Radial Ball Bearings

1. Introduction

A bearing is a part of a mechanical object that constrains motion to a desired path, ranging from rotations, oscillations, and pivots to linear slides. The restriction of motion typically involves lowering friction along and limiting forces normal to the ideal path, using a rolling contact, guides, low-friction materials and surfaces, lubrication, magnets, or a combination of all these and more. The first use of bearings date back to the BC era, where ancient civilizations placed tree trunks or wooden balls under structures too heavy to carry. By then pushing the structures along, the wood acted as a bearing by rolling, reducing friction between the structure and ground, and constraining the motion of the structure to a linear path [1].

At present, there are seemingly infinite types of bearings on the market. One of the more common is the radial ball bearing (also known as the deep-grove single-row or Conrad bearing), which consists of two concentric rings with grooves, otherwise called “races,” numerous metal balls separating these rings, and a retainer or “cage” to maintain ball spacing. The radial ball bearing is illustrated in Fig. 1, detailing how the components are assembled. Noteworthy is the clever use of the races, which create a snug path for the balls to follow as the rings rotate. If one of the rings is held stationary while the other can rotate freely, the balls will also rotate since contact is maintained with both surfaces. To allow higher speeds, lower
friction, and retain more lubricant, a cage is incorporated and functions to hold the balls at an even spacing with minimal radial movement as it is held in the assembly. The precise rolling contact created by this system of balls, races, and a cage provides low overall rotational friction while supporting radial and axial loads, and is therefore ideal for applications ranging from complex mechanical systems like the inside of turbines for jet engines to toys as simple as yo-yos and fidget spinners.

Fig. 1. Components of a radial ball bearing [2].

In this paper, the material choices for radial ball bearings will be outlined and analyzed, leading into a discussion of the manufacturing steps and processes that produce radial ball bearings. Performance of the ball bearings is heavily dependent on gaps and tolerances, so a set of standards will also be briefly introduced. Ultimately, the discussion will be brought full-circle by a high-level overview of the many applications and industries where radial ball bearings serve a crucial purpose.
2. Materials

Ball bearings may be made of an almost-infinite combination of materials, but there are three major materials that have dominated the bearing component market for their superior performance characteristics: steel, ceramics, and plastics [3]. Each set of materials has its benefits and challenges, therefore implying that each has applications where it is ideal and where it is not. The design constraints of the races, balls, and cage will be analyzed, then the possible materials will be mentioned and outlined for their benefits and unique challenges.

2a. Race Material

The first set of components to be considered are the inner and outer races, and to reiterate, their function is to provide the bearing surfaces and guide the balls as they rotate within the races. As the rings rotate relative to one another, each of the balls is making simultaneous contact with each of the rings. The points of contact make radial loading, axial loading, friction, operating speeds, and fatigue life important factors in choosing a material. The rings may also be mounted into an external assembly (outer ring to a housing, inner ring to a shaft that must rotate freely), and so consideration must be given to external conditions such as improper mounting which may cause misalignment, environmental factors such as dirt and dust, and many other variables.

By far the most common material for bearing races is steel for its high strength, good machinability, and generally low cost. Chrome and stainless steels are the most used, offering high load capabilities (up to 30,000 pounds) and a high operating speed. Drawbacks are straightforward in steel bearings: they often can lack chemical resistance, conduct electricity, are heavy, cause noise from metal-on-metal contacts, and are magnetic [4]. Steel will also not
absorb lubrication, therefore requiring occasional maintenance to prevent excessive wear in the grooves of the races. Steel races are compatible with many types of balls, including ceramics, steel, and plastic [3].

The introduction of all-plastic races is relatively new to the bearing industry. Plastic races perform the best in situations where weight and noise must be critically low, and self-lubrication is necessary. The races are compatible with glass, plastic, and stainless-steel balls, and are therefore suitable for mid-range operating speeds. Challenges arise in high force and high temperature applications: plastics tend to be much weaker than steels and degrade significantly at temperatures above 300°F [3].

Although rare, races can also be manufactured from ceramics to give good corrosion resistance and self-lubrication. However, due to the hardness of the ceramic races and its typical pairing with ceramic balls, these all-ceramic bearings can be noisy, brittle, subject to chipping and breakage under load, and able to spark during operation [5].

