

Study Unit

Bearings and Seals

Part 2

Preview

Antifriction bearings are found in almost every type of machine. These bearings are universally used because they allow shaft rotation and other motion to occur smoothly, with very little resistance. This study unit will help you learn how to identify, lubricate, maintain, and replace antifriction bearings and seals.

This unit introduces the basic characteristics of each major type of antifriction bearing and discusses how these characteristics are employed in various applications. You'll learn to recognize the different parts of various types of antifriction bearings. This study unit also introduces proper installation and maintenance techniques.

This study unit will help you understand the importance of seals in maintaining antifriction bearings. You'll learn about the function of a seal, the different types of seals, and the types of material from which seals are manufactured.

When you've completed this study unit, you'll be able to

- Identify the various parts of an antifriction bearing
- Identify the various parts of a seal
- Choose the proper seal for a given application
- Explain the importance of providing bearings with a sufficient supply of the proper lubricant and the result of failing to do so
- Differentiate between the features and capabilities of the different types of antifriction bearings
- Identify common problems that occur in antifriction bearings and suggest potential solutions

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Bearings and Seals, Part 2

ANTIFRICTION BEARINGS

When motion occurs between two surfaces in contact with one another, friction occurs. Friction resists motion. Bearings are used to reduce friction between two moving surfaces. An *antifriction bearing* reduces friction by inserting a rolling element between the surfaces. *Rolling elements* placed between the surfaces reduce friction and wear at the point of contact. The rolling element reduces friction by replacing sliding contact (such as occurs where a plain bearing supports a shaft) with rolling contact. Two similar surfaces offer much less resistance to motion in rolling contact than they do in sliding contact, as shown in Figure 1. There are many types of antifriction bearings, each with a different type of rolling element. These rolling elements can be spherical balls, cylindrical rollers, tapered rollers, or cylindrical needles. Shortly you'll learn more about the bearings that contain these elements.

Loads on Antifriction Bearings

Bearings supporting a rotating shaft must handle the same types of loads as are applied to the shaft. Bearings must be able to absorb these loads without failing. Therefore, bearings are selected based on the quantity and direction of load they can support, the speed at which they can support this load, and the amount of time they'll last under the load conditions.

There are three types of loads that act on an antifriction bearing: radial, thrust, and combination. Loads acting parallel to the axis of the bearing are known as *axial* or *thrust loads*. The directions of radial and axial loads are shown in Figure 2. A *radial* load acts in a direction perpendicular to the shaft and bearing axis. This type of load tries to bend or deflect the shaft. In turn, the shaft transmits the effort to the bearings that support it. Belt drives, gear drives, and chain drives are examples of machine components that impose radial loads on bearings. When radial and thrust forces act at the same time, *combination loads* occur.

Figure 2 also shows the direction in which axial loads act. These loads, which act parallel to the shaft's and bearing's axes, are caused by the actions of components such as screws, worm and bevel gears, and fans.

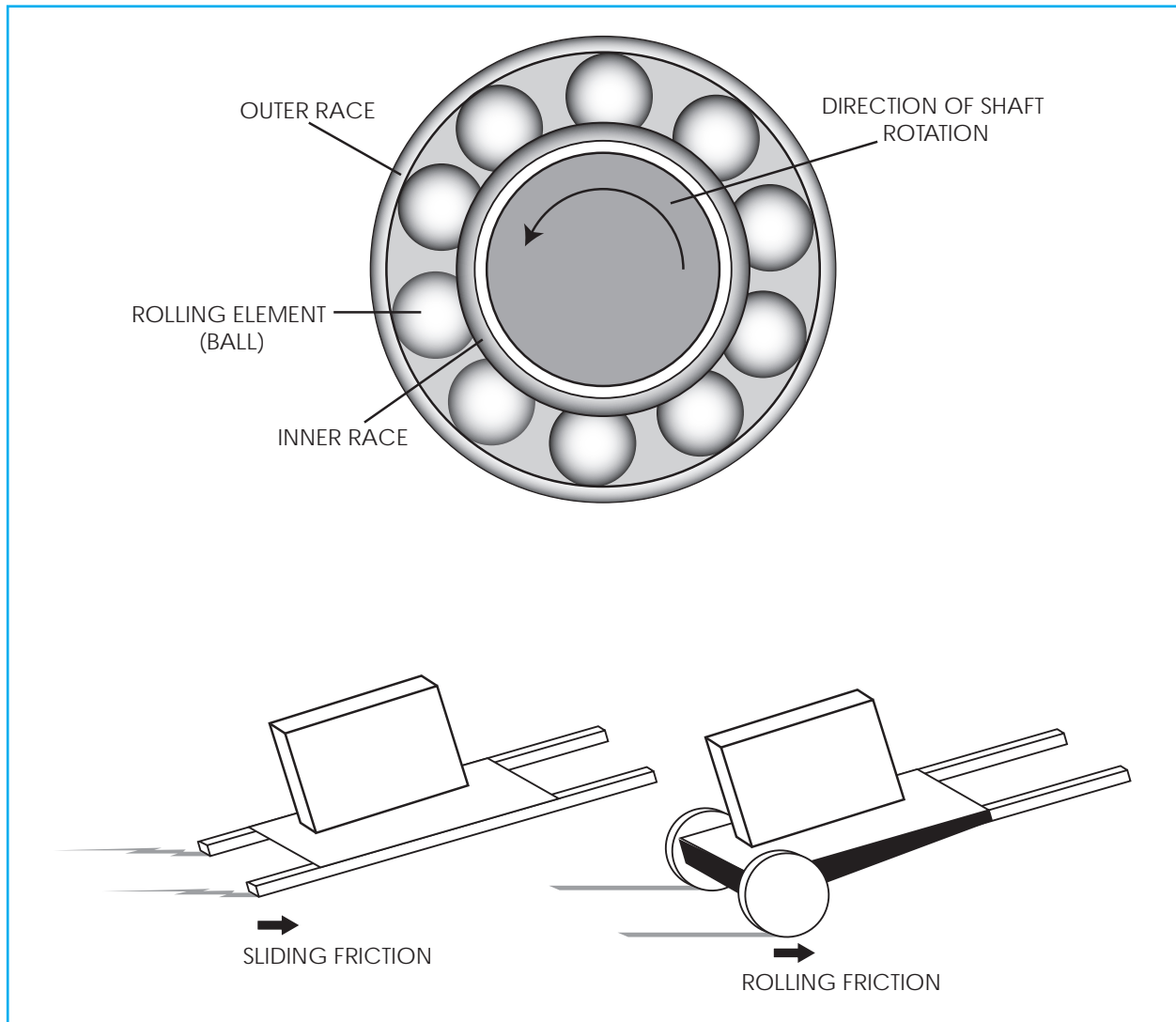


FIGURE 1—Antifriction bearings offer less resistance to motion because their operation is based on rolling rather than sliding friction.

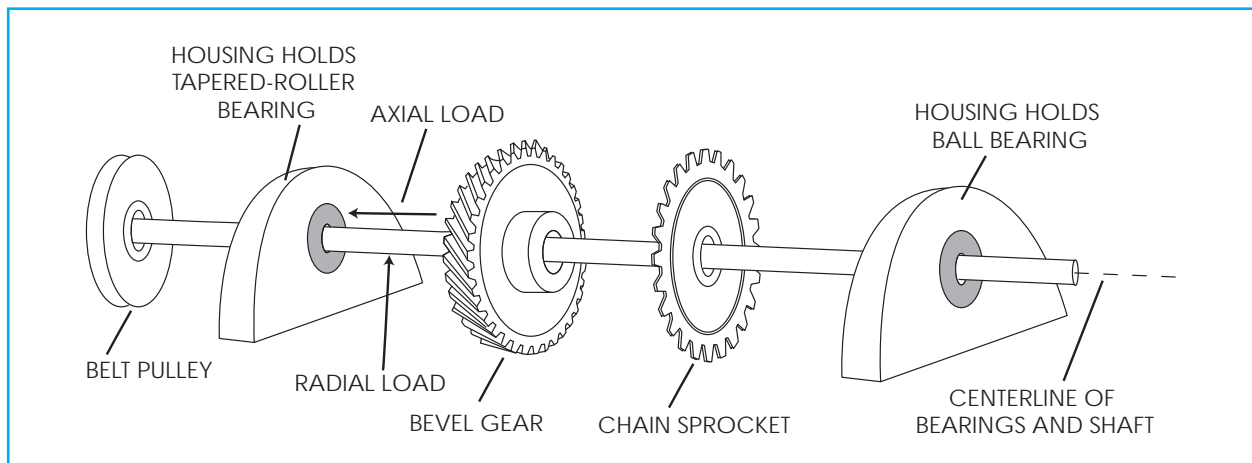


FIGURE 2—Radial and axial loads are shown here.

Some applications impose combination (radial and thrust) loads on the shaft at the same time. Design engineers select suitable bearings to handle this type of load. The direction of the larger of the two loads is generally used as the main standard in bearing selection. Often, more than one bearing is installed to support a machine shaft or other component.

In Figure 2, the pulley and sprocket primarily impose radial loads on the shaft and bearings, but the bevel gear imposes both radial and axial loads. The bearings absorb these loads and hold the shaft in a relatively fixed position. As you'll soon learn, only the tapered-roller bearing is capable of supporting axial loads, so it alone is responsible for maintaining this shaft's axial position. However, both bearings are capable of supporting the shaft in the radial direction.

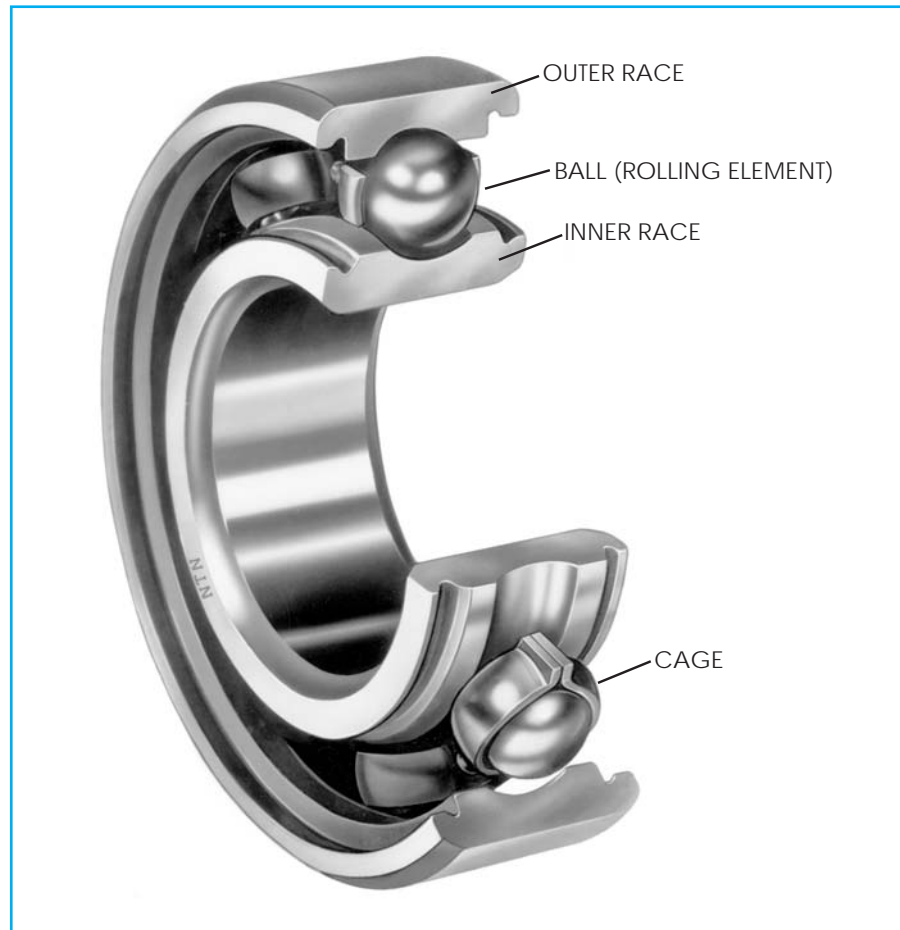
The difference in the capabilities of various types of antifriction bearings requires machine designers to use great care when selecting the proper bearing for any particular installation. It also means that you must install the specified bearing any time you're working on a mechanical system.

Ball Bearings

The most common type of antifriction bearing, with ball-shaped rolling elements, is the *ball bearing*. The other components of antifriction bearings, as shown in Figure 3, are the *inner race* (cup), *outer race* (cone), and the *cage*, which positions the rolling elements and prevents them from contacting one another.

The ball bearing shown in Figure 3 is a single-row ball bearing. The outer race and the inner race hold the balls and the cage in position. In this case, the inner race will be pressed tightly onto the shaft being supported. The outer race will be secured tightly in a machine housing. The balls are constrained between the two races. The bearing's outer race is stationary. The shaft's centerline must fall on the same line, or *coincide*, with the centerline of the bearing. In this way, the balls will rotate with minimal resistance as the shaft turns.

FIGURE 3—The basic components of a ball bearing are shown here. (Courtesy of NTN Bearing Corporation of America)

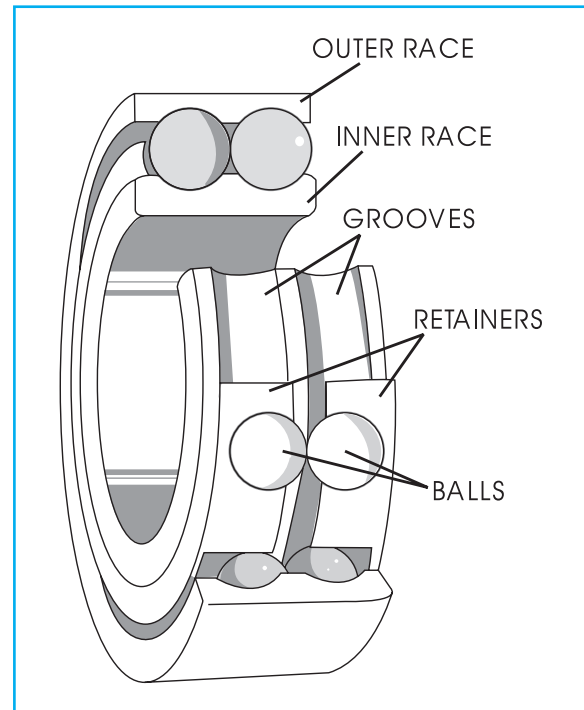


Double-Row Ball Bearings

Another type of ball bearing is the double-row ball bearing. A typical *double-row ball bearing* (with two separate sets of rolling elements) is shown in Figure 4. This design carries larger loads. Note that the inner and outer races are each constructed as one piece. The *retainers*, or cage that surrounds the balls, can be made of one or two individual pieces. Both single-row and double-row ball bearings can support a small amount of thrust load in addition to radial load.

Ball-type rolling elements are manufactured from extremely hard material, allowing them to carry heavy loads without losing their spherical shape. The desirable size and quantity of balls depend on the weight being supported. For that reason, it's very important that removed bearings be replaced with an exact duplicate. If an alternative model is used, be sure to match as many of the removed bearing's physical features as possible. This includes not only the most obvious features (which must always be matched) such as the number and size of balls, material type, load capacity, and speed capacity, but also less obvious features such as finish quality. To ensure proper operation and maximum life, a ball bearing should be installed carefully. Also,

FIGURE 4—A Double-Row Ball Bearing



the entire bearing system (including the shaft, bearing, and machine housing) should be accurately aligned.

Angular-Contact Ball Bearings

Angular-contact bearings are designed to support a heavy thrust load in one direction. The thrust-load capacity is obtained by using a high-thrust-supporting shoulder on the inner race, as shown in Figure 5, and a similar shoulder on the opposite side of the outer race. This

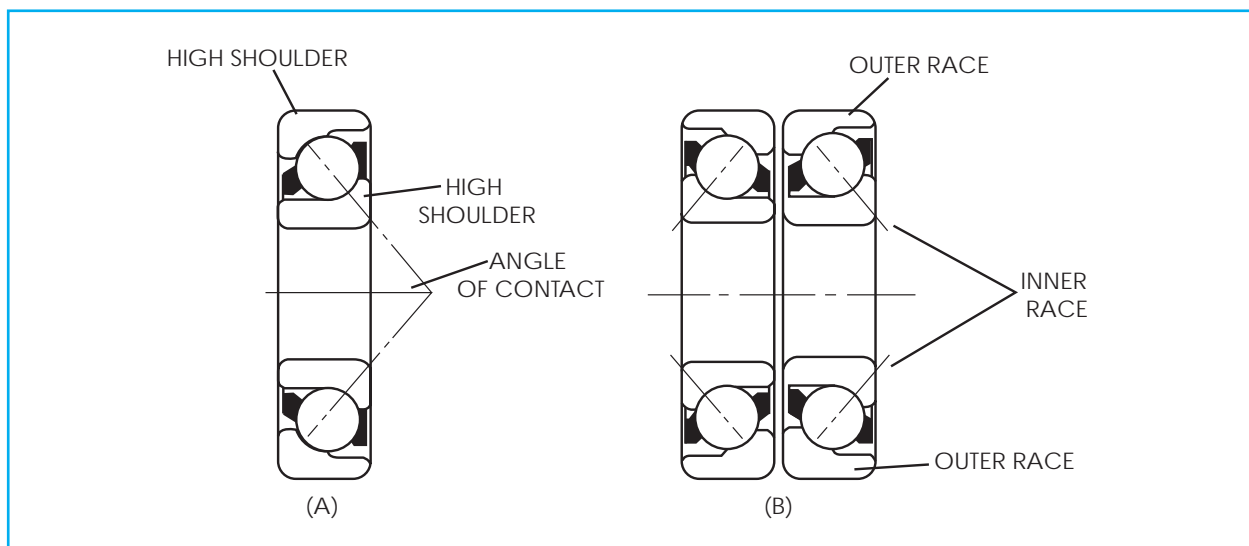


FIGURE 5—(A) shows the angle of contact in an angular-contact bearing, while (B) shows two angular-contact ball bearings.

causes the balls to contact the raceways at an angle. The shoulders hold the balls in place and allow them to be supported at the required angle.

Angular-contact ball bearings can support thrust loads in only one direction. Therefore, to provide bi-directional axial support, two of these bearings should be mounted with contact angles opposed (Figure 5B). Angular-contact bearings are available with several different contact angles for use in various applications.

