between the wheel and its axle. This was followed by the *roller bearing*, in which the sleeve is replaced by a number of cylindrical rollers. Each roller behaves as an individual wheel. The first practical caged-roller bearing was invented in the mid-1740s by horologist John Harrison for his H3 marine timekeeper. This uses the bearing for a very limited oscillating motion but Harrison also used a similar bearing in a truly rotary application in a contemporaneous regulator clock.

An early example of a wooden ball bearing (see rolling-element bearing), supporting a rotating table, was retrieved from the remains of the Roman Nemi ships in Lake Nemi, Italy. The wrecks were dated to 40 AD. Leonardo da Vinci is said to have described a type of ball bearing around the year 1500. An issue with ball bearings is the balls rub against each other, causing additional friction, but rubbing can be prevented by enclosing the balls in a cage. The captured, or caged, ball bearing was originally described by Galileo in the 1600s. The mounting of bearings into a set was not accomplished for many years after that. The first patent for a ball race was by Philip Vaughan of Carmarthen in 1794.

Friedrich Fischer's idea from the year 1883 for milling and grinding balls of equal size and exact roundness by means of a suitable production machine formed the foundation for creation of an independent bearing industry.

A patent, reportedly the first, was awarded to Jules Suriray, a Parisian bicycle mechanic, on 3 August 1869.[1] The bearings were then fitted to the

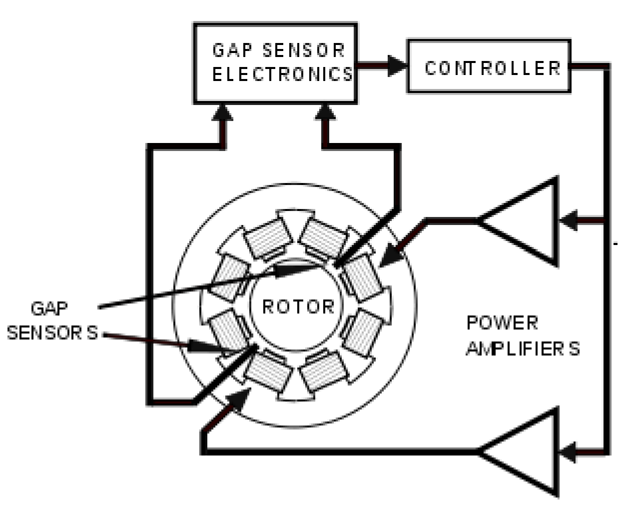
It is difficult to build a magnetic bearing using permanent magnets due to the limitations imposed by Earnshaw's theorem, and techniques using diamagnetic materials are relatively undeveloped. As a result, most magnetic bearings require continuous power input and an active control system to hold the load stable. Because of this complexity, the magnetic bearings also typically require some kind of back-up bearing in case of power or control system failure.

Two sorts of instabilities are very typically present with magnetic bearings. Firstly attractive magnets give an unstable static force, decreasing with greater distance, and increasing at close distances. Secondly since magnetism is a conservative force, in and of itself it gives little if any damping, and oscillations may cause loss of successful suspension if any driving forces are present, which they very typically are.

With the use of an induction-based levitation system present in cutting-edge MAGLEV technologies such as the Inductrack system, magnetic bearings could do away with complex control systems by using Halbach Arrays and simple closed loop coils.

Rafsegulssviðs legur: An active magnetic bearing (AMB)

Basic Operation



Basic Operation for a Single Axis

An active magnetic bearing (AMB) consists of an electromagnet assembly, a set of power amplifiers which supply current to the electromagnets, a controller, and gap sensors with associated electronics to provide the feedback required to control the position of the rotor within the gap. These elements are shown in the diagram. The power amplifiers supply equal bias current to two pairs of electromagnets on opposite sides of a rotor. This constant tug-of-war is mediated by the controller which offsets the bias current by equal but opposite perturbations of current as the rotor deviates by a small amount from its center position.

The gap sensors are usually inductive in nature and sense in a differential mode. The power amplifiers in a modern commercial application are solid state devices which operate in a pulse width modulation (PWM) configuration. The controller is usually a microprocessor or DSP.

Magnetic bearing advantages include very low and predictable friction, ability to run without lubrication and in a vacuum. Magnetic bearings are increasingly used in industrial machines such as compressors, turbines, pumps, motors and generators. Magnetic bearings are commonly used in watt-hour meters by electric utilities to measure home power consumption. Magnetic bearings are also used in high-precision instruments and to support equipment in a vacuum, for example in flywheel energy storage systems. A flywheel in a vacuum has very low windage losses, but conventional bearings usually fail quickly in a vacuum due to poor lubrication. Magnetic bearings are also used to support maglev trains in order to get low noise and smooth ride by eliminating physical contact surfaces. Disadvantages include high cost, and relatively large size.

A new application of magnetic bearings is their use in artificial hearts. The use of magnetic suspension in ventricular assist devices was pioneered by Prof. Paul Allaire and Prof. Houston Wood at the University of Virginia culminating in the first magnetically suspended ventricular assist centrifugal pump (VAD) in 1999[citation needed].