2b. Ball Material

Consistent with the materials used in races, balls are also typically manufactured from steels, but there are vastly greater options in terms of alloys, plastics, glass, or ceramics. In terms of material properties, the same general principles previously described apply: steels (such as 52100 chrome alloy steel) are the most popular option for their low cost, high hardness, and good machinability; plastics are suitable for quiet operation with low forces; and ceramics excel in highly corrosive environments or those where electrical insulation is necessary [3], [4], [5]. Race and ball materials may differ in order to realize the benefits of two materials in combination, such as in a hybrid ceramic bearing. Using traditional 52100 chrome
steel rings and ceramic balls, hybrid bearings benefit from electrical insulation, higher speed capabilities, and longer service lifetime from less required grease and decreased wear on the balls [5]. Many other options are possible, including steel cage/plastic balls, plastic cage/steel balls, plastic cage/glass ball, etc., and can be tailored to the operating conditions of the bearing.

2c. Cage Material

The material of the cage is the last design consideration since the role of the cage is simple: to maintain ball spacing. However, proper functioning is extremely important for ensuring a long-life, high-performance ball bearing is created. The cage can also be designed to reduce excess torque, resist heat, and isolate the bearing in a harsh environment. Plastics, such as phenolic resin and polyether ether ketone (PEEK), excel in situations with moderate temperatures (250°F to 300°F), high inertial forces, and absorb lubrication to ensure friction reduction. Metals, such as brass or different types of steel, are ideal for low to medium speed applications with higher temperatures or harsher operating conditions, i.e. excess vibrations [6], [7].

The type of cage can also be a determining factor in selecting a material, as cages can be a variety of styles as shown in Fig. 2. All cages perform best when a form of lubrication is present with seals or are otherwise shielded from contaminants. The ribbon cage is seen in larger bearings that must operate at low to medium speeds, handle high forces, and survive high temperatures. Ribbon cages call for the use of a metal such as brass or stainless steel, and are therefore more expensive. The balls guide this style cage. The crown cage is best suited for smaller bearings, can be guided by either ring or the balls depending on design, and can be made of metal or plastic, although plastic is much more common. Plastics in crown-style cages
can also be termed “molded” by some manufacturers to make clear the distinction between metal crowns. Plastics offer smoother sliding characteristics which minimize noise and excess torque, making it an ideal choice for high speed applications. The balls guide these cages, too [6], [7], [8].

Fig 2. (a) Metal crown style cage, (b) Metal ribbon style cage, and (c) Plastic crown-style cage for retaining ball spacing within a bearing assembly [7].

3. Standard Manufacturing Process

Each of the four main components in a bearing assembly must be manufactured separately and assembled afterward, and so the following outline will follow a similar structure. The manufacturing process will be that of the standard ball bearing: one that consists of a stainless or chrome steel race, chrome steel balls, and either a plastic or metal cage. The inner and outer race will be discussed first, followed by the balls and cages, and finally the assembly process will be detailed.

3a. Manufacturing the Races

The inner and outer races both consist of a steel which begins as steel tubing. The steel tubing is initially untreated and machined to approximate size using lathe-like machines. These oversized races are then heat treated by placing them into a furnace around 1550°F until they
are adequately heated, then dipped in oil to quickly cool. They are then tempered at a lower temperature to decrease the hardness and brittleness of the steel and thereby achieving a hard and tough material [9].

At this stage, the races are oversized and potentially slightly warped, and must be machined to their high-precision standards. Standard cutting processes will be too difficult given the heat-treated steel properties, so grinding wheels must be utilized. First, the width of the races is ground to the correct thickness and measured upon exiting toward the next step. The outer race is first: its outer surface is ground to its precise specifications by rotating the race against the grinding wheel, ensuring a perfectly smooth and circular circumference. Coolants must be used to prevent heat buildup and warping of the metal. The inner surface, which will house the groove for the balls, is cut first by an abrasive stone wheel to reach precisely the correct groove shape and size. Another abrasive stone polishes the surface until a mirror-like finish is achieved. As for the inner race, the exact opposite occurs: first, the inner surface is ground to its precise diameter and then an abrasive stone wheel cuts the outer surface to obtain the outer race. The rings are cleaned, greased, and set aside, ready for assembly [9]. Between the inner and outer rings lies a groove which will snugly house the balls.