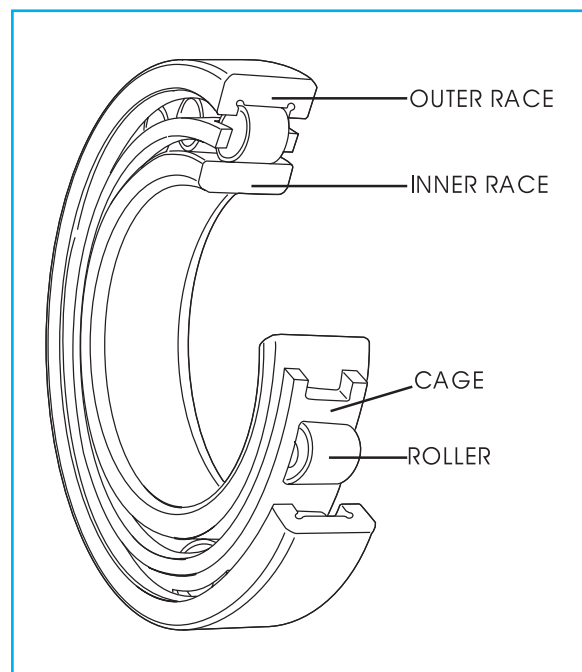
Roller Bearings

Another type of antifriction bearing is the *roller bearing*. Roller bearings come in many varieties. The rollers can be set with their axes parallel to or at an angle with the shaft. Rollers can have a constant diameter along their entire length, be tapered, or have a more spherical shape. They can be set in one row or multiple rows between the bearing's races. It's important to know how to differentiate between types of roller bearings and to understand why one type is best suited for a specific application.

Cylindrical-Roller Bearings

A *cylindrical-roller bearing* is shown in Figure 6. This bearing has a series of cylindrical-rollers between the outer race and the inner race. Cylindrical-roller bearings are available in a vast number of sizes and designs. The diameter of each roller is the same along its entire length.

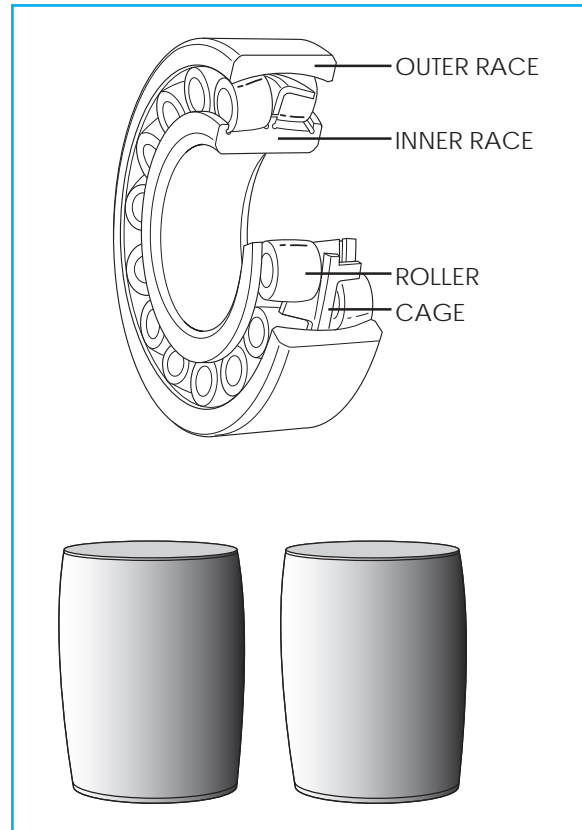
FIGURE 6—A Cylindrical-Roller Bearing (Courtesy of NTN Bearing Corporation of America)



The roller's ideal length and diameter depend on the application. The cylindrical-roller bearing can support large radial loads with very little friction.

Unlike cylindrical-roller bearings, the *spherical-roller bearing* has a rolling element with a diameter that isn't constant along its length. Figure 7 shows an example of the rolling elements found in a spherical-roller bearing.

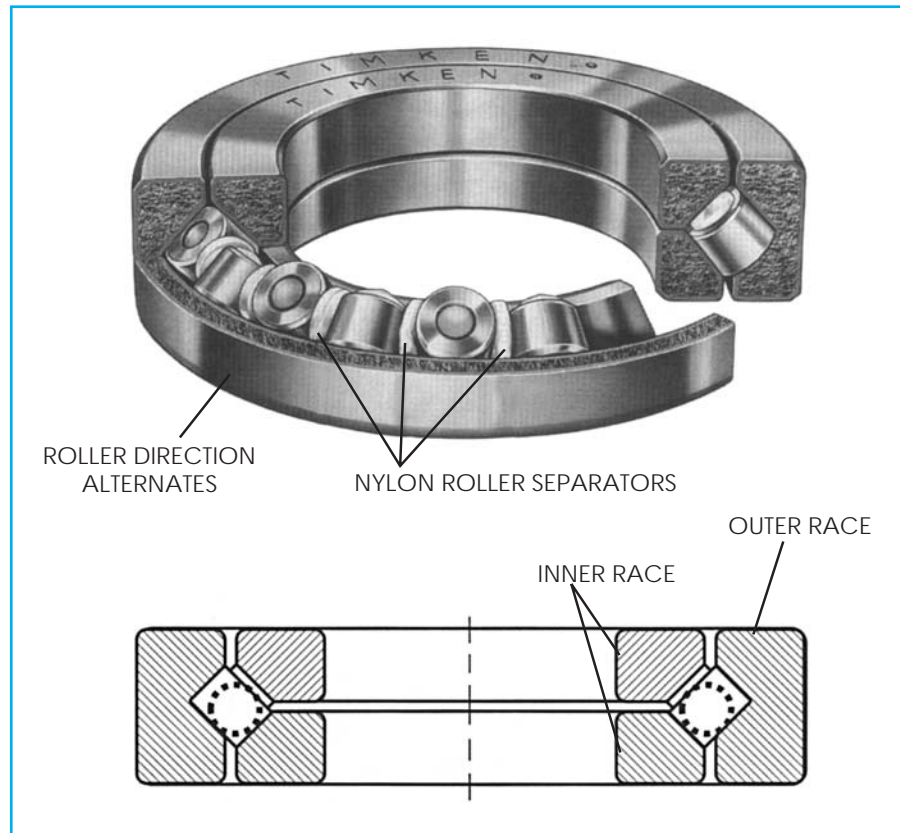
FIGURE 7—Note the shape of the rolling element in a spherical-roller bearing.
(Courtesy of NTN Bearing Corporation of America)



Crossed-Roller Bearings

The *crossed-roller bearing*, shown in Figure 8, has rollers arranged so that the centerlines of adjacent rollers are positioned at ninety degrees to each other. In addition, each roller is separated from its neighboring rollers by nylon spacers. These crossed rollers function and provide the same amount of support as two single-row bearings.

FIGURE 8—A Crossed-Roller Bearing (Courtesy of The Timken Company)

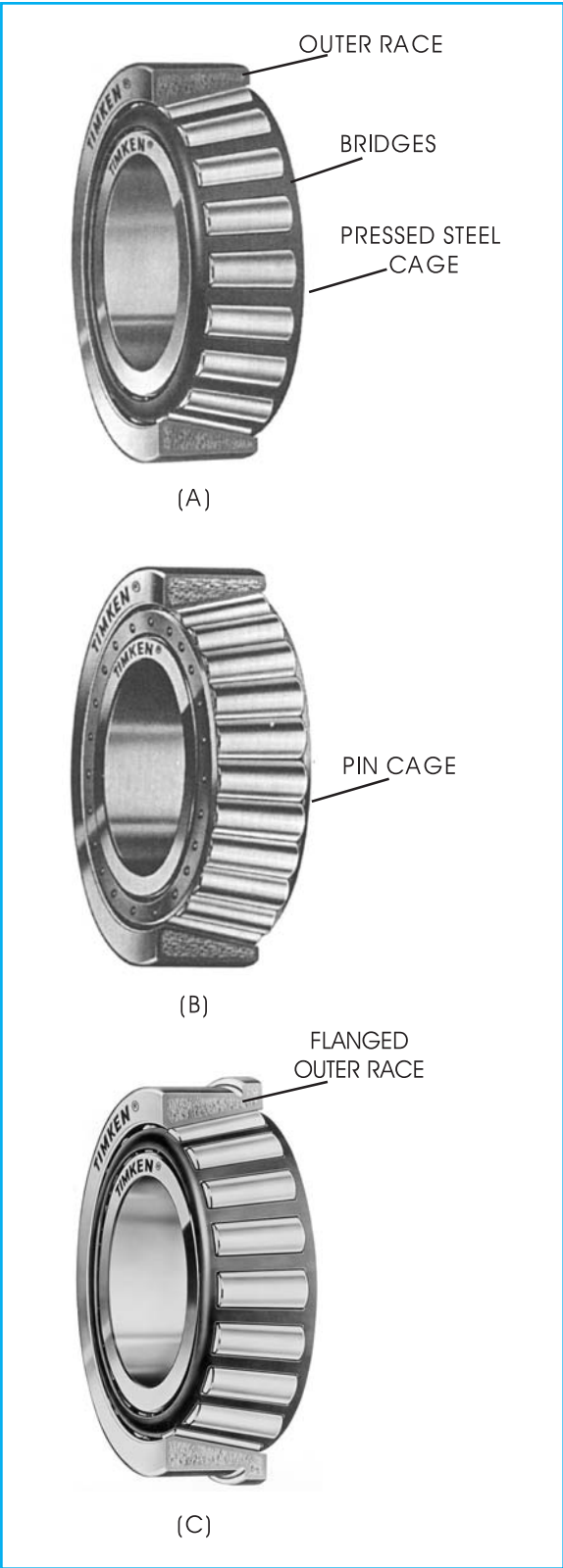


Tapered-Roller Bearings

The edges of rollers in some antifriction bearings form an angle to the bearing's centerline, as shown in Figure 9. This type of antifriction bearing is known as a *tapered-roller bearing*. The rollers in a tapered-roller bearing are normally cylindrical but can have diameters that vary along their length. Notice the steel cage surrounding the rollers in Figure 9A. This cage includes bridges that keep rollers separated and prevent the rollers from moving off their axis. Figure 9B shows a tapered-roller bearing with a needle cage. This cage design incorporates a pin, which runs through the center of the roller. In this case the cage doesn't surround the roller. The roller spins on the needle. Figure 9C shows a tapered-roller bearing that includes a flanged outer race.

A tapered-roller bearing can support a heavier load than a cylindrical-roller bearing of the same size. Tapered-roller bearings can support radial loads, thrust loads, and combination loads. In many shaft installations, one or both ends of a shaft are supported by a single tapered-roller bearing. However, when larger loads are involved, you'll often find a pair of these bearings located at one end of the shaft. When two tapered-roller bearings are used together, the other end of the shaft is supported with a ball or cylindrical-roller bearing.

FIGURE 9—Three Styles of Tapered-Roller Bearing
(Courtesy of The Timken Company)



Tapered-roller bearings are also available with multiple sets of rollers. The one shown in Figure 10, called a *double-row tapered-roller bearing*, has two sets of rollers. This type of bearing can contain up to four rows of rollers set at varying angles. The bearing's load-carrying capacity varies depending on the number of rollers and the angles at which they're set. These bearings contain a lubrication hole at their center to allow the flow of lubricant into the lubricant groove located between the rows of rollers.

FIGURE 10—A Double-Row Tapered-Roller Bearing (Courtesy of The Timken Company)

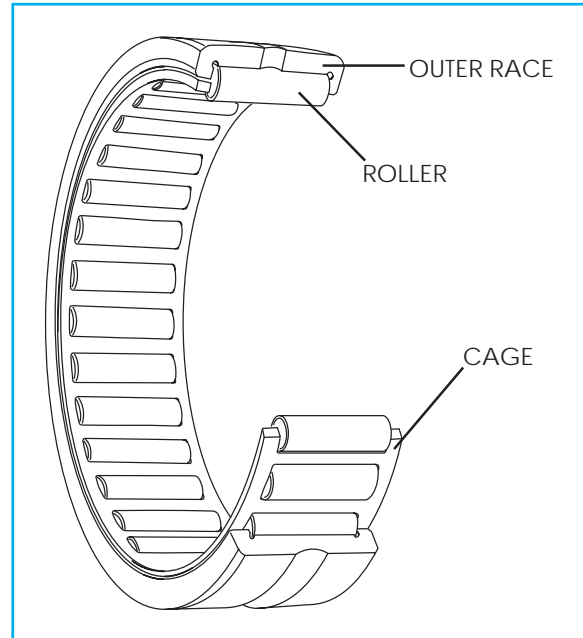


Needle Bearings

A *needle bearing* is a type of cylindrical-roller bearing with long needle-shaped rollers. The length of each needle is at least four times its diameter. As shown in Figure 11, the needle bearing consists of an outer race and a number of needles retained by a cage. The shaft on which the bearing is mounted acts as the inner race.

The bearing shown in Figure 11 can support only radial loads. When supporting thrust loads, specially designed needle-thrust bearings are used. Needle bearings are normally less expensive than other types. Needle bearings also take up less space compared to other bearings capable of carrying similar loads. You'll encounter conventional needle bearings in those installations that tolerate very little rotational resistance but offer no axial loading.

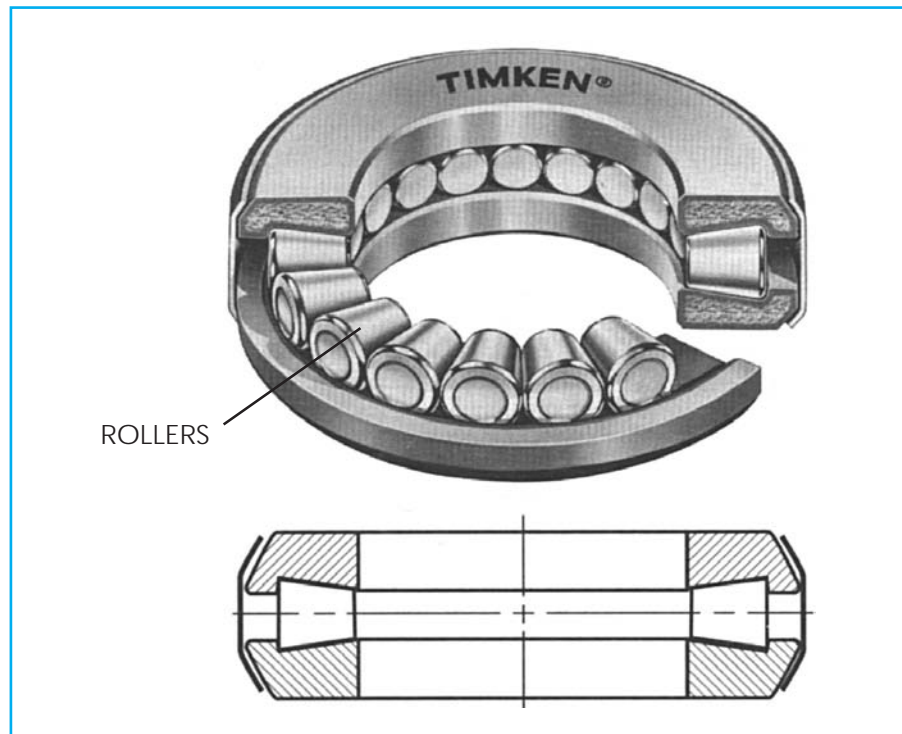
FIGURE 11—A Needle Bearing (Courtesy of NTN Bearing Corporation of America)



Antifriction Thrust Bearings

While many of the antifriction bearings you've learned about thus far are capable of absorbing radial or combination loads, there are also antifriction bearings made exclusively to absorb thrust loads. These bearings can incorporate ball or roller-type rolling elements. A roller-thrust bearing is shown in Figure 12.

FIGURE 12—A Roller-Thrust Bearing (Courtesy of The Timken Company)



Pre-mounted Antifriction Bearings

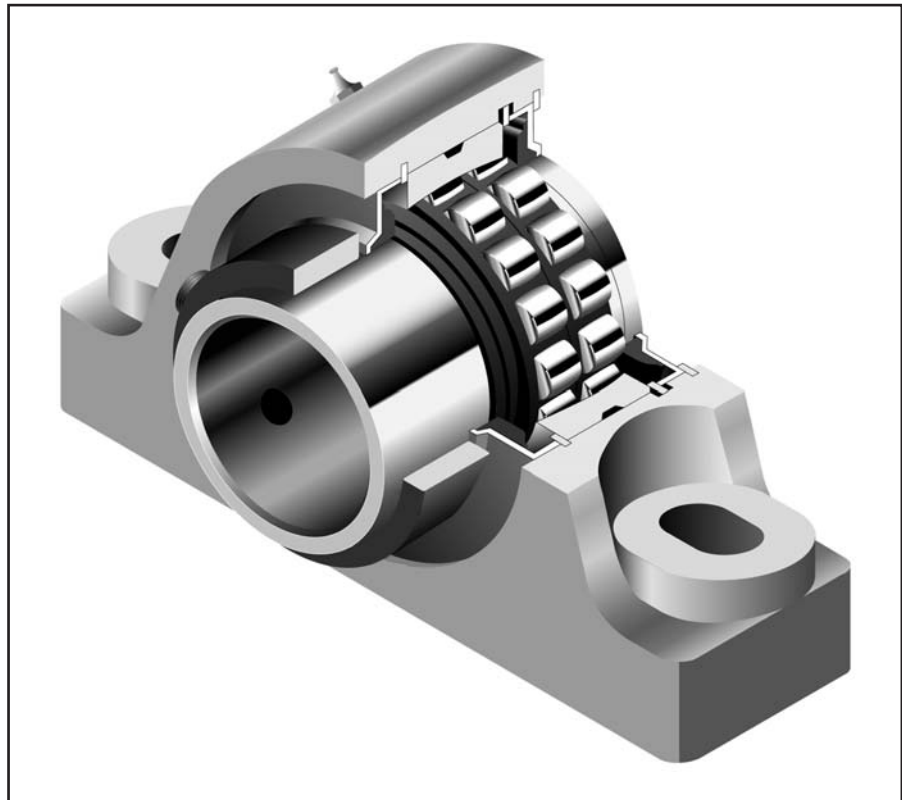
A *pre-mounted bearing* unit consists of an antifriction bearing contained in a suitable housing. The housing is then mounted to the machine. The housing has an oil reservoir (or grease fitting) and seals. The oil reservoir holds the oil needed to lubricate the bearing. If grease is used for lubrication, it's supplied to the bearing through a fitting. The seals keep the lubricant from leaking out of the housing and prevent dirt from entering the bearing. The housing has two or more mounting holes for bolting the unit onto a machine.

Solid Housing

A pre-mounted unit with a one-piece, or *solid housing*, is shown in Figure 13. The double-roller bearing is mounted in a housing made of cast iron, cast steel, or pressed steel. The mounting surfaces are machined to assure flat, true faces. A locking setscrew holds the bearing in position. Seals, which you'll learn more about later in this study unit, keep the lubricant in and foreign matter out of the bearing. Finally, two slotted mounting holes are used for bolting the complete unit to a foundation, machine frame, or other location.

Solid housings, which provide strong, rigid support, are best suited for installations where the bearings are mounted close to the end of a shaft. In these installations, the pre-mounted unit can be slid over the shaft's end.

