CLASSIFICATION OF ROLLING-ELEMENT BEARINGS

Ball bearings can operate at higher speed in comparison to roller bearings because they have lower friction. In particular, the balls have less viscous resistance when rolling through oil or grease. However, ball bearings have lower load capacity compared with roller bearings because of the high contact pressure of point contact. There are about 50 types of ball bearings listed in manufacturer catalogues. Each one has been designed for specific applications and has its unique characteristics. The following is a description of the most common types.

12.2.1 Ball Bearings

12.2.1.1 Deep-Groove Ball Bearing

The deep-groove ball bearing (Fig. 12-2) is the most common type, since it can be used for relatively high radial loads. Deep-groove radial ball bearings are the most widely used bearings in industry, and their market share is about 80% of industrial rolling-element bearings. Owing to the deep groove in the raceways, they can support considerable thrust loads (in the axial direction of the shaft) in addition to radial loads. A deep-groove bearing can support a thrust load of about 70% of its radial load. The radial and axial load capacity increases with the bearing size and number of balls. For maximum load capacity, a filling-notch type of bearing can be used that has a larger number of balls than the standard bearing. In this design, there is a notch on one shoulder of the race. The circular notch makes it possible to insert more balls into the deep groove between the two races. The maximum number of balls can be inserted if the outer ring is split. However, in that case, external means must be provided to hold and tighten the two ring halves together.

12.2.1.2 Self-Aligning Ball Bearings

It is very important to compensate for angular machining and assembly errors between the centerlines of the bearing and the shaft. The elastic deflection of the shaft is an additional cause of misalignment. In the case
of a regular deep-groove ball bearing, the misalignment causes a bending moment in the bearing and additional severe contact stresses between the balls and races. However, in the self-aligning bearing (Fig. 12-3), the spherical shape of the outer race allows an additional angular degree of freedom (similar to that of a universal joint) that prevents the transfer of any bending moment to the bearing and prevents any additional contact stresses.

Self-aligning ball bearings have two rows of balls, and the outer ring has a common spherical raceway that allows for the self-aligning characteristic. The

![Self-aligning ball bearing](image)

inner ring is designed with two restraining ribs (also known as lips), one at each side of the roller element, for accurately locating the rolling elements’ path on the inner raceway. But the outside ring has no ribs, in order to allow for self-alignment. A wide spherical outer race allows for a higher degree of self-alignment.

Self-aligning ball bearings are widely used in applications where misalignment is expected due to the bending of the shaft, errors in the manufacture of the shaft, or mounting errors. The design engineer must keep in mind that there are always tolerances due to manufacturing errors. Self-aligning bearings can be applied for radial loads combined with moderate thrust loads. The feature that self-aligning bearings do not exert any bending moment on the shaft is particularly important in applications that require high precision (low radial run-out) at high speeds, because shaft bending causes imbalance and vibrations.

The concept of self-alignment is useful in all types of bearings, including sleeve
bearings.

12.2.1.3 Double-Row Deep-Groove Ball Bearing
This bearing type (Fig. 12-4) is used for relatively high radial loads. It is more sensitive to misalignment errors than the single row and should be used only for applications where minimal misalignment is expected. Otherwise, a self-alignment bearing should be selected.

The design of double-row ball bearings is similar to that of single-row ball bearings. Since double-row ball bearings are wider and have two rows, they can carry higher radial loads. Unlike the deep-groove bearing, designs of split rings (for the maximum number of balls) are not used, and each ring is made from one piece. However, double-row bearings include groups with larger diameters and a larger number of balls to further improve the load capacity.

12.2.1.4 Angular Contact Ball Bearing
This bearing type (Fig. 12-5) is used to support radial and thrust loads. Contact angles of up to 40 (from the radial direction) are available from some bearing manufacturers, but 15 and 25 are the more standard contact angles. The contact angle determines the ratio of the thrust to radial load.