3b. Manufacturing the Balls

The balls begin as thick wire which is trimmed into short sections and smashed into rough balls. This process occurs at room temperature in a process known as cold heading, which simply means that no heat is applied. From being smashed to form, the balls will have a lip or ring around their center, known as the “flash,” along with small bumps on top and bottom. The roughly shaped balls are then fed into a stationary plate with a circular groove.
Another plate with a similar circular groove is placed on top of the plate and balls, which is then rotated as illustrated in Fig. 3. The surface of the grooves is rough and will cut the flash and burrs off the balls, leaving them oversized but ever closer to becoming a perfect sphere. This process may be repeated many times to ensure the flash is adequately removed [9], [10].

![Fig. 3. Illustration of the grinding and lapping plates with grooves that are used to machine balls to size [11].](image)

At this point, the balls can be heat treated and tempered to become tough and hard, in a manner like the races. After the heat treating and oil bath are finished, the balls are finely ground through similar plates as those used in Fig. 3 but with a grinding surface to reduce the balls within ten thousandths of their final diameter. The final step is a lapping process which places a mirror finish on the balls after several hours of rotations. The result is extremely smooth balls that are then precisely measured for quality assurance and to sort the ball diameters to match the race profiles.
3c. Manufacturing the Cage

If a metal cage is desired, there are many potential manufacturing steps that must be taken. Processes can include stamping, forming, molding, forging, and machining depending on whether the cage is ribbon or crown style. On the other hand, a plastic cage is straightforward to manufacture as it only requires injection molding. Melted plastic is extruded into a metal mold, cooled, and the final part is achieved.

3d. Assembly

At this stage, all parts are finished and must be assembled. The components are measured and can be matched to one another to ensure that the grooves in the races will house the appropriately sized balls, achieving the specified tolerances. To assemble the bearings, the inner race is placed into the outer race and shifted off-center. The misaligned rings will create a gap that is large enough to insert the balls into. Once the specified number of balls are inserted, the rings may be centered, and the balls will now be free to move in the grooves inside the races. The cage may now be inserted. In the case of a plastic cage, it may simply be snapped into place. A metal cage may require insertion and riveting, but this final step produces the assembled bearing which can be greased, sealed, and sold to consumers [9].

4. Performance Guidelines and Tolerancing

Radial ball bearings of high quality are classified according to a set of standards which may vary depending on location. In North America, the industry standard for defining bearing tolerances was developed by the Annular Bearing Engineering Committee (ABEC), and is known as the ABEC scale. This scale consists of five different classes: 1, 3, 5, 7, and 9. A smaller
number corresponds to the largest tolerances, meaning that these bearings are the least precise, efficient, and may not perform extremely well at high speeds [12].

The scale allows consumers to choose bearings according to their necessary performance specifications, but the ABEC scale has its limitations. It does not specify performance with respect to load handling, vibration, material, or lubricant, and so it is indeed true that an ABEC 3 bearing may perform better than a bearing that is higher on the scale. Other factors to consider when choosing a bearing include, but are not limited to: fatigue, loading, friction, fit, and contamination.

5. Applications and Conclusions

Although an extremely simple mechanical tool, the radial ball bearing finds extensive use in many different industries. Most notable was the production of the bicycle, arguably made possible due to its use of bearings in the wheel/axle assemblies. As alluded to, there is no limit to the complexity or simplicity required by the systems that make use of ball bearings; just that a component needs to rotate with minimal friction. Some of these applications include food blenders, electrical motors and engines, elevators, power tools, stage lighting, credit card readers, and the list goes on.

The role of a radial ball bearing is often overlooked in many complex systems, but they remain a feat of engineering nonetheless. These devices function to restrict motion to a singular rotational direction while significantly reducing friction, all using four simple components. The clever use of tiny balls creates a continuous rolling contact and, when combined with high-precision manufacturing processes, produce an almost perfectly smooth
path as the bearing rotates freely. Nearly infinite material combinations between components implies that radial ball bearings can be tuned for a wide range of applications and environments, and standard manufacturing processes can build the bearings to a large range of sizes. Because of their versatility, radial ball bearings can and will continue to be found in nearly every mechanical system with a rotational degree of freedom.

6. References