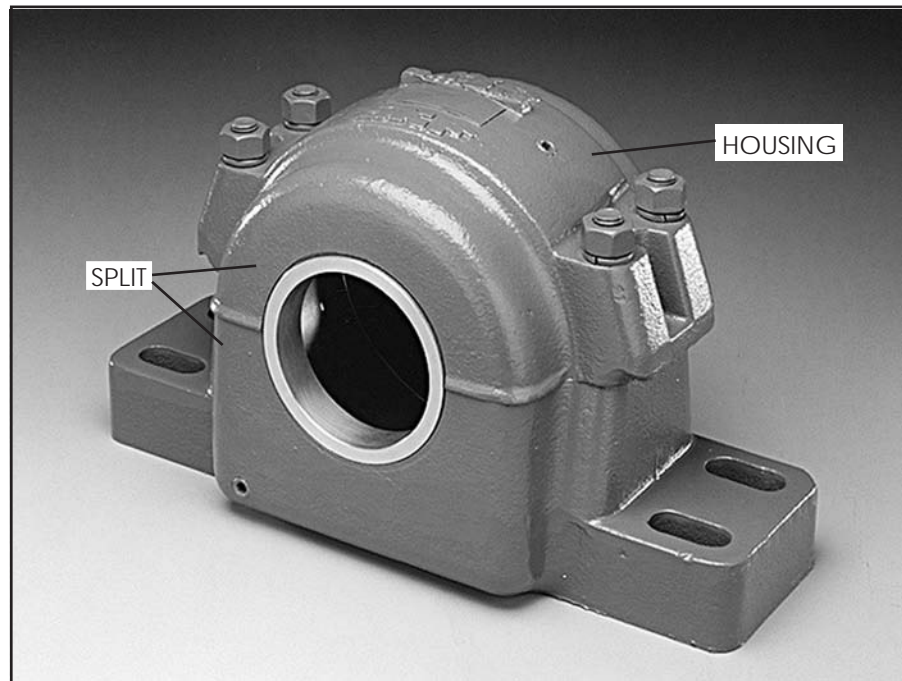
FIGURE 13—Pre-mounted Roller Bearing (Photo Courtesy of SKF USA Inc.)



Split Housing

A *split housing* is used when it's necessary to lift a shaft from a machine, normally for maintenance purposes. An example of a split-housing unit is shown in Figure 14. Note that the split in the housing is in a horizontal plane. Bolt-and-nut assemblies hold the two halves together. The upper half of the housing can be removed for inspection and disassembly purposes.

FIGURE 14—Pre-mounted bearings sometimes incorporate split housings for easier mounting and machine maintenance.
(Photo Courtesy of SKF USA Inc.)



Take-up Units

Take-up units, like the one shown in Figure 15, are used in applications that require lateral adjustment of the supported shaft. For instance, assume a take-up unit supports a shaft that's attached to a belt pulley. During normal operation the position of the bearing, and therefore the shaft's centerline, is locked into one position within the guide rails of the take-up unit. Releasing the bearing and moving it and the contained shaft laterally (within the unit) permits adjustment of slack in the belt. In Figure 15 the bearing is moved along the unit's guides by turning the adjusting nut. Turning the screw moves the bearing backward or forward. You'll find these units in conveyer systems (where the unit is secured to the framework of the conveyer) and chain-drive assemblies.

FIGURE 15—A Take-up Unit
(Photo Courtesy of SKF USA Inc.)



Non-metallic Bearings

Not all bearings are made of metal. Some are constructed of ceramic or plastic material. Because bearing material can vary widely, it's critical that the material be able to withstand the temperature, loading, and friction to which it will be subjected.

Bearings subject to high speeds must be able to withstand high temperatures. Recent developments in bearings have led to the use of ceramic materials to help improve bearing life. These ceramics can overcome the problems of thermal expansion, which may occur when the bearing temperature reaches extremely high levels. Ceramic ball and roller bearings also have better operating qualities that prevent the ball from slipping between the races. This slippage occurs as the ball is spinning within the races and begins to slide, rather than roll, over the race's surface. Slippage scars both the race(s) and the rolling element. Ceramic rolling elements are available with metal races and housings, or in bearings made entirely of ceramic materials.

Plastic bearings are used in the food and pharmaceutical production industries because they don't require lubricants. Lubrication could contaminate the material that's being produced. Of course, bearing material has a large effect on the applications for which it's suited and the bearing's life.

Self-Lubricated Bearings

Self-lubricating bearings contain rolling elements that are made of pressed metal. In the process of being manufactured, pressed-metal objects form a naturally porous surface. This surface allows lubricant to be impregnated or absorbed into the material, with the pores absorbing the lubricant. As the bearing begins to operate and its temperature rises, the lubricant thins and is released into the bearing. After the bearing's motion stops and the bearing cools, the lubricant is absorbed back into the bearing.

Applications of Antifriction Bearings

Antifriction bearings are available to absorb both radial and thrust loads. The type of rolling element determines the bearing's classification and, to some extent, its capabilities. Ball bearings carry lighter loads with less friction, while the roller types carry heavier loads and withstand high-impact shocks. The load-carrying capacity and some common applications of various antifriction bearings are given in Table 1.

APPLICATIONS OF ANTIFRICTION BEARINGS				
Type	Remarks	Radial Load	Thrust Load	Applications
Ball Bearing Types				
Single-row	Careful alignment necessary	Moderate	Moderate	Electric motors, automobiles, light machinery
Double-row	Lower axial displacement	Heavy	Moderate in either direction	Worm drives, pumps, centrifuges, spindles
Angular contact	Can be tandem-mounted	Moderate	Heavy, one direction	Worm drives, pumps, centrifuges, spindles
Self-aligning	Adjust for slight misalignments	Heavy	Moderate	Woodworking machines, small hammer mills, fans, centrifuges, pillow blocks
Thrust	Not for high speeds unless loaded heavily	None	Heavy	Crane hooks, machine tool spindles
Roller Bearing Types				
Spherical	Inherently self-aligning	Heavy	Heavy in either direction	Steel, paper, and rubber mill equipment crushers, railway journals, fans, blowers, pumps, compressors, pillow blocks
Cylindrical	Accurate guiding of rollers; true rolling friction	Heavy	Little	Traction, motors, transmissions, shafts, spindles, engines, turbines
Tapered	Multiple rows for very heavy thrust loads	Heavy (when used with another bearing to take induced thrust load)	Heavy	Automobiles, mine cars, steel mill equipment, journal boxes, pumps, gear drives
Spherical thrust	Compact; self-aligning	Moderate	Heavy	Worm drives, steel mill equipment, pumps, turntables, water turbines

Now, before you continue your studies, take a few moments to complete *Self-Check 1*.



Self-Check 1

At the end of each section of *Bearings and Seals, Part 2*, you'll be asked to pause and check your understanding of what you've just read by completing a "Self-Check" exercise. Writing the answers to these questions will help you to review what you've studied so far. Please complete *Self-Check 1* now.

Complete the following statements with the correct answer.

1. A(n) _____ bearing uses rolling motion to reduce friction.
2. A(n) _____ - _____ ball bearing can carry a heavy thrust load in one direction.
3. The lubricant for a pre-mounted bearing is held in a(n) _____ .
4. The rollers of a crossed-roller bearing are separated by _____ .
5. In a tapered-roller bearing, _____ separate the rollers.
6. _____ bearings are used in food-production equipment.
7. A(n) _____-roller bearing has rollers positioned so that each roller's centerline intersects its neighboring roller's centerline at a right angle. This design allows a bearing to support a heavier load while occupying less space.

Check your answers against those on page 61.

ANTIFRICTION BEARING REPLACEMENT

No matter how much care is taken to extend the life of a bearing, all bearings will eventually fail. Therefore, it's important not only to understand how a bearing works but also to know how to replace a failed bearing.

There are many steps required to properly replace a bearing. First, a replacement bearing must be obtained. To be sure that the correct replacement is available, you must know how bearings are classified. In many cases, the repair technician is responsible for selecting the correct replacement bearing for an existing installation. The installed bearing must then be removed without further damaging the bearing, shaft, or housing. The removed bearing should initially be cleaned and inspected for obvious faults related to installation, lubrication, or corrosion problems. In the same manner, the housing and shaft should be checked for damage or excessive wear that could immediately harm the replacement bearing. Depending on the installation and shop practices, a more detailed inspection of the removed bearing may follow.

Next, when applicable, the shaft, housing, and replacement bearing will be measured to ensure the correct fits and clearances. Because technicians need to understand the terms *fit*, *clearance*, and *tolerance* to properly size and install bearings, these terms will be discussed in the following section. Finally, the replacement bearing must be correctly handled and installed. Improperly installed bearings won't reach their expected service life. Antifriction bearing removal and installation techniques differ depending on the specific bearing type and installation. Later in this section you'll learn about the general procedures to be followed when installing an antifriction bearing.

Antifriction Bearing Classifications

Bearings are classified with various letters that represent a specific characteristic or type. Most bearing manufacturers have their own system for classifying bearings according to the bearing's physical characteristics and load-carrying capacity.

The method for ordering a bearing varies from one manufacturer to another. It's important to become familiar with bearing classifications to be sure you're installing the correct type and size. A typical classification system, described in terms of bearing part number codes, is shown in Figure 16. The classification system shown in Figure 16 identifies physical features and dimensional characteristics in a bearing's part number. Physical features identified by the part number include material type, design style, and the shape of the cage and seal. Dimensional characteristics identified include internal clearance and

dimensional tolerance. In this particular manufacturer's classification system, the lubricant in which the bearing is packed is also identified.

The codes used for ordering bearings may seem confusing. However, once you're familiar with the various characteristics of antifriction bearings, it will be easier to understand different manufacturer's codes. Figure 16 shows one specific identification system. One bearing manufacturer may use different identification codes for different product lines. For instance, identification codes may include an indication of bore diameter, ring modifications, and internal design features.

Clearance and Tolerance

Clearance and tolerance are terms frequently associated with bearing design and use. *Clearance* refers to the empty space between components in an assembly after they've been installed. There are two ways in which the term clearance can be applied to antifriction bearings. First, the fit between the bearing's inner race and the shaft is defined in terms of clearance. If the bearing's inner race must be forced or pressed onto the shaft, this fit is called an *interference fit*. If the bearing slips into a housing, for instance, without the need for force to be applied, this fit is known as a *loose fit*.

Internal clearances refer to the spaces within a bearing and are generally designed into a bearing assembly to allow for lubrication, friction reduction, and thermal growth. *Thermal growth* occurs when the heat produced by the bearing action causes the bearing materials to expand. Internal clearance in an antifriction bearing is set during the manufacturing process and, with a few exceptions such as a tapered-roller bearing's axial clearance, can't be adjusted. At times, a bearing system that requires exceptionally rigid support includes a *preloaded bearing*. Preloaded bearings are those assemblies built without internal clearance. *Tolerances* are quantities that represent how closely actual dimensions are to stated dimensions. For instance, a specified clearance of 0.002 inch may have allowable tolerances of plus or minus (\pm) 0.0001 inch (one ten-thousandth of an inch). This means that the actual clearance is expected to vary between 0.0019 and 0.0021 inch.

All bearing manufacturers publish detailed installation and engineering information for their product. These usually include the recommended class of fit and other important data to help you in replacing and interchanging the bearings of one manufacturer with those of another. Never replace a bearing without first reviewing the equipment and/or bearing manufacturer's information to be sure you've selected an acceptable replacement.

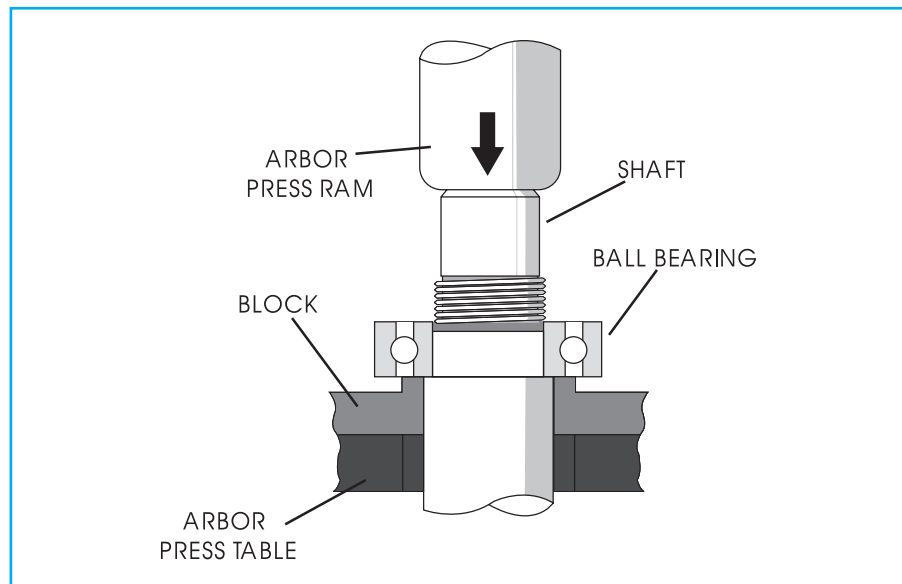
Bearing Fit

When referring to bearings, the term *fit* describes the degree of tightness between a bearing and its supported shaft or containing housing. A tight fit is known as an interference fit because material from the two mating parts would normally interfere between the bearing's inner diameter and the shaft it supports. Plain bearings are generally held firmly in a housing by an interference fit while the shaft is allowed to rotate loosely within the bearing bore. In most antifriction bearing applications, however, the inner race is fitted tightly on the shaft, and the outer race, if stationary, is held tightly within the housing. Thus, as only the rolling elements allow the shaft to turn with respect to the housing, only rolling friction is present. As you already know, when all other factors are equal, rolling friction offers much less resistance to motion than sliding friction.

Methods for Mounting Antifriction Bearings

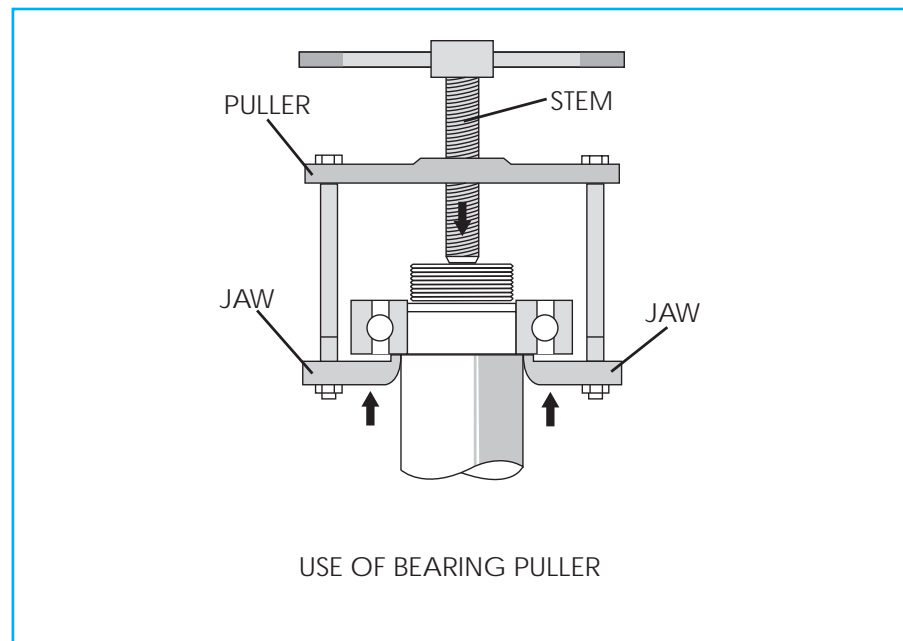
Bearings are removed and installed in different ways, depending on the fit between the bearing and mating component. For instance, if there's a loose fit between a bearing and its housing, no force is needed to separate the two. More often, however, the fit between the bearing and shaft will be a tight one, as will be the fit between the bearing and housing. The tightness of fit obviously increases the force required to assemble the parts. Also, as the bearing diameter increases, the assembly force increases. A large bearing requires more force, for a given tightness of fit, than a smaller bearing. When a tight fit exists, the mounting or disassembly force required determines the tooling required. Figure 17 shows an arbor press being used to remove this type of bearing.

FIGURE 17—Use of an Arbor Press



Whenever mounting or removing an antifriction bearing, the most important consideration is that none of the mounting or removal forces be transmitted through the bearing's rolling elements. This means that if a bearing's inner race is to be installed on a shaft, the force used to form this assembly must act only against the inner race. Refer to Figure 18 for an example. Applying this force to the outer race or other part of the bearing (such as the cage) allows the force to act through the rolling elements, ensuring that the bearing's effective life will be greatly reduced. All mounting force should act on and be isolated to whichever bearing race is involved in the tight fit.

FIGURE 18—When removing this bearing from the shaft, be sure to direct all removal force against the inner race.

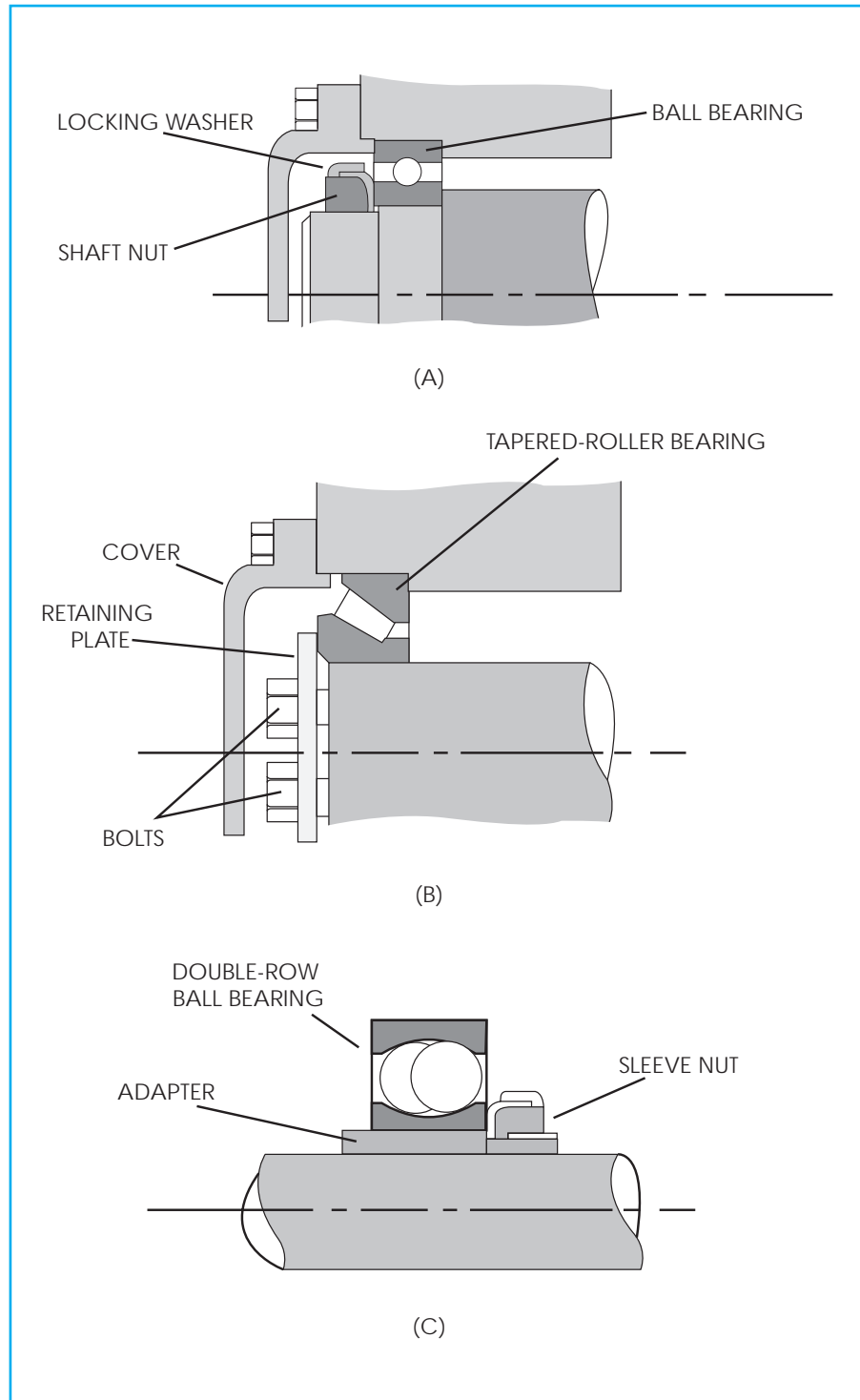


There are many common mounting designs, some of which are shown in Figure 19. The locking washer and shaft nut combination that's very popular for bearings carrying radial loads is shown in Figure 19A. Bearings supporting the shaft's end are sometimes mounted using self-locking bolts that are safety wired for additional security. Of course, the mounting configuration shown in Figure 19B relies on a shoulder in the housing to retain the bearing. When no housing feature fixes a bearing's axial mounting position, an adapter sleeve, like the one in Figure 19C, can be used. In this case, the supported bearing is a tapered-bore double-ball bearing. The wedge-shaped interface between the bearing's bore and the angled adapter sleeve locks the bearing in place as the sleeve nut is tightened.