Angular contact bearings are widely used for adjustable arrangements, where they are mounted in pairs against each other and preloaded. In this way, clearances in the bearings are eliminated or even preload is introduced in the rolling contacts. This is often done to stiffen the bearings for a rigid support of the shaft. This is important for reducing the amplitude of shaft vibrations under oscillating forces. This type of design has significant advantages whenever precision is required (e.g., in
Machine tools), and it reduces vibrations due to imbalance. This is particularly important in high-speed applications. An adjustable arrangement is also possible in tapered bearings; however, angular contact ball bearings have lower friction than do tapered bearings. However, the friction of angular contact ball bearings is somewhat higher than that of radial ball bearings. Angular contact ball bearings are the preferred choice in many important applications, such as high-speed turbines, including jet engines.

![Angular contact ball bearing.](image)

**Fig. 12-5** Angular contact ball bearing.

Single-row angular contact ball bearings can carry considerable radial loads combined with thrust loads in one direction. Prefabricated mountings of two or more single-row angular contact ball bearings are widely used for two-directional thrust loads. Two bearings in series can be used for heavy unidirectional thrust loads, where two single-row angular contact ball bearings share the thrust load.

Precise axial internal clearance and high-quality surface finish are required to secure load sharing of the two bearings in series. The bearing arrangement of two or more angular contact bearings facing the same direction is referred to as tandem arrangement. The bearings are mounted adjacent to each other to increase the thrust load carrying capacity.

### 12.2.2 Roller Bearings

Roller bearings have a theoretical line contact between the unloaded cylindrical rollers and races. This is in comparison to ball bearings, which have only a theoretical point contact with the raceways. Under load, there is elastic deformation, and line contact results in a larger contact area than that of a point contact in ball bearings. Therefore, roller bearings can support higher radial loads. At the same time, the friction force and friction-energy losses are higher for a line contact; therefore, roller bearings are usually not used for high-speed applications.
Roller bearings can be classified into four categories: cylindrical roller bearings, tapered roller bearings, needle roller bearings and spherical roller bearings.

12.2.2.1 Cylindrical Roller Bearings
The cylindrical roller bearing (Fig. 12-6) is used in applications where high radial load is present without any thrust load. Various types of cylindrical roller bearings are manufactured and applied in machinery. In certain applications where diameter space is limited, these bearings are mounted directly on the shaft, which serves as the inner race. For direct mounting, the shaft must be hardened to high Rockwell hardness, similar to that of the bearing race. For direct mounting, the radial load must be high in order to prevent slipping between the rollers and the shaft during the start-up. It is important to keep in mind that cylindrical roller bearings cannot support considerable thrust loads. Thus, for applications where both radial and thrust loading are present, it is preferable to use ball bearings.

12.2.2.2 Tapered Roller Bearing
The tapered roller bearing is used in applications where a high thrust load is present that can be combined with a radial load. The bearing is shown in Fig. 12-7. The races of inner and outer rings have a conical shape, and the rolling elements between them have a conical shape as well. In order to have a rolling motion, the contact lines formed by each of the various tapered roller elements

![Cylindrical roller bearing](image)

Fig. 12-6  Cylindrical roller bearing.

and the two races must intersect at a common point on the bearing axis. This intersection point is referred to as an apex point. The apex point is closer to the bearing when the cone angle is steeper. A steeper cone angle
can support a higher thrust load relative to a radial load.

The inner ring is referred to as cone, while the outer ring is referred to as cup. The cone is designed with two retaining ribs (also known as lips) to confine the tapered rollers as shown in Fig. 12-7. The ribs also align the rollers between the races. In addition, the larger rib has an important role in supporting the axial load. A cage holds the cone and rollers together as one unit, but the cup (outer ring) can be pulled apart.

A single-row tapered roller bearing can support a thrust load in only one direction. Two tapered roller bearings are usually mounted in opposition, to allow for thrust support in both directions (in a similar way to opposing angular contact ball bearings). Moreover, double or four-row tapered roller bearings are applied in certain applications to support a high bidirectional thrust load as well as radial load.