Hot-Mounted Bearings

There are two general classifications of antifriction bearing assemblies: cold mounted and hot mounted. *Hot-mounted* assemblies are ones that rely on thermal expansion. For instance, suppose that there's an

FIGURE 19—Shown here are various mounting designs.



interference fit, signifying that the bearing's inner diameter is actually smaller than the shaft's outer diameter. Also, assume that the machine's maintenance manual specifies that this tight fit must be accomplished by applying heat to the bearing so that its diameter increases. A manual typically specifies the temperature to and duration for which the bearing should be heated. If the bearing is then

installed over the shaft and allowed to cool, the fit between the contracted bearing and shaft will be very tight. Previously, bearings were heated in a hot oil bath. Now most bearings are heated using either an electric hotplate or an *induction heater* like the one shown in Figure 20. An induction heater conducts electricity around the bearing. Current flows through the bearing, and the bearing heats. This process ensures that the bearing is evenly heated in a controlled manner. Part of the induction heating process causes the bearing to become magnetized, however, and the bearing must be demagnetized before being put into service. Be sure you understand the limitations and proper operation of the device you're using to heat a bearing.

Open flames, such as those produced by a torch, should never be applied to a bearing. Distortion and localized cracking can occur when using an improper heat source. Also, oil baths, electric hotplate heaters, and some induction heaters shouldn't be used to heat a bearing that contains shields or seals. While exact target temperatures and

FIGURE 20—Bearings can be heated with an induction heater to ensure uniform and highly controlled thermal growth.
(Photo Courtesy of SKF USA Inc.)



durations vary, most hot-mounting assemblies as well as removal processes call for the bearing to be heated to about 150 degrees Fahrenheit (83.3°C) above the temperature of the mating shaft. Normally, however, bearings shouldn't be heated above 230 degrees Fahrenheit (110°C) because temperatures above this may change the bearing's material properties. In some cases, the tightness of fit in an assembly will be so great that the bearing must be heated while the shaft is artificially cooled using either a freezer or dry ice.

Cold-Mounted Bearings

Tight-fit assemblies between bearings and shafts or bearings and housings can also be accomplished using cold-mounting methods. *Cold-mounted* assemblies are ones that take place when neither of the mating parts is heated or cooled. Types of tooling available, bearing size, the fit's degree of tightness, and the installation all factor together to determine how a cold-mounted bearing must be installed or removed. Of course, if a maintenance manual exists for the machine on which you're working, then you should always use the recommended tooling and mounting methods.

Mounting dollies and sleeves are often used in conjunction with a dead-blow hammer or an arbor press to mechanically seat a bearing's outer ring into a housing, or a bearing's inner diameter over a shaft. These devices, which are shown in Figure 21, rely on direct force to mate the components. As you can see in the figure, a dolly is used to cold mount a bearing into a housing while a sleeve is used to install it over a shaft. As discussed earlier, the most important consideration with any mounting method is that the mounting force not be transmitted through the bearing's rolling elements. All mounting forces should act on and be isolated to the bearing race that's involved in the tight fit.

Bearings can also be installed or removed using hydraulic pressure. Oil injection systems rely on a pressurized supply of oil, which is directed through ducts in the shaft to act on the inboard surface of a bearing. The outward force on the bearing, resulting from the pressurized oil, increases the bearing's diameter and allows the installation or removal to take place. This system is shown in Figure 22.

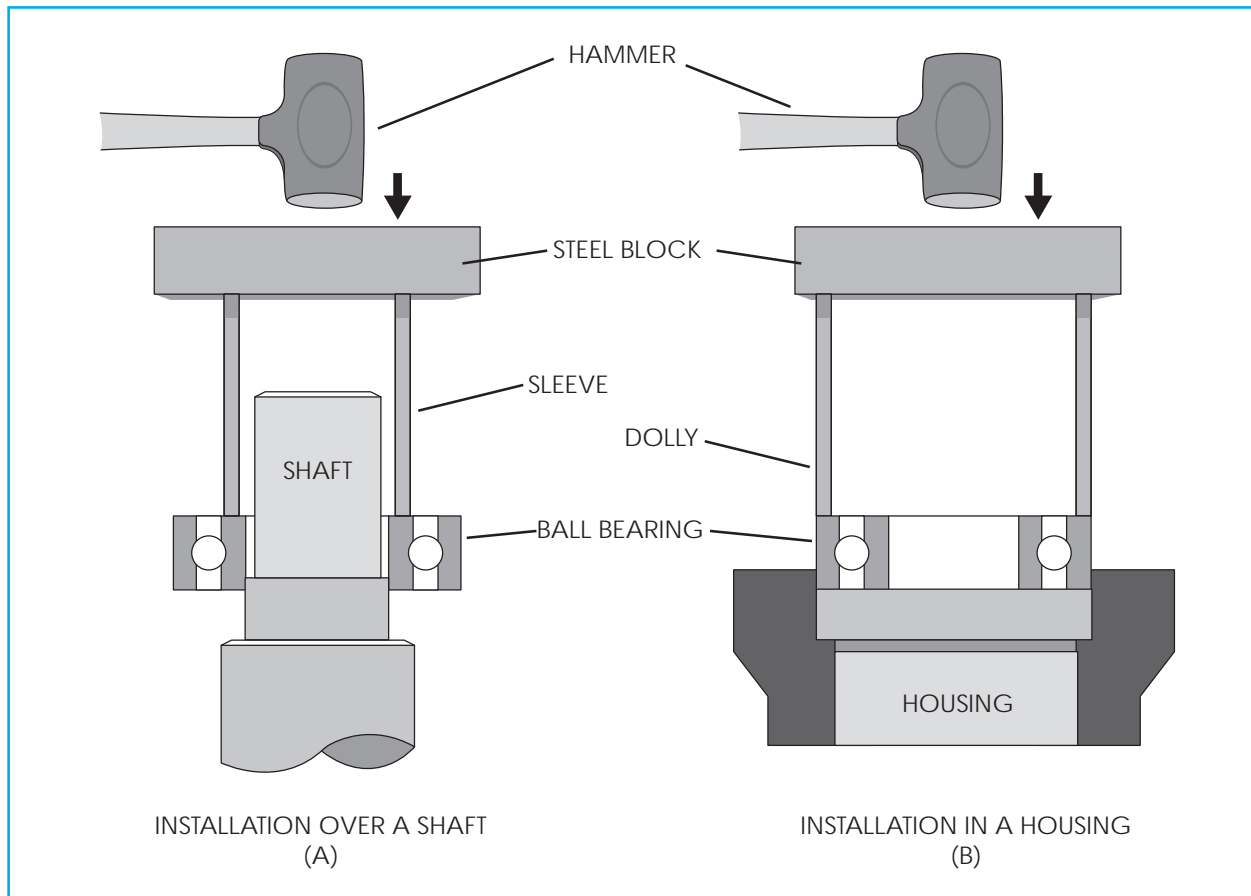


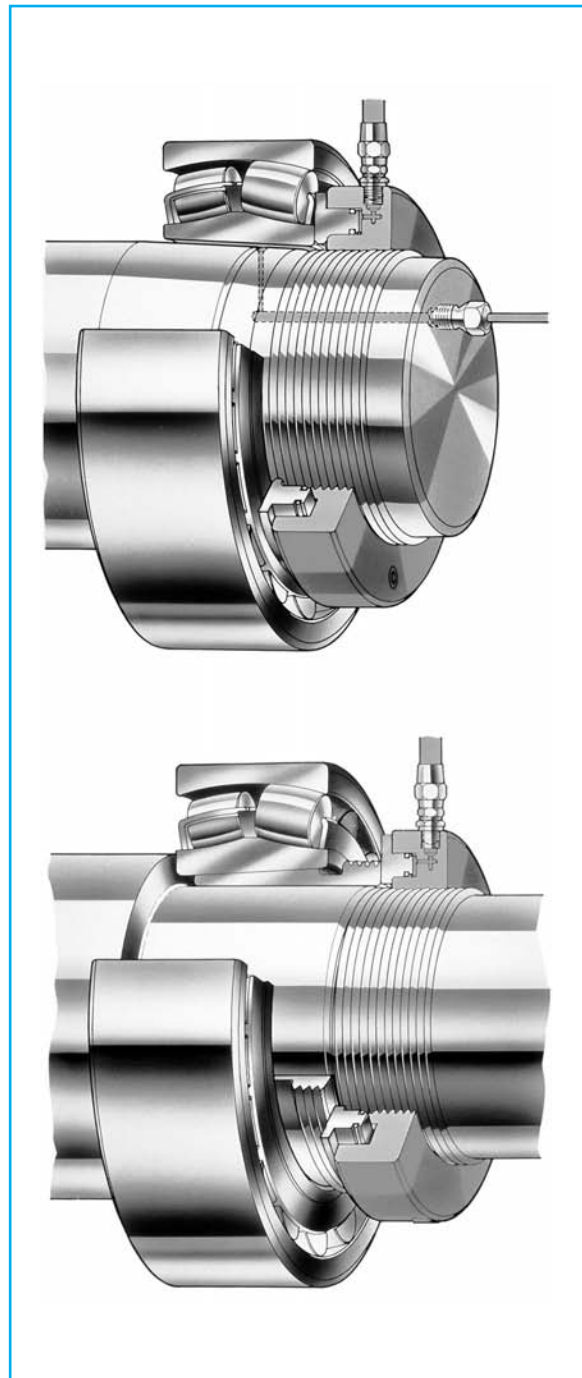
FIGURE 21—Dollies and sleeves are used to assemble bearings (A) onto shafts and (B) into housings.

Installation Practices

When selecting a bearing for a particular application, it's important to make sure that the materials are strong enough to hold the load it will be carrying. All materials have a certain amount of *resilience*. This term refers to the bearing's and shaft's ability to withstand changes in their original shape. If the shaft is too hard for the bearing material, then the bearing will fail. Similarly, if the bearing is too hard for the shaft, then damage to the shaft will occur. Properly combining bearing and shaft materials is an important step in designing mechanical equipment. It's equally important that a maintenance technician install a bearing made of the specified material when replacing an existing bearing.

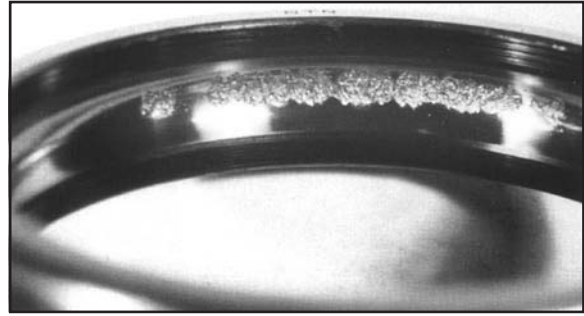
Proper handling also affects the life of the bearing being installed. Figure 23 shows an example of damage that occurred to a bearing that was handled improperly. Once installed, improperly handled bearings fail prematurely. Normally, you don't need to clean a new bearing before installation. It's already clean when you receive it from the factory. *Slushing oil*, or prelubricant, protects the bearing. This

FIGURE 22—Using pressurized oil, the hydraulic mounting system installs or removes a bearing.
(Photo Courtesy of SKF USA Inc.)



substance doesn't normally need to be removed. Slushing oil is designed so that it won't interfere with the bearing even after it has been installed. However, it's necessary to remove this compound before installation if the compound has become hardened or dirty. Also, as you learned earlier, bearing manufacturer's specifications typically indicate the type of prelubricant with which a bearing is provided. As long as the specified prelubricant is compatible with the lubricant found in the machine in which the bearing will be installed, there's no need to remove it.

FIGURE 23—This damage, known as flaking, occurred after an improperly handled bearing was installed. (Courtesy of NTN Bearing Corporation of America)



A bearing must be installed carefully with the correct tools. Using an incorrect or damaged tool may cause damage to the bearing. Figure 24 shows an example of what happens to a bearing when it's installed incorrectly. It's also important to use gloves when installing a bearing because dirt or oil from your hands can cause damage to the bearing.

FIGURE 24—This damage was caused by poor installation. (Courtesy of NTN Bearing Corporation of America)



Before installing the bearing, the shaft must be checked for high spots or rough spots. If rough or high spots are found, they must be removed with a scraper. If, on the other hand, the shaft is worn, it may need to be replaced or material may need to be added, through a plasma spray or similar process, then re-machined. The shaft and housing should also be cleaned thoroughly. The shaft and bearing should be carefully checked for misalignment, as shown in Figure 25. The support for the bearing housing, or the part of the machine to which the bearing will be mounted, should be checked to ensure its surface is flat. If the surface isn't flat, then the bearing may not line up correctly, causing uneven wear and premature failure.

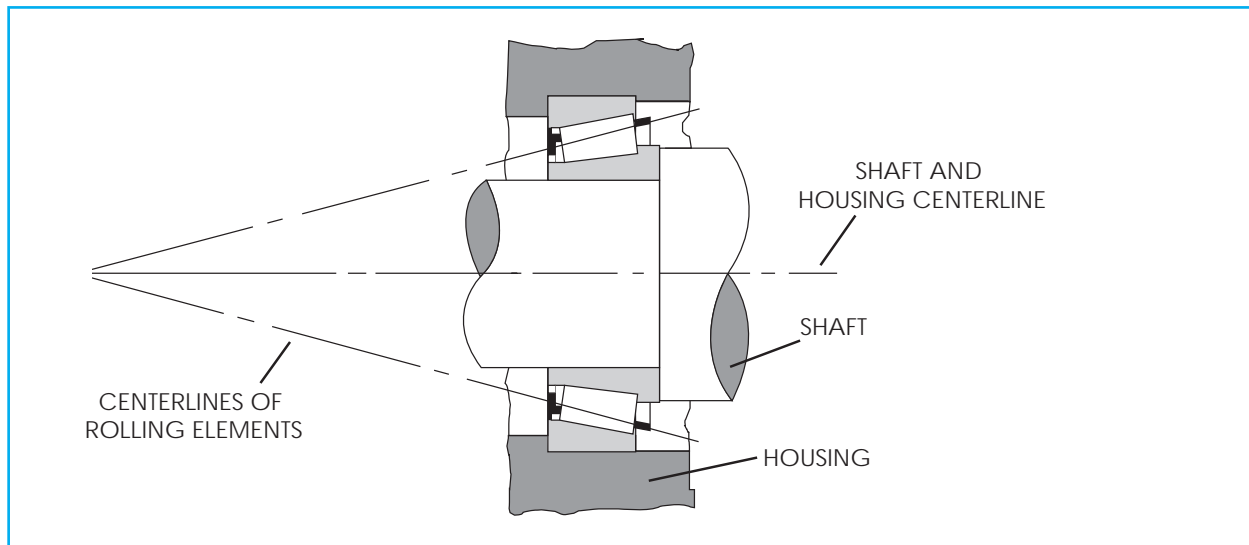
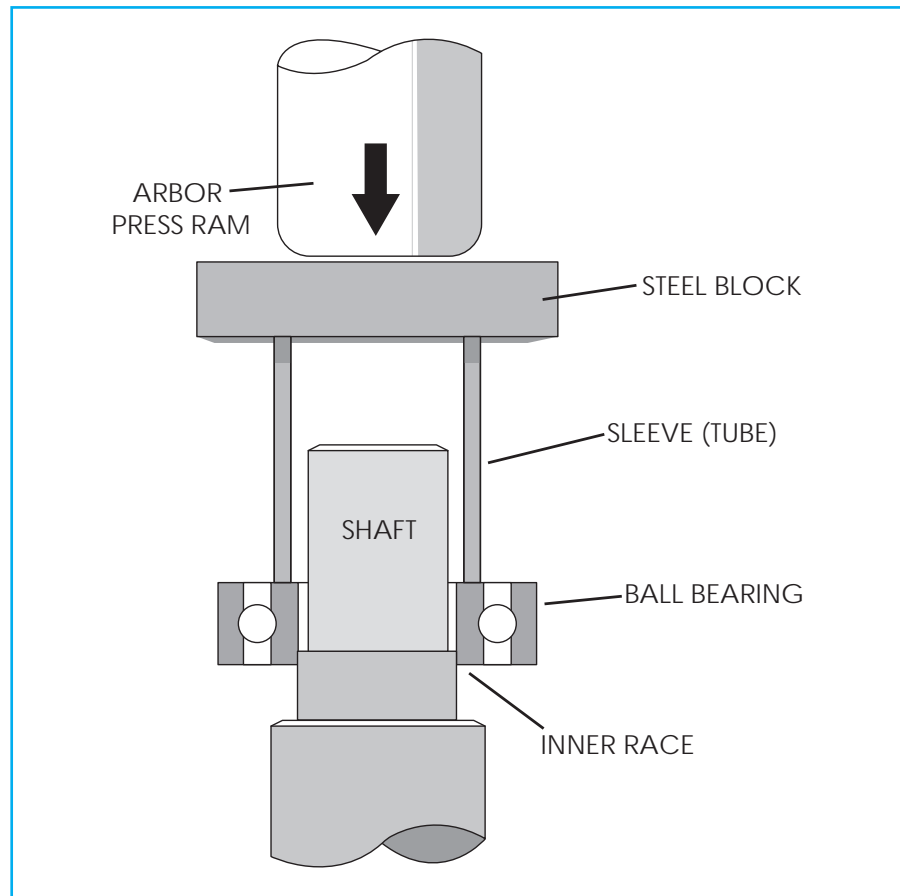


FIGURE 25—Bearing, shaft, and housing centerlines must align for maximum bearing service life.

There are several different installation techniques for antifriction bearings. As you've already learned, antifriction bearings are most often mounted tightly over the shaft they support. Of course, there are many cases where mounting is different than this. Specific mounting procedures are beyond the scope of this study unit. However, you've already learned about the range of hot and cold mounting procedures available. This section of your study unit describes a typical cold-mounting procedure.

Where the inner ring of the antifriction bearing is pressed over a shaft, a small amount of lubricant should be applied to the interface of the shaft and the bearing. When following the proper method for installing a single-row bearing, only the bearing race involved in the interference fit is directly acted on. At no time are the assembly forces allowed to act on the rolling elements or cage. For instance, when installing a bearing onto a shaft, a tube can be placed on the inner race of the bearing, and a steel block on the tube. A dead-blow hammer provides the force needed to mate the bearing onto the shaft. Note that neither brass hammers nor wooden mallets should be used for this procedure because soft metal or wooden chips can contaminate the bearing assembly. This force should be applied straight and square to evenly drive the bearing down over the shaft. Apply the force until the bearing is securely seated on the shaft. In some installations, an arbor press supplies the mounting force as shown in Figure 26.

FIGURE 26—An arbor press can be used to install a bearing over a shaft.



The proper method of installing a single-row ball bearing into a housing is similar to that shown in Figure 26 except that the tube rests on the outer race. Be sure to select the proper tube. For the installation of a bearing over a shaft, the tube diameter should allow the tube to be mounted on the inner race. For installation in a housing, the tube size should be large enough for the tube to be mounted over the bearing's outer race.

Always visually (and, if possible, dimensionally) inspect the bearing, shaft, and housing after installation. Inspection allows you to ensure that all components are properly aligned.

Removal of Antifriction Bearings

You'll sometimes remove bearings from a machine that's shut down for maintenance, repair, inspection, or cleaning. On such occasions, you should be extremely careful and use only the right tools and procedures. The tools you use for bearings should be used only for this purpose. The tools should always be free from burrs, contamination,

and other flaws that could harm bearing or mating surfaces. Whether the removed bearing will be refurbished or discarded, treat all bearing removals as if the bearing will be reused. If you follow this approach, you'll always be able to inspect the removed bearing for signs of damage that occurred during installation or operation. Armed with this knowledge, you can address potential problems before the new bearing is subjected to the same damaging factors.

First, take a few minutes to examine the bearing assembly. Such an examination will help you to decide on the method of removing the bearing. A common method of removing a bearing from a shaft is shown in Figure 27.



FIGURE 27—Careful removal of antifriction bearings is important. Here a bearing puller is used. (Photo courtesy of SKF USA Inc.)

The proper method of removing a bearing with a puller is shown in Figure 27. Two jaws are attached to the ends of the puller. The jaws grip the bearing's inner race because this is the bearing race that's tightly fitted to the mating part, the shaft. The puller stem is placed against the center of the shaft. As you turn the handle, the stem exerts an axial force on the shaft while the two jaws exert an equal but opposing force on the bearing. This opposing force pulls the bearing off the shaft.

When using the arbor press, place a block between the bearing and the table of the press to prevent the bearing from moving with the shaft. Then, bring the ram of the press squarely over the end of the shaft. As you lower the ram, the shaft will be pushed out of the bearing. As shown here, be sure that whatever is supporting the bearing can act

only on the race that's joined in a tight fit with the mating part. It's a good practice to be sure that the bearing elements and cage turn freely as the mounting or removal force is applied to one of the bearing's races. As long as the other components move freely, you know that the applied force isn't acting on the rolling elements.

As you already know, some mounting methods employ shaft nuts and, at times, an adapter sleeve. These nuts are most often installed and removed using a spanner wrench, as in Figure 28, or an impact wrench. Installations that rely on spanner wrenches are usually limited to smaller bearings with eight inches or less of bore diameter.

FIGURE 28—Spanner wrenches are often used to install and remove shaft nuts. (Photo Courtesy of SKF USA Inc.)



Cleaning Antifriction Bearings

When an antifriction bearing is removed from a machine, it's most often replaced with a new bearing. However, specialized or exceptionally large bearings may not be replaced unless they're found to be defective, or have outlived their rated service life. Bearings that will be reused, and those that will be inspected after removal, must be carefully cleaned.

Once removed, bearings that aren't permanently sealed should be cleaned with a commercial cleaning fluid, such as the type found in a parts-cleaning tank. Bearings should never be cleaned with water, water-based cleaning fluids, or steam, as the bearing material will quickly oxidize. Be sure to practice all required safety procedures and to wear the correct personal protective devices when working with cleaning solvents. Once cleaned, the bearings can be blown dry using shop air. There are three important cautions that apply to this practice. First, never direct pressurized air at your bare skin. Second, be sure that all water has been removed from the shop air in your workplace, as this water will not only corrode the bearings you're drying but also harm pneumatically powered equipment and tools. Third, hold the bearing, as shown in Figure 29, to direct the flow of drying air along the length of the rolling element. Under no circumstances should the bearing be allowed to spin under the force of the compressed air. Spinning the bearing in this manner could cause it to fail catastrophically, launching bearing fragments into the surrounding area.

FIGURE 29—When using pressurized air to clean a bearing, be sure that the bearing isn't allowed to spin.



As a summary, be sure to follow these procedures when cleaning a bearing prior to inspection:

1. Always clean a bearing before judging its condition.
2. Don't allow a bearing to spin before it's been cleaned. The action could cause dirt trapped in the bearing to scar its surfaces. Rotate it slowly while washing it.
3. If the bearing is to be cleaned with compressed air, then hold both races in your hand to avoid spinning. Spinning a dirty bearing will allow dirt trapped between the races to damage the bearing's surfaces. Be sure to use a clean, dry air source.
4. Be sure that the solvent containers are clean. Allow the dirty bearing to soak in a solvent container until grease and dirt are loosened. (This may take several hours.) After soaking, slosh the bearing around near the top of the container, until clean. Rinse the bearing in another container of clean solvent.
5. Use a brush with short, clean bristles to remove dirt, chips, or other foreign material.
6. If the bearing is cleaned but immediate reassembly into the machine isn't possible, dip the wet bearing in a slushing compound and store it wet in a tightly covered container.
7. Don't leave bearings exposed in partial assemblies. Cover the parts with a clean cloth until the assembly can be completed. The cloth will prevent the entry of dirt or other foreign elements.

The bearing is now ready for inspection. Bearings should never be allowed to spin if they aren't lubricated. Even the slightest motion of a nonlubricated bearing can lead to scarring of the bearing's races or rollers. Also, bearings should be handled only with lint-free rags or gloves. Using dirty or otherwise unacceptable rags introduces particles into the bearing and, therefore, into the lubrication system. Especially once a bearing has been cleaned, it should be handled only with clean, dry hands or while wearing lint-free gloves.

Your shop should have and follow established procedures for inspecting bearings. These procedures should dictate that the housing and shaft with which the bearing mates must also be checked whenever the bearing is inspected. Burrs, corrosion, and signs of physical damage or excess wear are all reasons to immediately replace a bearing. If removable seals are detached as part of the inspection process, then they should probably be replaced with new seals.

Bearings can also be inspected visually. Noticeable damage on the bearing components, such as scarring, denting, or flaking, indicates that failure is occurring. Later in this study unit you'll learn to identify several failure modes specific to antifriction bearings. Recognizing one of these modes allows you to identify a failed bearing and to address the cause of failure. Often, an antifriction bearing's job is so critical to machine operation that your shop's standard procedure will be to automatically replace certain bearings with a good spare when an assembly is taken apart. The removed bearing will then be discarded, or specially trained technicians in an inspection department can check the removed bearing before identifying it as a good spare or scrap.

Now, take a few moments to review what you've learned by completing *Self-Check 2*.



Self-Check 2

Indicate whether the following statements are True or False.

- ___ 1. Allowing the bearing to spin before installation won't cause damage.
- ___ 2. Cold and hot mountings are the two general classifications of bearing assemblies.

Complete the following statements with the correct answer.

- 3. Bearings can be mounted with an arbor press and a _____.
- 4. _____ should be worn to protect bearings from dirt or oil that's found on your hands.
- 5. Shaft nuts can be removed using a(n) _____ _____.
- 6. The term _____ describes the tightness between a bearing and shaft.

Check your answers against those on page 61.

MAINTAINING ANTIFRICTION BEARINGS

While antifriction bearings may provide good service for their entire specified design life, they often fail due to improper handling, poor maintenance, and unacceptable loading conditions. A maintenance technician can help improve bearing life by

- Handling and installing bearings properly
- Supplying the proper quantity and type of lubrication
- Monitoring the condition of the bearing's lubricant (when applicable)
- Regularly observing the bearing during operation
- Inspecting replacement bearings prior to installation
- Evaluating removed bearings for signs of unusual wear or operation

So far in this study unit you've learned how to properly handle and install many types of antifriction bearings. In this section, you'll learn about lubrication systems, predictive monitoring programs (for both bearings and lubricants), and basic inspection practices. Of course any one of these topics could be the focus of one or more study units. Therefore, in this unit, you'll simply be introduced to each maintenance practice.

Proper maintenance has an important impact on bearing life. Although all bearings fail eventually, proper maintenance prevents premature failure. When premature failure occurs, possible damage to the machine and expensive downtime can result.

In some cases, bearing failure can be predicted, and the bearing replaced before the machine suffers more extensive damage.

It's important to realize that, although regular inspection and monitoring of bearings can help eliminate damages to the shaft or machine, you may not be able to successfully prevent failures. Failures sometimes occur without warning and can create the need for machinery shutdown and repair.

Lubricating Antifriction Bearings

Antifriction bearings are lubricated to prevent metal surfaces in the bearing system from contacting each other. To be effective, the lubricant must form a layer over the bearing's contacting surfaces.

Ultimately, the proper lubrication of an antifriction bearing is necessary to prevent many types of bearing failure. More specifically, an antifriction bearing's lubrication increases its serviceable life by reducing friction, removing heat, preventing rust, and washing away contamination from those surfaces between which relative motion takes place.

Of course, the lubrication system is responsible for supplying the proper lubricant, such as oil or grease, onto the rolling elements and other bearing components they contact. Some bearings are permanently lubricated. In this case, lubricant is applied during assembly, and the bearing is permanently sealed. Normally, a permanently lubricated bearing receives no additional lubrication, nor are its seals designed to be removed and reinstalled. In this section of your study unit, the focus is on nonpermanently lubricated bearings.

Lubrication Delivery Methods

Antifriction bearings are lubricated in many ways. Sometimes, bearings are manually lubricated prior to installation and aren't lubricated again until they're removed. More often, lubricant is delivered to the bearing either continuously or on a periodic basis. Two typical methods of lubricant delivery are shown in Figure 30. The double-row roller bearing in Figure 30A is contained in a housing, which also holds an oil bath. The housing is equipped with seals that prevent leakage and help keep the oil within the housing. Pouring lubricating oil through the elbow fills the oil bath. The desired oil bath level is even with the top of the filling elbow. Note that this level ensures that only about half of the bearing's lowest ball or roller is immersed in oil. A higher oil level would result in excessive oil churning and higher oil temperature. A lower oil level could result in an insufficient amount of lubrication reaching the bearing.

Grease lubrication of a single-row ball bearing is shown in Figure 30B. The drain plug should be removed while the grease is applied to the bearing. New grease is applied through the grease fitting, flows through the ball bearing, and forces old grease from the bearing housing through the drain. As the new grease flows through the bearing and pushes out the old grease, it also flushes away any contaminants present.

Lubricant Types and Characteristics

Grease lubricants are used in many types of installations. One advantage of grease over oil lubricants is that the thickness of grease lessens the chance of leaks. When applying a grease lubricant, check the bearing manufacturer's specifications to determine the proper quantity and type of grease. As a grease lubricant heats up during operation, it will

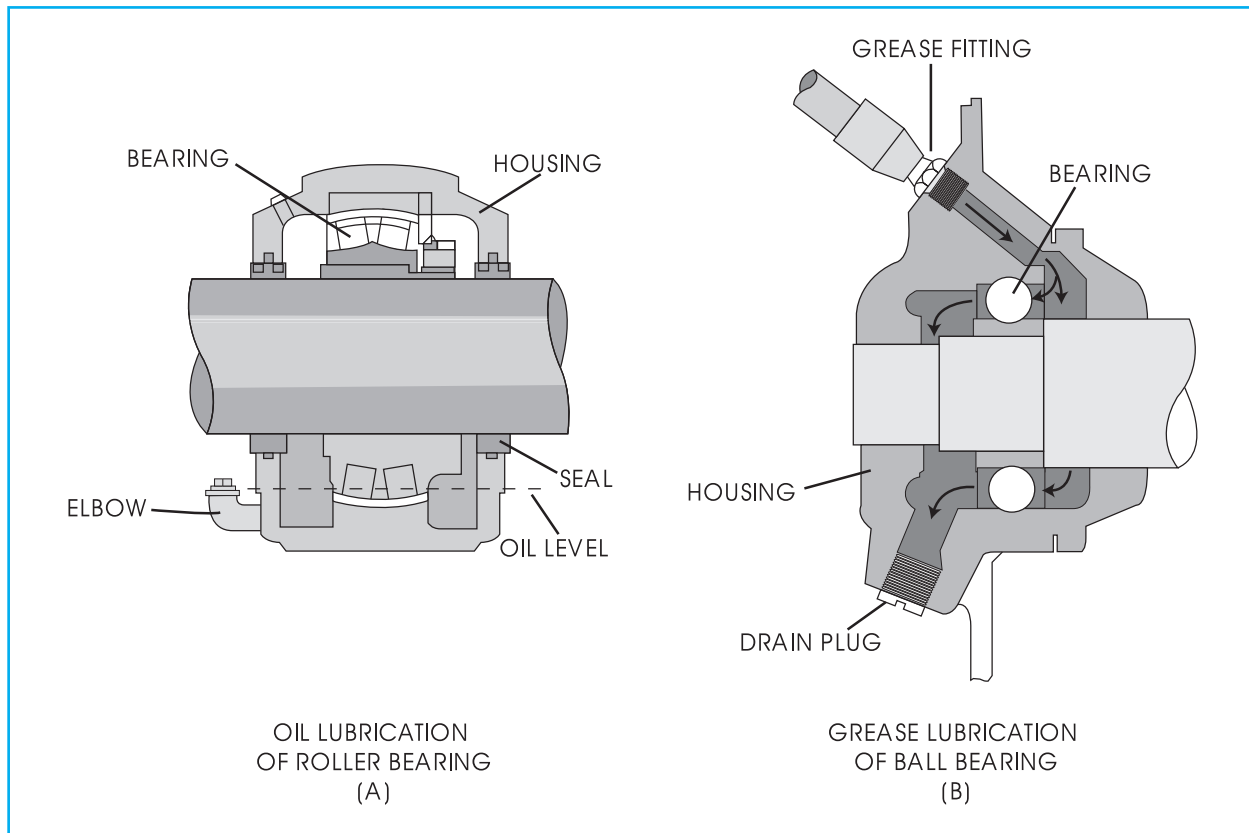


FIGURE 30—Bath oiling, shown in (A), is very economical and requires no attention other than regular inspection for correct oil levels and periodic draining and refilling of the oil reservoir. The ball bearings in (B) are serviced when new grease is applied to the grease fitting and pushes the old grease out of the removed drain plug.

become thinner and expand, needing more room. If too much grease is used, excessive heat will be produced, causing increased expansion of the lubricant and higher pressure on the bearing and seal. This pressure can, in turn, cause leaks and possibly damage.

Lubricants come in many types and grades. The makers of bearings provide lists of lubricants that can be used on their bearings. Use only recommended lubricants. Table 2 contains a sample selection chart that gives a general recommendation of the type of lubricant to use for various shaft diameters and speeds.

When a lubricant reaches its useful service life or needs to be replaced because of contamination or other problems, it's important to completely remove the old lubricant. Never mix one type of lubricant with another or add more than the specified quantity of lubrication. Too much lubricant may cause operating temperatures to rise due to excessive churning. Too little lubricant allows excessive friction, which can also result in elevated operating temperatures. Additives help to improve the quality of lubricants. *Detergents* help keep the surfaces of the shaft and bearing clean, while *viscosity improvers* aid in preventing

Table 2							
RECOMMENDED LUBRICANTS							
Shaft Diameter					Operating Temperature °F	Lubricant Recommended	
Up to 1 in.	1 to 2 in.	2 to 3 in.	3 to 4 in.	Over 4 in.		Oil viscosity SUS* at 100°F	Greases NLGI** Consistency No.
Up to 1000 rpm	Up to 500 rpm	Up to 300 rpm	Up to 200 rpm	Up to 100 rpm	Below 32 32 to 100 100 to 200 Over 200	150 to 185 250 to 350 400 to 1000 1500 to 2500	0 to 1 1 2 2 to 3
1000 to 3000 rpm	500 to 1500 rpm	300 to 1000 rpm	200 to 750 rpm	100 to 500 rpm	Below 32 32 to 100 100 to 200 Over 200	150 to 185 250 to 350 400 to 600 700 to 1000	0 to 1 1 2 2
3000 to 10000 rpm	1500 to 5000 rpm	1000 to 3000 rpm	750 to 2000 rpm	500 to 1000 rpm	Below 32 32 to 100 100 to 200 Over 200	90 to 120 150 to 185 250 to 350 500 to 1000	0 to 1 0 to 1 1 2
Over 10000 rpm	Over 5000 rpm	Over 3000 rpm	Over 2000 rpm	Over 1000 rpm	Below 32 32 to 100 100 to 200 Over 200	33 to 85 50 110 75 to 250 350 to 550	0 to 1 0 to 1 1 2

*Saybolt Universal Seconds (SUS)
**National Lubricating Grease Institute (NLGI)

the lubricant from becoming too thin at high operating temperatures. Other additives help bond the lubricant to the surfaces for improved lubrication.

Taking an oil sample and having it analyzed can help you evaluate the effectiveness of lubricating oil. Typically, a special laboratory performs oil analysis. The lab analysis includes an evaluation of the lubricant's purity and general condition and provides very specific data on various properties. Based on this analysis, you may choose to increase the frequency of lubricant changes, or you may wish to adjust the additives introduced to the system. Most importantly, the analysis provides a reasonable indication of whether or not the lubricant is capable of protecting the antifriction bearing.

Bearing Operating Analysis

Obviously, an antifriction bearing should be inspected if it's removed from service. As you've already learned, this practice allows you to determine if the bearing can be safely returned to service. If it isn't in serviceable condition, then this inspection may help you to determine the failure cause.

It's equally important that an installed bearing be inspected or, more specifically, its operating characteristics observed. This practice, known as *predictive maintenance*, seeks to identify a failing bearing before it fails catastrophically, damaging other machine components and halting the machine's operation.

Predictive maintenance programs usually involve listening to the bearing during operation, checking the lubricant's temperature level, inspecting the bearing's vibration level, realigning the supported shafts when necessary, and monitoring the lubricant's condition.