The reaction force on the cup acts in the direction normal to the line of contact of the rolling elements with the cup race (normal to the cup surface). This force can be divided into axial and radial load components. The intersection of the resultant reaction force (which is normal to the cup angle) with the bearing centerline is referred to as the effective center. The location of the effective center is useful in bearing load calculations.

For example, when a radial load is applied on the bearing, this produces both radial and thrust reactions. The thrust force component, which acts in the direction of the shaft centerline, can separate the cone from the cup by sliding the shaft in the axial direction through the cone or by the cup’s sliding axially in its seat. To prevent such undesired axial motion, a single-row tapered bearing should be mounted with another tapered bearing in the opposite direction. This arrangement is also very important for adjusting the clearance.
One major advantage of the tapered roller bearing is that it can be applied in adjustable arrangement where two tapered roller bearings are mounted in opposite directions (in a similar way to the adjustable arrangement of the angular contact ball bearing that was discussed earlier). This arrangement allows one to eliminate undesired clearance and to provide a preload (interference or negative clearance). Bearing preload increases the bearing stiffness, resulting in reduced vibrations as well as a lower level of run-out errors in precision machining. However, the disadvantage of bearing preloading is additional contact stresses and higher friction. Preload results in lowering the speed limit because the higher friction causes overheating at high speeds.

The adjustment of bearing clearance can be done during assembly and even during steady operation of the machine. The advantage of adjustment during operation is the precise elimination of the clearance after the thermal expansion of the shaft.

### 12.2.2.3 Multirow Tapered Roller Bearings

The multirow tapered roller bearing (Fig. 12-8) is manufactured with a predetermined adjustment that enables assembly into a machine without any further adjustment. The multirow arrangement includes spacers and is referred to as a spacer assembly. The spacer is matched with a specific bearing assembly during manufacturing. It is important to note that components of these assemblies are not interchangeable. Other types, without spacers, are manufactured with predetermined internal adjustment, and their components are also not interchangeable.

![Fig. 12-8](image)

**Fig. 12-8** Multirow tapered roller bearings.

### 12.2.2.4 Needle Roller Bearing
These bearings (Fig. 12-9) are similar to cylindrical roller bearings, in the sense that they support high radial load. This type of bearing has a needle like appearance because of its higher length-to-diameter ratio. The objective of a needle roller bearing is to save space. This is advantageous in applications where bearing space is limited. Furthermore, in certain applications needle roller bearings can also be mounted directly on the shaft. For a direct mounting, the shaft must be properly hardened to a similar hardness of a bearing ring.

Two types of needle roller bearings are available. The first type, referred to as full complement, does not include a cage; the second type has a cage to separate the needle rollers in order to prevent them from sliding against each other. The full-complement bearing has more rollers and can support higher radial load. The second type has a lower number of rollers because it has a cage to separate the needle rollers to prevent them from rubbing against each other. The speed of a full-complement bearing is limited because it has higher friction between the rollers. A full-complement needle bearing may comprise a maximum number of needle rollers placed between a hardened shaft and a housing bore. An outer ring may not be required in certain situations, resulting in further saving of space.

12.2.2.5 Self-Aligning Spherical Roller Bearing
This bearing has barrel-shaped rollers (Fig. 12-10). It is designed for applications that involve misalignments due to shaft bending under heavy loads and due to manufacturing tolerances or assembly errors (in a similar way to the self-aligning ball bearing). The advantage of the spherical roller bearing is its higher load capacity in comparison to that of a self-aligning ball bearing, but it has higher frictional losses.

Spherical roller bearings are available as single-row, double-row, and thrust types. The single-row thrust spherical roller bearing is designed to support
only thrust load, and it is not recommended where radial loads are present. Double-row spherical roller bearings are commonly used when radial as well as thrust loads are present.

The double-row spherical roller bearing has the highest load capacity of all rolling bearings. This is due to the relatively large radius of contact of the rolling element. It can resist impact and other dynamic forces. It is used in heavy-duty applications such as ship shafts, rolling mills, and stone crushers.