To carry out an effective periodic maintenance program, you must first understand how the bearing system operates under normal conditions. To be able to successfully detect when a bearing is approaching failure, you must become familiar with its vibration, temperature, and noise characteristics under normal operating conditions. Certain levels of vibration or heat, for instance, are normal. However, excessively high vibration or oil temperature levels or a rapid change in these levels indicates a problem.

Figure 31 shows an example of fretting damage, possibly caused by excessive vibration. This may have occurred during shipping, from an improper fit, or in operation while supporting a poorly balanced shaft.

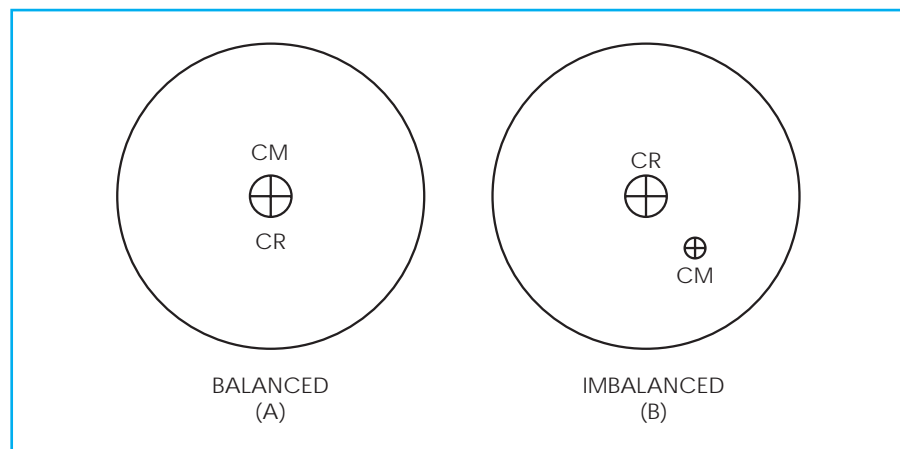
Vibration Monitoring

Excessive vibration in a rotating mechanical system (such as turning shaft supported by two bearings) is often caused by an *imbalance*. An imbalance exists when the system's center of rotation doesn't occur at the same point as its center of mass. The system should always be in balance, as in Figure 32A. Another cause of excess vibration is looseness. Sometimes the looseness comes from excess space between the bearing's inner race and the shaft. In other cases looseness may develop between the bearing's outer race and housing, or in the mounting of the housing to the machine. All equipment is designed to tolerate a very small amount of looseness.

FIGURE 31—These races were damaged by vibration. (Courtesy of NTN Bearing Corporation of America)



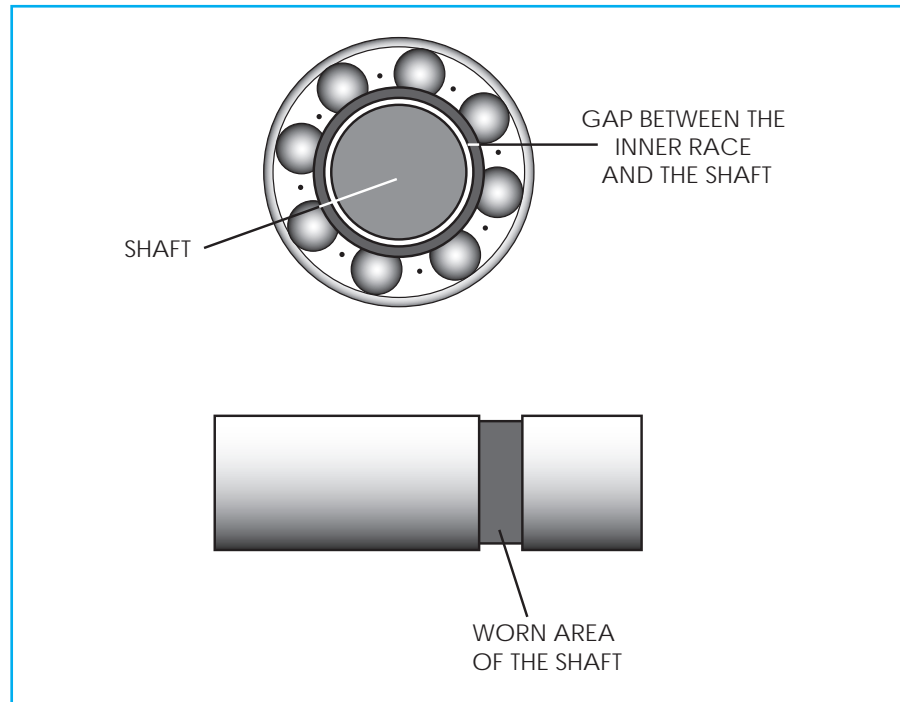
FIGURE 32—In (A), the center of mass (CM) and the center of rotation (CR) are at the same location. This means that the rotating system is in balance. In (B), the CM and CR aren't in the same location, leading to an imbalance.



One instance of excess looseness occurs when the shaft has worn from friction. Assume that the initial fit between the bearing's inner race and the shaft was too loose. The shaft and inner race rub against each other as the direction of loading changes. If the bearing material is harder than the shaft, then the shaft slowly wears away, as shown in Figure 33. Initially, lubrication may fill the space between the two but, eventually, the gap becomes too large to be filled by lubricant. Now, the shaft bounces around inside the inner race as the shaft and

bearing rotate, greatly increasing the vibration level and speed with which the shaft wears. Keep in mind that these types of wear problems can just as easily occur where the bearing's outer race fits into a housing. Most often the supporting housing is made of a cast material that's much softer than the outer race.

FIGURE 33—If the fit of the shaft in a bearing is too loose, then the shaft will move up and down within the bearing, making small impacts with the inner race. These impacts quickly wear the shaft.



Most predictive maintenance programs for rotating equipment include measurement of vibration levels using equipment designed for that purpose and analysis of the results. While a detailed discussion of vibration analysis is beyond the scope of this study unit, you should understand that vibration levels for individual bearings can be measured, recorded, and compared to earlier measurements in an organized approach. As shown in Figure 34, vibration levels are monitored by mounting a measurement device, such as a *velocity transducer*, to a bearing's housing or other location on a machine.

The signal from the velocity transducer (which measures the speed with which the monitored surface moves) is directed to a vibration-frequency analyzer. The vibration monitoring equipment quantifies the vibration energy. When objects vibrate, they're said to do so at specific frequencies. *Frequency* refers to the speed with which the object vibrates. For instance, an object that vibrates back and forth 10 times in a second is said to vibrate at a frequency of 10 Hertz (Hz). Measuring vibration levels in a machine is more complicated, however, as vibrations occur at many frequencies. Vibration-monitoring equipment helps you determine at what frequency or frequencies the bulk of the vibration energy occurs. The equipment allows you to compare this frequency with the rotational speed of the machine's shaft. Comparing

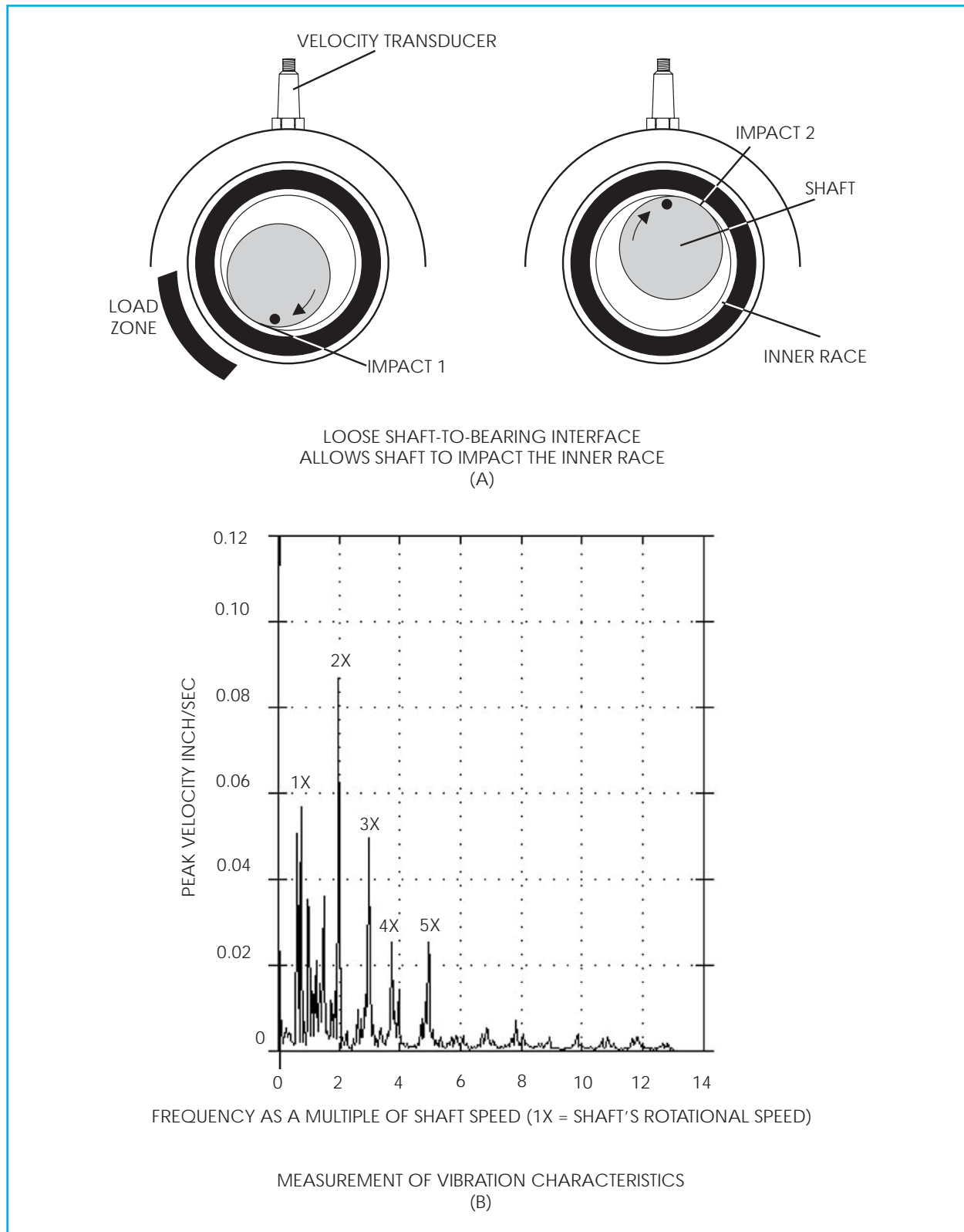


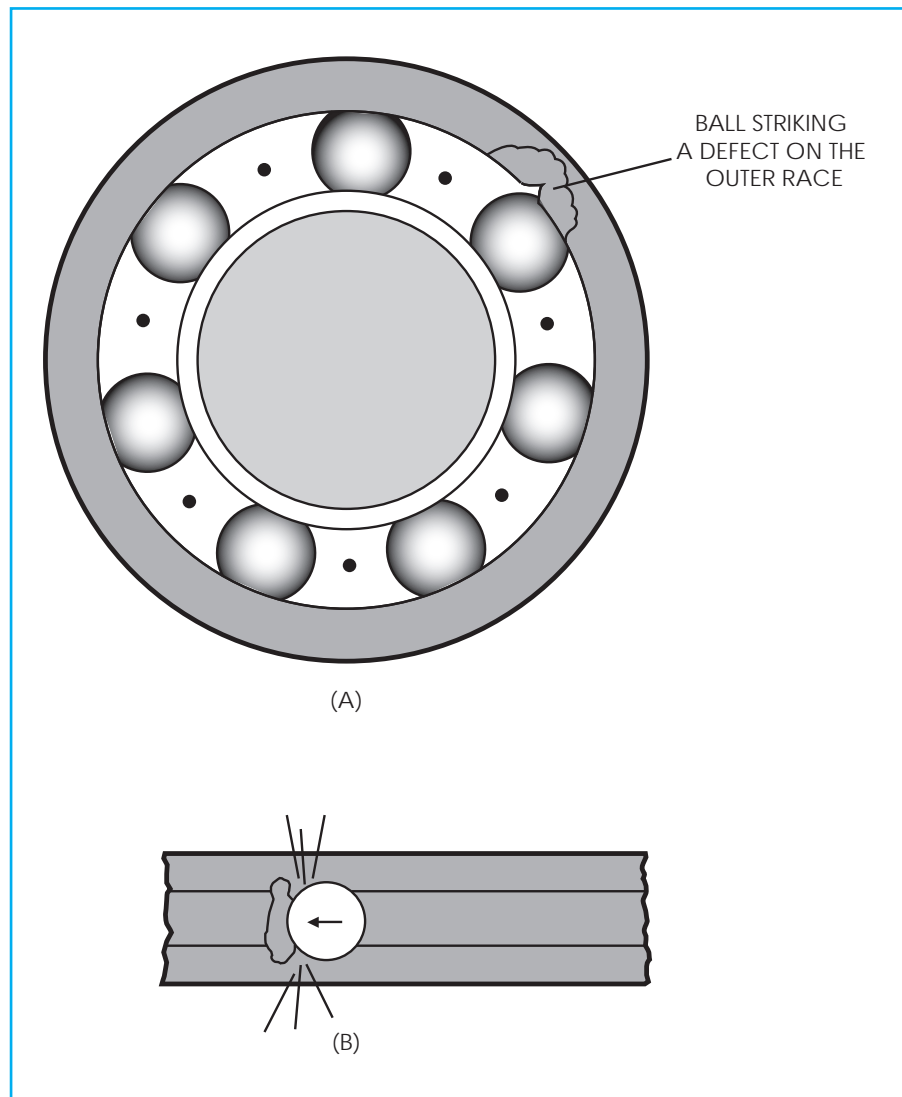
FIGURE 34—Vibration-monitoring equipment can detect changes in the shaft and bearing's operating characteristics. Here, a shaft that's loose within a bearing's inner race contacts the race two times per revolution (A). This is indicated on the vibration-monitoring equipment's display (B), with higher levels of vibration occurring at the frequency equal to twice the shaft's rotating speed.

the frequency at which the bulk of the vibratory energy exists with the shaft's rotational speed can help identify specific problems.

For instance, a vibration analysis program can help predict failures caused by bearing defects. Defects occur for various reasons in the inner and outer race, the ball or rollers, or the cage. Vibration caused by these bearing defects occurs at frequencies that can be detected and identified with the proper equipment.

Race failure occurs at the location of a defect on the outer race as shown in Figure 35, or on the inner race. As rolling elements move over the race, each element contacts the defect, and a large amount of energy is released. This energy results in vibration. The frequency at which most of the vibration energy occurs is some multiple of the shaft speed.

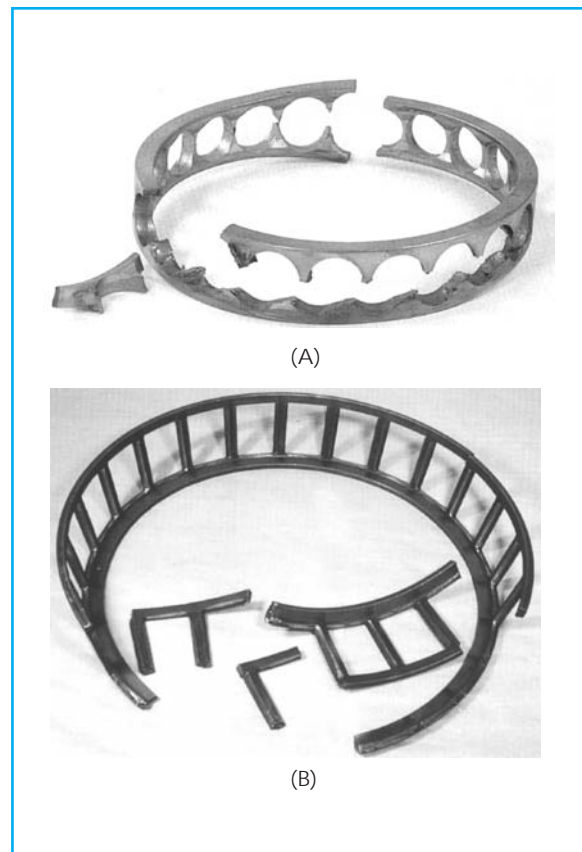
FIGURE 35—Rotating balls alternately strike an outer race defect. The vibration caused by this action can be detected with the proper analysis tools.



Failure of a rolling element produces vibration energy each time the defect contacts a point on one of the two races. The random nature of these collisions means that this type of defect produces vibration signals at frequencies higher than but not a direct multiple of the shaft speed.

The final type of failure may occur in the cage. This failure produces vibration at frequencies below the shaft's rotational speed. A bearing with this type of failure, even in its earliest stage, should be replaced immediately. Figure 36 shows some examples of cages that have failed.

FIGURE 36—The cage in (A) failed due to poor lubrication. In (B), the pockets that separate the rollers have broken, allowing the rollers to come in contact with one another, causing even more damage. (Courtesy of NTN Bearing Corporation of America)



As you may have guessed, vibration analysis isn't a simple check. Instead, it's a technology that must be learned and used over a period of time to develop a trend of acceptable and unacceptable vibration measurements. Not all manufacturing operations have established a vibration analysis program. However, this method is becoming an accepted standard in plant maintenance departments.

Audible Detection

A maintenance technician must develop the ability to listen to the equipment he or she maintains in order to observe changes in operating characteristics. Table 3 shows some typical sounds to listen for

when maintaining equipment that contains bearings. As each person's interpretation of a noise may be different, this isn't an exact method for predicting a bearing failure and predetermining the failure cause. Instead, it's most important to observe changes in the noises a machine produces and be sure to investigate these changes as soon as possible after they're observed.

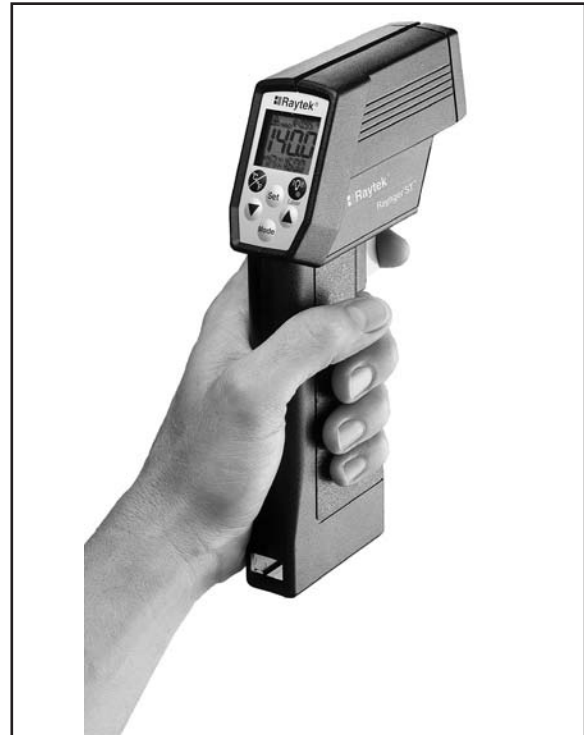
Table 3		
COMMON SOUNDS INDICATING BEARING PROBLEMS		
Sound	Features	Causes
Hiss	Small bearings	Raceway, ball, or roller surfaces are rough
Buzz to roar	Loudness and pitch change with speed	Resonance Poor fit Bearing rings deformed Vibration of raceways, balls, or rollers (For large bearings, if this sound is minor, then this is considered normal) Brinelling
Crunch	Felt when the bearing is rotated by hand	Scoring of raceway surface (regular) Scoring of balls or rollers (irregular) Dust/contamination Deformed bearing ring (partial interference clearance)
Hum	Disappears when power supply is switched off	Electromagnetic sound of motor
Chatter	Noticeable at low speeds Continuous at high speeds	Bumping in cage pockets (insufficient lubricant) Eliminated by clearance reduction or pre-loading Rollers bumping into each other on full-roller bearing
Clang/Clatter	Metallic, loud bumping sound Thin section large bearing (TTB) at low speeds	Bearing ring deformed Grating of key

Monitoring Temperature

You've already learned that the condition of a bearing's lubricant can be evaluated by performing a test known as an oil analysis. Measuring and observing the temperature of its lubricant can also gage the operating behavior of the bearing. As with vibration analysis, oil-temperature analysis isn't usually an exact science with clear-cut answers. Instead, you must develop an oil-temperature trend that will ultimately allow you to spot a shift in oil temperatures that predicts bearing failure.

More advanced temperature-monitoring equipment includes the handheld device shown in Figure 37. Simply pointing the device at a specific location on a machine and actuating a trigger causes a readout of the temperature at that location to appear on the digital display.

FIGURE 37—This is a handheld temperature-measuring instrument that can give a very accurate temperature reading of a single point of interest. (Courtesy Raytek Portable Products, Inc. Web site www.raytek.com)



Failure Modes

So far in this study unit, you've been shown a few failed bearings and told what caused the failure. In fact, it's sometimes very difficult to exactly determine the reason a bearing failed. Following are a few additional examples of failed bearings with a brief description of their cause. When evaluating a failed bearing, try to develop an understanding of suspected causes of failure and look for corrective actions that are likely to address one or more of the causes you suspect. There are accepted standard terms to describe bearing failure modes. While a complete discussion of failure analysis is beyond the scope of this study unit, it's useful for you to know what some of these terms are.

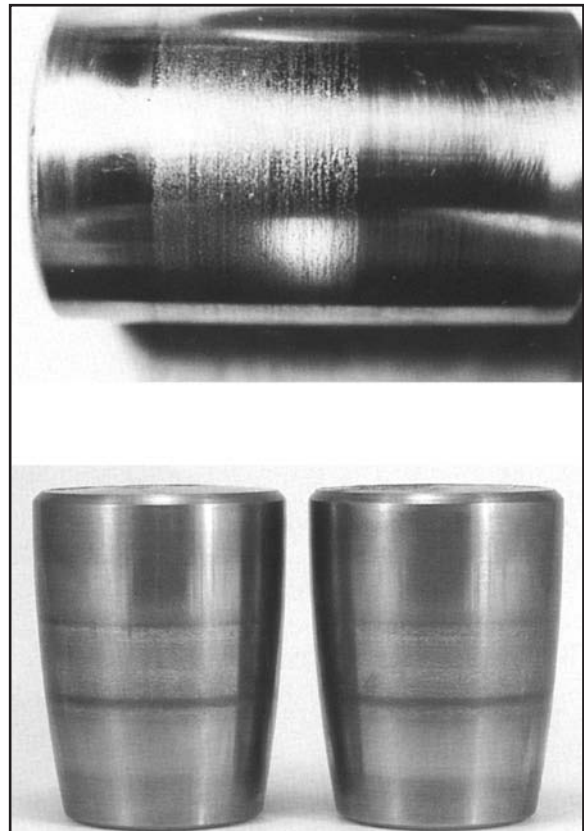
- *Spalling*—scratches or scores on the surfaces of the bearing components. Marks are in the direction of travel.
- *Peeling*—very small cracks or a grouping of very small spalls, concentrated in the same area

- *Flaking*—very rough surfaces on contacting bearing components
- *Smearing*—rough surface (less rough than flaking)

As you've learned, it's important to keep bearings clean before, during, and after installation. Dirt, grit, and other foreign matter can damage the surfaces of the balls, rollers, and outer and inner races, as shown in Figure 38. Dirt in the lubricant will also cause the lubricant to gradually break down until it no longer does its job. Foreign matter in the bearing will also cause excess noise.

You've also learned that a bearing must be supplied with enough lubrication to coat the contacting surfaces. Examples of what can happen when bearings are provided insufficient lubrication are shown in Figure 39.

FIGURE 38—This smearing damage was caused by foreign matter in a bearing. (Courtesy of NTN Bearing Corporation of America)



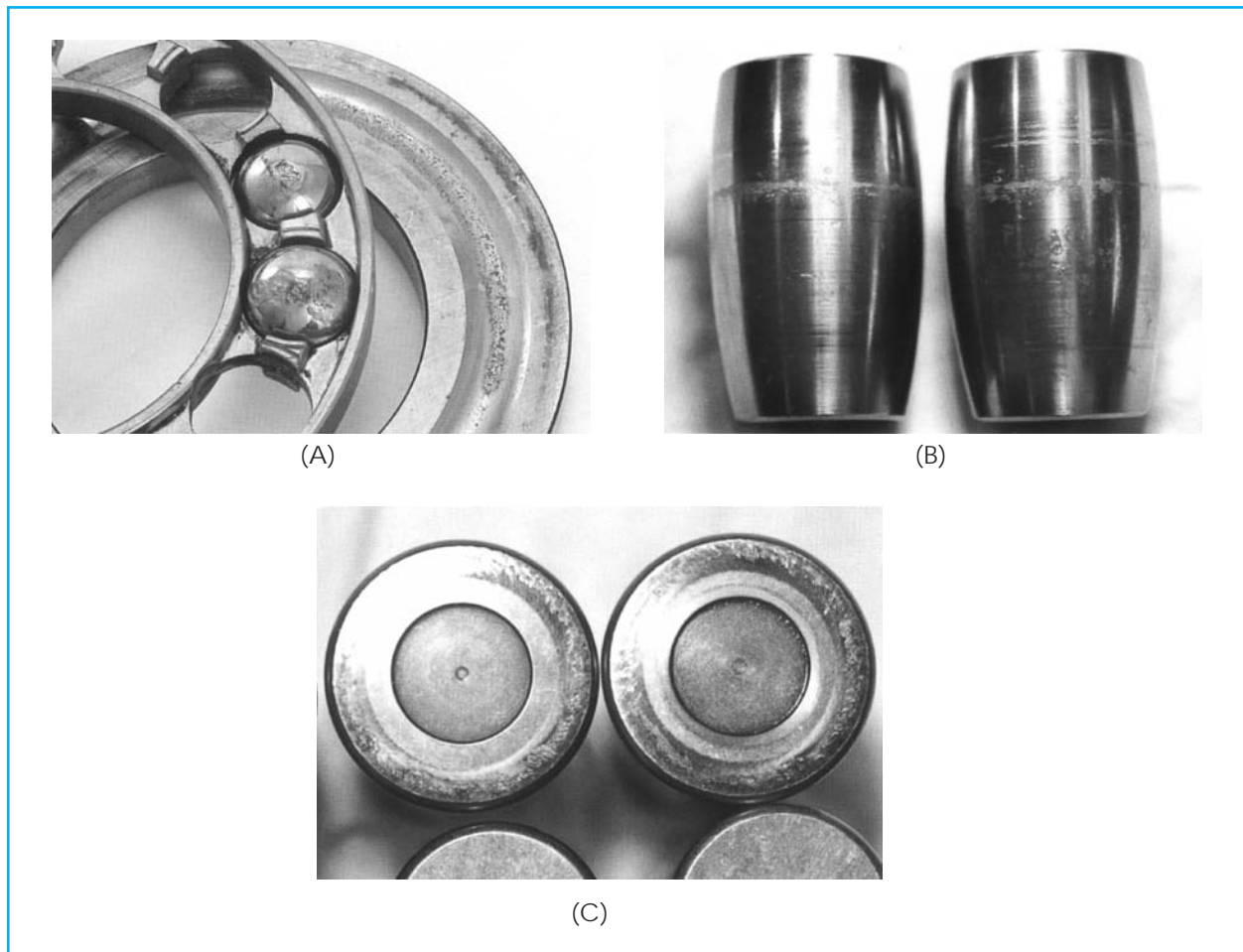


FIGURE 39—The flaking in (A), peeling in (B), and spalling in (C) occurred because of insufficient lubrication.
(Courtesy of NTN Bearing Corporation of America)

Table 4 lists many operational problems that may occur with antifriction bearings. It includes some suggested actions to correct each of the problems.

Table 4			
OPERATIONAL PROBLEMS OF ANTIFRICTION BEARINGS			
Trouble	Observed Characteristic	Probable Cause	Corrective Action
Excessive vibration	During acceleration or deceleration periods	Critical speeds of machine components	Stiffen shaft or other machine components to avoid critical speeds.
	During operation at fixed speeds	Unbalanced rotating parts	Dynamically balance rotating parts.
		Shaft bent	Straighten and rebalance.
		Cams, gears, linkage	Adjust, improve, or redesign.
		Misalignment	Correct machine parts.
Runout	Shaft doesn't run true.	Shaft bent	Straighten shaft and rebalance.
		Bearing misaligned	Correct machine parts and alignment procedures.
	Shaft binds when turned by hand.	Bearing races out of square	Check squareness of shaft and housing shoulders, spacers, etc.
		Dirt	Wash all parts, replace with new bearing if necessary, use clean lubricant, improve seals.
		Machining deflection	Stiffen machine members.
Temperature	High after initial start	Grease redistribution	Allow machine to cool. Restart.
	Continuously high during operation	Churning of lubricant	Use lower oil level, less grease, or stiffer grease.
		No lubricant	Add lubricant.
		Excessive axial load	Check outer race fit in housing and/or shoulder location to allow thermal expansion.
		Excessive radial load	Use correct fit of inner race on shaft. For radial bearings, use bearing with greater internal clearance. For preloaded paired bearings, use lighter preload.
		Bearing misaligned	Correct machine parts and alignment procedures.
		Excessive seal drag	Use different type of seal.

(Continued)

Noise	High pitch, steady tone	Excessive axial load	Correct outer race for housing and/or shoulder location to allow thermal expansion.
		Excessive radial load	Use correct fit of inner race on shaft. For radial bearings, use bearing with greater internal clearance. For preloaded paired bearings, use lighter preload.
		Misalignment	Correct alignment.
	Low pitch, continuous or intermittent	Too much clearance in bearing	Use correct shaft fit. For radial bearings, use bearing with less internal clearance. For preloaded paired bearings, use heavier preload.
		Raceways pitted due to dirt	Wash all parts, replace with new bearing, use clean lubricant, improve seals.
	Intermittent squeal or high pitch	Balls skidding	Provide thrust preload spring. Use thinner grease. For radial bearings, use bearing with less internal clearance. For preloaded paired bearings, check for correct preload.
		Shaft rubbing housing	Correct seals and machine parts.
	Intermittent rumbles, rattles, clicks, etc.	Too much clearance in bearing	Correct shaft fit. For radial bearings, use adjusting spring or bearing with less internal clearance. For preloaded paired bearings, check for correct preload.
		Dirt in bearing	Wash all parts, replace with new bearing if necessary, use clean lubricant, improve seals.
		Loose machine parts	Tighten all fans, pulleys, closures, spacers, slingers, etc.
Inner race wears loose on shaft	Wear of the shaft seat	Incorrect shaft fit	Use recommended shaft fit.
		Poor shaft finish	Smooth turn or grind shaft to size after metal spraying or chrome plating.
<i>(Continued)</i>			

Outer race wears loose in housing	Wear in housing bore	Housing fit too loose	Use recommended housing fit.
		Unbalanced forces	Dynamically balance rotating parts. Clamp outer race faces. Use cylindrical-roller bearing and press fit outer and inner races.
		Poor finish	Bore or grind housing inside diameter oversize, press in a bushing, and finish bore or grind to size.
		Soft housing material	Use steel liners. Work-harden bore.

Now, take a few moments to review what you've learned by completing *Self-Check 3*.



Self-Check 3

Complete the following statements with the correct answer.

- Without proper lubrication, bearing _____ will happen prematurely.
- In an oil bath lubrication system, too much oil will cause the temperature to _____.
- When a rolling element moves over a defect in the race, _____ occurs.
- As a grease lubricant heats, it becomes _____ and expands.

Indicate whether the following statements are True or False.

- _____ 5. Monitoring the changes in a machine's vibration level is a form of predictive maintenance.
- _____ 6. Lubrication helps prevent damage during installation.
- _____ 7. For grease applications, a new type grease can simply be added to the existing lubrication.

Check your answers against those on page 61.

SEALS

As you may already know, industries spend large amounts of money on bearings. What you may not know is that most bearings fail or are removed before reaching their full life expectancy. Furthermore, contaminated lubricant is the greatest single cause of bearing failure. Even the smallest amount of water, dirt, or debris in a lubricant reduces bearing life significantly. To avoid these problems, it's important that lubrication systems and bearings be properly sealed and maintained. You'll find many types of seals in industrial systems. All seals can be classified as either static or dynamic types. *Static seals* prevent leakage between two surfaces that don't move with respect to each other. *Dynamic seals* prevent leakage between surfaces that are in motion with respect to each other. While equipment containing antifriction bearings certainly contains both static and dynamic seals, you'll most often find a specific type of dynamic seal, known as a lip seal, mounted adjacent to and directly responsible for protecting an antifriction bearing.

Lip Seals

Lip seals, as shown in Figure 40, keep contamination out of a bearing while holding lubricant inside the bearing. Lip seals are considered to be *contact seals*, meaning that they operate by maintaining contact with another component (in this case, a rotating shaft). When the mating shaft is spinning and lubrication is present, lip seals actually operate with a very slight clearance (approximately 0.001 inch) between their sealing surface and the shaft. This thin gap is filled with a layer of lubricant. This layer protects the sealing feature (known as the *lip*)

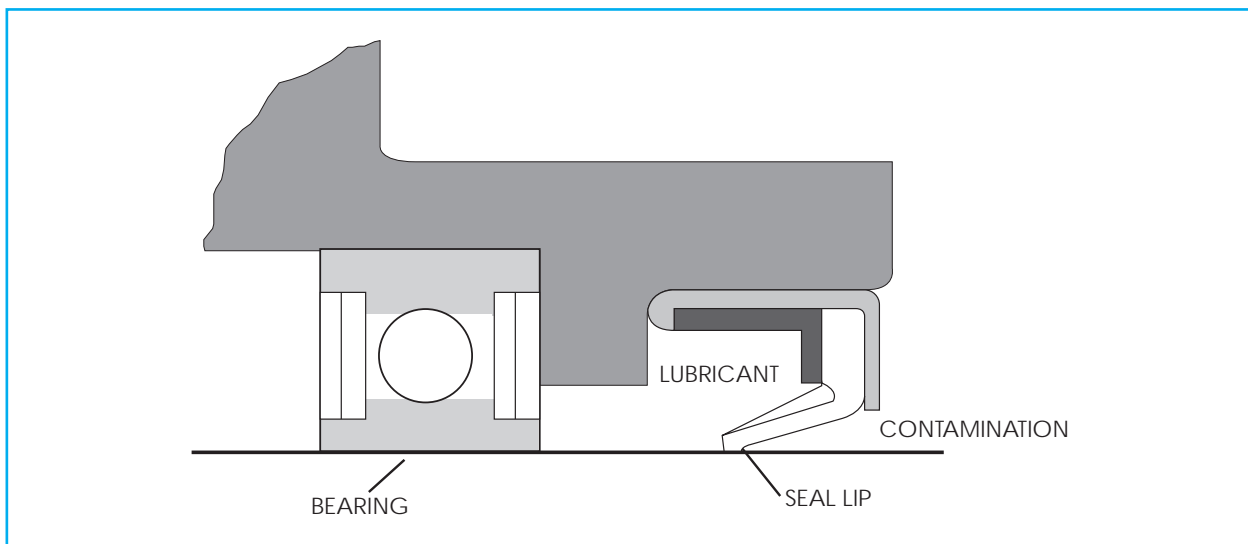


FIGURE 40—Depending on the sealing lip's orientation, lip seals can be used to keep lubrication in or contamination out. (Drawing courtesy of Garlock Sealing Technologies)

from wearing out due to direct contact with the spinning shaft. Too little clearance causes the lip to wear, while too much clearance allows the contained fluid or external contaminate to pass by the seal. As you'll soon learn, the smoothness and hardness of the shaft's surface affect the type of seal that can be used and predict the seal's expected running life. Uneven shaft finish or rough spots will cause the seal to wear prematurely. Harder materials, such as steel, stainless steel, chrome plating, and nickel plating, are best suited for shafts in contact with lip seals.

There are many different lip seal designs, each offering specific advantages. Most lip seal assemblies include both rigid and flexible components. Rigid components may be metallic or non-metallic, but are responsible for adding structural strength to and maintaining the shape of seals. Flexible component parts, including those directly responsible for sealing, are made of a non-metallic material, such as nylon or rubber. Shortly, you'll learn more about the advantages of these material types. All types of lip seal designs can be grouped, depending on how they're fabricated, into one of two categories: assembled lip seals and bonded lip seals, as shown in Figure 41. *Assembled lip seals* rely on mechanical assembly or crimping to join the flexible sealing element with rigid mechanical supporting components. When a design includes a chemical bonding between the flexible and rigid components, it's classified as a *bonded lip seal*.

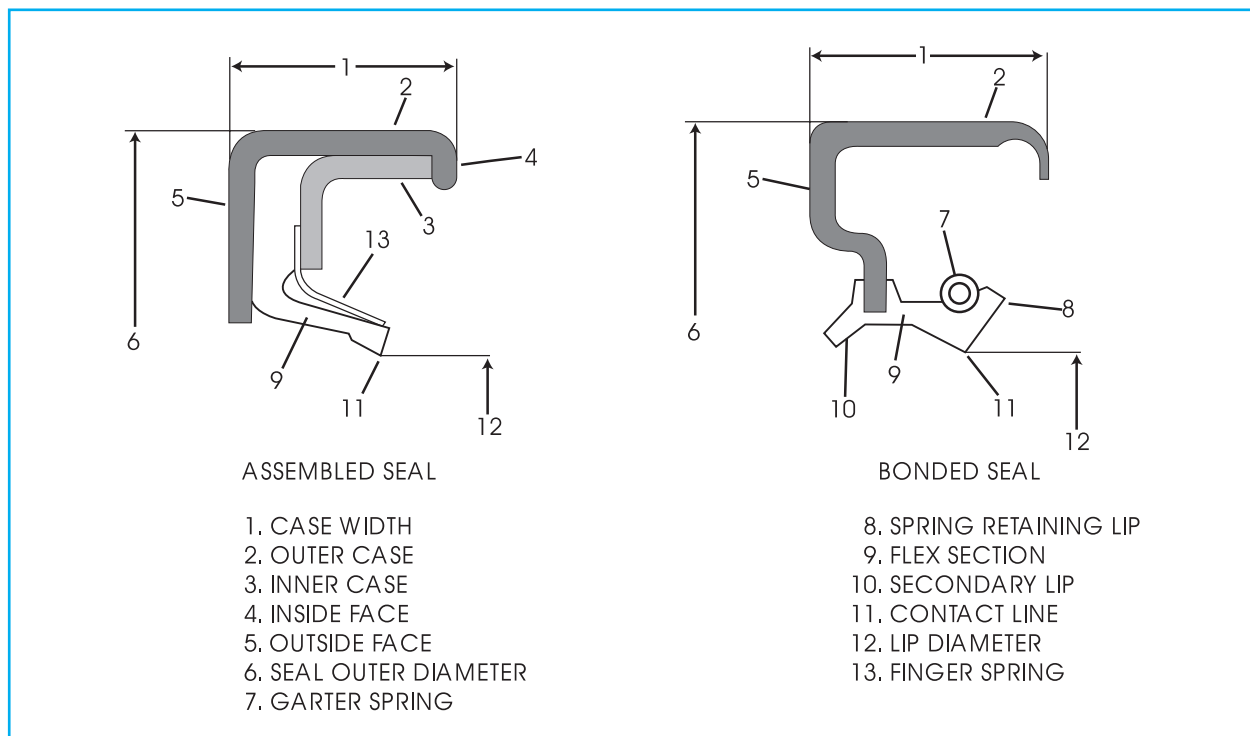
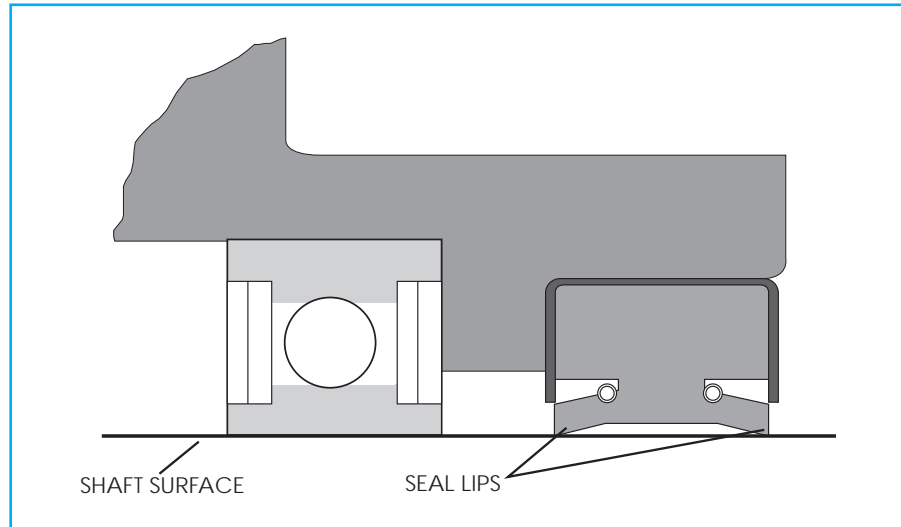


FIGURE 41—Lip seals can be generally classified as assembled or bonded types. (Drawing courtesy of Garlock Sealing Technologies)

The next most substantial difference between lip seal designs is the shape of the sealing lip itself. Various lip shapes and orientations can affect the seal's operating characteristics. The lip's orientation determines whether a seal is primarily able to keep lubricant in or keep contamination out. Seals may incorporate two lips of similar or opposite orientation. Figure 42 shows a two-lip seal that's designed both to retain lubricant and prevent external contamination from entering the bearing.

FIGURE 42—This seal has two opposing lips. It's able to contain lubricant and prevent contamination from entering the protected bearing.

(Drawing courtesy of Garlock Sealing Technologies)



The seal in Figure 42 incorporates two garter springs that exert additional sealing pressure on the seal's flexible components, ensuring even and constant contact between the lip and the rotating shaft. Some seal types, including those intended for grease-lubricated systems, don't contain garter springs. Since grease doesn't flow as easily as oil, the contact force between the seal and shaft isn't as critical.

Lip seals are available with flexible sealing components made of many materials, including synthetics, such as nitrile, polyacrylate elastomers, silicone polymers, and fluoroelastomers, as well as rubber and even leather. The material selected for a given seal application depends on several operating conditions:

1. Rotating speed of the shaft
2. Operating temperature
3. Lubricant pressure acting on the seal
4. Surface conditions of the rotating shaft

Seals made from *silicone polymers* are able to operate in a wide temperature range; however, they don't work well when little or no lubrication is present. A second limitation of silicone polymers is that they swell when exposed to certain lubricating oils with which they're

considered to be incompatible. Also, silicone sealing elements are easily damaged. *Fluoroelastomer* materials also operate within a wide range of temperatures up to about 400 degrees Fahrenheit (204°C) and aren't as likely to swell as silicone seals. These materials are much more costly than silicone and may require special installation tooling or techniques. *Nitrile* seals are less expensive and don't swell easily, but harden when exposed to temperatures above 250 degrees Fahrenheit (121°C).

Installing Lip Seals

Lip seals must be carefully installed to ensure that the sealing surface is in even contact with the shaft and that the edge of the seal isn't damaged.

When choosing the proper seal, you must consider the shaft size and speed, what the seal will be doing, and the temperatures to which it will be subjected.

To determine the size of radial lip seal needed you must subtract the shaft diameter from the bore diameter. Dividing the answer by two gives you the seal's *radial height*. You must also know the overall axial length (the dimension measured along the length of the shaft's center-line) of the seal, as shown in Figure 43. This width should usually equal the housing's bore depth.

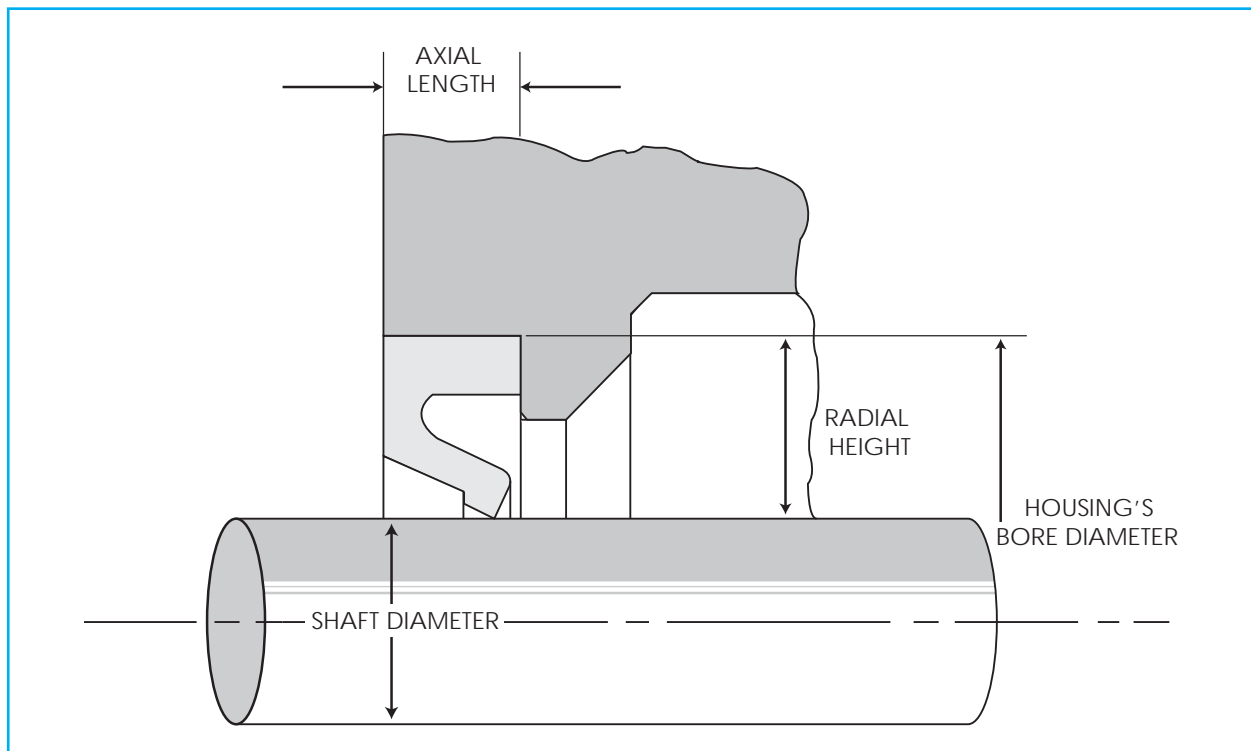
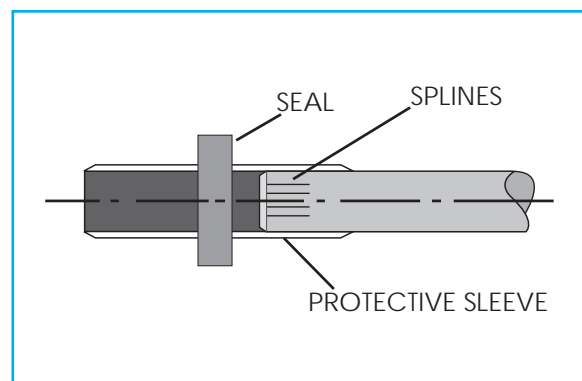


FIGURE 43—The radial height and axial length determine the size of the seal needed. (Drawing courtesy of Garlock Sealing Technologies)

Follow these general procedures when installing lip seals:

1. Measure the shaft and housing in which the seal will be mounted. Ensure that the seal to be installed is suitable for these dimensions.
2. Check the shaft and housing surfaces for tool marks, nicks, corrosion, and scratches. If these surfaces require refinishing, be sure that they conform to the seal's requirements (typically the surface finish should be in the range of 10 to 20 microns).
3. Be sure the seal lip and shaft are lubricated before attempting to install the seal.
4. Be certain to use the correct installation tools so that the seal lip won't be cut, scratched, bent back, or scraped over sharp keyways, corners, or burrs. If installing one over a keyway, temporarily cover the shaft with a protective sleeve. An example of this is shown in Figure 44. As a general guideline, a lip seal is properly oriented if its lip faces the material to be sealed.
5. If no special installation tool is available to drive the seal onto the shaft, be sure to use a fabricated tool (such as a piece of pipe) that's soft enough not to damage the seal's housing. Force should be applied evenly but should never be applied by directly striking the seal with a hammer.
6. If cement is used to coat the outside diameter of the seal, make sure none of it gets on the shaft or seal lip.
7. Be sure when the seal is installed in the housing that its centerline is parallel to the shaft axis. Crooked or misaligned seals are more likely to experience heavy wear and fail prematurely. Scoring marks on the seal housing's outer diameter are signs of poor alignment between the seal and housing, rough housing surface finish, or contamination between the housing and the seal.

FIGURE 44—Temporarily install a protective sleeve when sliding a seal over a shaft's keyway, splines, or other sharp edge.



Maintaining and Troubleshooting Lip Seals

Lip seals require very little specific maintenance. The only normal maintenance they require is a sufficient amount of the correct type of lubricant. Since lip seals that protect a bearing installation are normally exposed to the bearing's lubricant, their lubrication is applied without any additional maintenance. Lack of lubrication may cause the seal's lip to directly contact the shaft, allowing friction to wear it away or tear it, causing leakage. As you already know, lubricants that are incompatible with the material type of the seal's flexible components can lead to chemical breakdown of those components.

When working around an installed lip seal, follow these good practices:

1. When painting a machine, be sure to cover the seal to prevent the paint from getting on the lip or shaft.
2. While cleaning the shaft or surrounding area, don't let the seals contact any agents or fluids that could damage them.
3. If changing the type of lubricant in a machine, check catalogs or other literature provided by the seal manufacturer to ensure that the new lubricant is compatible with any installed lip seals. In fact, this recommendation should be extended to all non-metallic components installed in the machine.

When problems with lip seals do occur, the troubleshooting hints in Table 5 may help you identify the cause and corrective actions.

Table 5		
TROUBLESHOOTING LIP SEALS		
Trouble	Probable Cause	Corrective Action
Excessive shaft wear	Shaft material too soft	Check hardness of shaft. The hardness should be a minimum of 30 on the Rockwell C scale.
	Abrasive contaminants	Check lubrication for presence of contaminants. If found, determine source, rectify, and inspect bearing(s).
Excessive leakage of lubricant	Insufficient or uneven contact between the sealing lip and shaft	Check and correct shaft-to-lip clearance and ensure that runout is within acceptable tolerances for the type of seal installed.
	Overstretched lip	Properly install new seal.
	Nicks, cuts, or tears in lips	Properly install new seal. Be sure to handle the seal carefully and to inspect the shaft for surface flaws.
	Hardened, brittle sealing lip	Monitor seal's operating temperature. Install seal of a material type suited to the temperature.
	Excessive pressure	If practical, monitor lubricant's operating pressure in the seal's location. Install seal of a design and material type suited to the pressure.
	Damaged garter spring	Replace spring or entire seal. Be sure to avoid rough handling and installation procedures that will lead to spring failure.
Excessive wear of lip	Rough shaft finish	Check that shaft surface is smooth.
	Lack of lubrication	Check that lubrication system is functioning properly.

Now, take a few moments to review what you've learned by completing *Self-Check 4*.



Self-Check 4

Complete the following statements with the correct answer.

1. To prevent lubricant from leaking around the shaft and bearing, a _____ is used.
2. When a seal functions between two surfaces that move in relationship to each other, it's called a(n) _____ seal.
3. A(n) _____ exerts pressure to tighten the seal around the shaft.
4. _____ seals are less expensive than fluoroelastomer seals.

Indicate whether the following statements are True or False.

- _____ 5. A lip seal can incorporate a chemical bonding between the flexible and rigid components.
- _____ 6. Lubrication should be added to a lip type seal before installation.

Check your answers with those on page 61.

NOTES

Self-Check Answers

1

1. antifriction
2. angular-contact
3. oil reservoir
4. nylon spacers
5. bridges
6. Plastic
7. crossed

2

1. False
2. True
3. dolly
4. Gloves
5. spanner wrench
6. fit

3

1. failure
2. rise
3. vibration
4. thinner
5. True
6. True
7. False

4

1. seal
2. dynamic
3. garter spring
4. Nitrile
5. True
6. True

NOTES

Bearings and Seals, Part 2

EXAMINATION NUMBER:

28609400

Whichever method you use in submitting your exam answers to the school, you must use the number above.

**For the quickest test results, go to
<http://www.takeexamonline.com>**

When you feel confident that you have mastered the material in this study unit, complete the following examination. Then *submit only your answers to the school* for grading, using one of the examination answer options described in your “Test Materials” envelope. Send your answers for this examination as soon as you complete it. *Do not wait until another examination is ready.*

Questions 1–20: Select the one best answer to each question.

1. When a bearing is installed using thermal expansion, the bearing is considered to be
 - A. cold mounted.
 - B. hot mounted.
 - C. radial mounted.
 - D. thrust mounted.
2. If the shaft's diameter is 1 ½ inches and the housing's bore diameter is 3 inches, the radial height of an installed lip should be
 - A. ¾ in.
 - B. 1 in.
 - C. 1½ in.
 - D. 3 in.
3. The rollers of which bearing type always have diameters that vary along their length?
 - A. Double-row roller
 - B. Tapered-roller
 - C. Spherical-roller
 - D. Thrust
4. Which of the following types of loads act perpendicular to a rotating shaft's axis?
 - A. Axial
 - B. Radial
 - C. Combination
 - D. Parallel

5. A 3-inch shaft that reaches speeds of 600 rpm and operating temperatures of 170 degrees Fahrenheit needs a lubricant with an SUS viscosity of
- A. 250 to 350.
 - B. 400 to 1000.
 - C. 400 to 600.
 - D. 500 to 600.
6. Which of the following *isn't* considered a form of predictive maintenance?
- A. Evaluating the vibration level of the bearing
 - B. Checking the lubricant level of a bearing
 - C. Checking the alignment of the shaft and bearing
 - D. Decreasing the shaft's speed
7. In an oil bath lubricant system, if the level of oil exceeds the intended maximum level, it could result in
- A. high vibration levels.
 - B. misalignment.
 - C. high temperatures.
 - D. spalling.
8. Bearings that aren't permanently sealed should be cleaned after removal using
- A. steam pressure.
 - B. a parts cleaner.
 - C. a mild acid.
 - D. high pressure water.
9. When a failed bearing displays a closely spaced group of very small cracks, the failure mode is most likely
- A. spalling.
 - B. smearing.
 - C. flaking.
 - D. peeling.
10. When choosing a seal that will be placed between two surfaces that don't move in relationship to one another, the seal would be classified as a(n)
- A. bonded lip seal.
 - B. static seal.
 - C. assembled lip seal.
 - D. dynamic seal.
11. To give bi-directional support of a shaft, two _____ ball bearings should be mounted at opposing angles.
- A. angular-contact
 - B. needle
 - C. self-aligning
 - D. cylindrical
12. Which of the following types of bearings incorporates rolling elements arranged to occupy less space than other bearing types while carrying identical large loads?
- A. Double-row roller bearings
 - B. Crossed-roller bearings
 - C. Ceramic roller bearings
 - D. Needle bearings
13. If the lip of a lip seal shows excessive wear, which of the following is the most likely cause?
- A. Abrasive contaminants
 - B. Soft shaft material
 - C. Excessive pressure
 - D. No lubrication
14. A bearing's _____ contacts the shaft it supports.
- A. inner race
 - B. outer race
 - C. cage
 - D. housing

15. Which of the following loads occurs when the load acts parallel to a ball bearing's axis?
- A. Radial load
 - B. Transfer load
 - C. Combination load
 - D. Thrust load
16. If a specified clearance is 0.004 inch and it varies between 0.0035 inch and 0.0045 inch, then the _____ would be ± 0.0005 inch.
- A. fit
 - B. tolerance
 - C. allowance
 - D. clearance
17. When monitoring the vibration level of a machine, you notice that the frequency at which most vibration energy occurs is higher than the shaft speed. You also notice that the peak-vibration frequency level isn't a direct multiple of the shaft speed. This tells you that the vibration is a result of
- A. too much lubrication.
 - B. not enough lubrication.
 - C. one or more defects on the rolling elements.
 - D. misalignment.
18. A solution added to a lubricant to help improve its ability to remove contaminants from the bearing surface is called a
- A. corrosion inhibitor.
 - B. viscosity improver.
 - C. solvent.
 - D. detergent additive.
19. When a designer selects a bearing for a particular application, he or she must consider the bearing material's properties. If the designer checks to make sure the bearing material allows change of shape, he or she is checking
- A. the resilience of the bearing material.
 - B. that the shaft-to-bearing tolerance is correct.
 - C. for high spots on the bearing.
 - D. for weak bearing components.
20. Assume that you must avoid a material that swells easily when exposed to some types of lubricants. Which material would you choose for installation in a portion of a machine where temperatures may reach as much as 400 degrees Fahrenheit?
- A. Nitrile
 - B. Polyacrylate elastomers
 - C. Fluoroelastomer
 - D. Silicone polymers