Bearings

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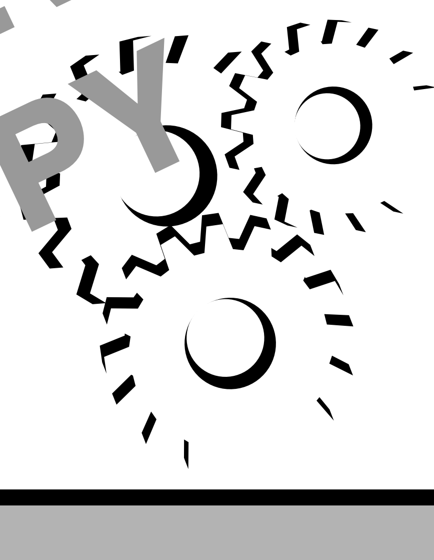
BEARINGS

Lesson One

Bearings and Shafts



TPC Training Systems

30401

Lesson

1 Bearings and Shafts

TOPICS

Bearing Classification
Bearing Selection
Principles of Bearing Operation
Shafts and Shafting
Shaft Materials
Shaft Stresses
Vibration and Critical Speed
Fits and Clearances

OBJECTIVES

After studying this lesson, you should be able to…

- Name the two main categories of bearings and cite their advantages.
- Identify bearings by the kind of support they provide.
- Describe the three kinds of stresses acting on shafts.
- Explain natural frequency of vibration and critical speed.
- Name and describe three classes of fits.

KEY TECHNICAL TERMS

Spindle 1.01 a light-duty axle shaft

Journal 1.03 the portion of a shaft in immediate contact with a bearing

Stress 1.33 force exerted on and by an elastic body (term applies to both the action and reaction forces)

Deflection 1.39 distortion or bending away from nominal position

Frequency 1.42 number of events in a given length of time (cycles per second)

This lesson introduces you to industrial machinery bearings. It briefly explains a number of different classification schemes. Then it outlines the basic principles of how bearings are selected for various machines.

This lesson also includes a section about shafts and how they operate. You will see that shafts are not completely rigid bodies. Instead, they undergo a fair amount of twisting and flexing., These elastic motions of shafts have a profound effect on bearing life and performance.Therefore, the design and selection of shafts are closely related to the design and selection of bearings. These factors are important to consider when installing both bearings and shafting, to assure proper performance of the equipment.

The final section introduces a system to describe the looseness or tightness of fit in machine parts. Depending on the purpose, machine parts that mate together can have varying degrees of snugness of fit. Maintenance mechanics who install shafts and bearings should be aware of this system for designating fits and clearance in order to avoid accidental damage to costly components.

Bearing Classification

1.01 The term *bearing* refers to any kind of support in direct contact with a moving machine part. Most bearings support rotating shafts or *spindles*. Bearings can also support or guide machine parts that slide, rather than turn. Examples include the side rails of an elevator shaft and the ways of a lathe.

1.02 Bearings are designed to minimize friction, wear, and power losses. Nearly every kind of machine uses bearings of some kind. Conveyors are the number one user of bearings, followed by fans and blowers.

1.03 Machines use two basic kinds of bearings: *plain bearings* and *antifriction bearings*. A plain bearing (also called a *sleeve bearing*) is nothing more than a simple cylinder, whole or in pieces, made to fit around the *journal* of a shaft. A film of lubricant separates the bearing surface from the journal, as shown in Fig. 1-1.

1.04 Plain bearings are usually made of relatively soft material that will not scratch the shaft. This protection is important if there should be a momentary loss of lubrication. Plain bearings can be made of bronze, babbitt metal (a tin alloy), powdered metals, cast iron, graphite, or plastic.

1.05 Plain or sleeve bearings are used mainly to support low-rpm shafts carrying heavy loads. They provide several advantages over other bearings:

- small size
- allow initial cost
- quiet operation
- easy installation and replacement
- good resistance to contaminants
- long shelf life without deterioration.

1.06 Antifriction bearings use various kinds of rolling elements. Hardened steel balls (see Fig. 1-2 on the following page) or rollers (see Fig. 1-3 on the following page) ...

Fig. 1-1. Plain journal bearing

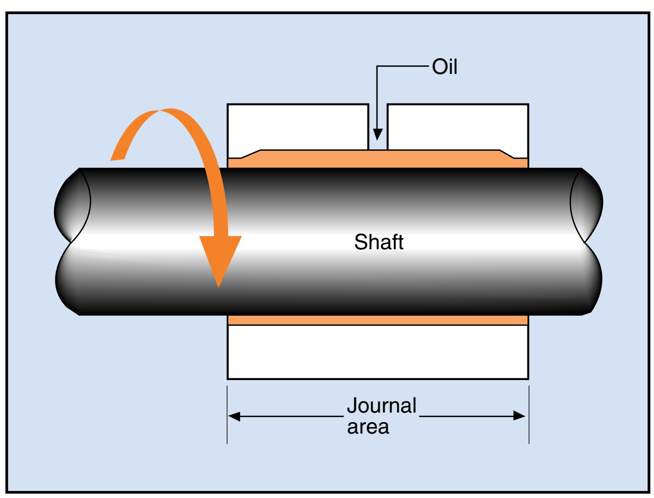


Fig. 1-2. Typical ball bearing

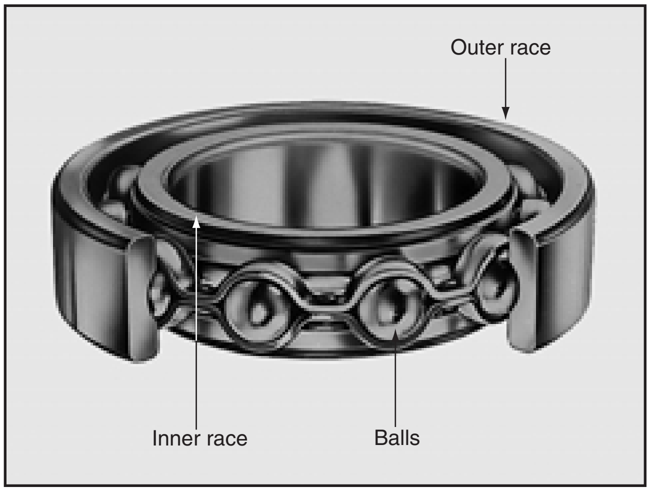
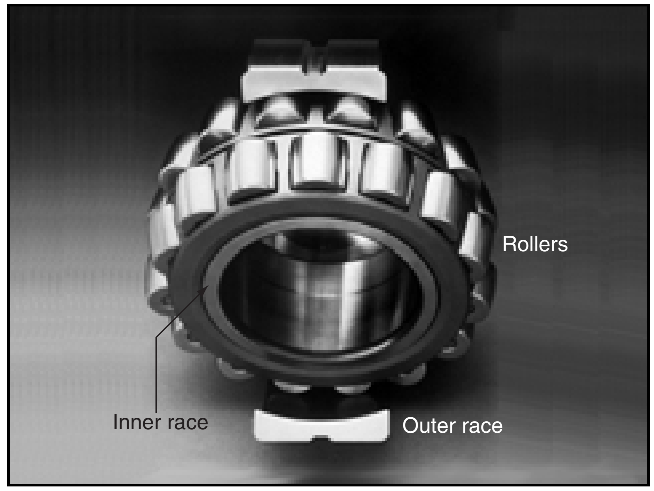


Fig. 1-3. Typical roller bearing



lowing page) surround the shaft to carry the load. This arrangement reduces friction and wear.

1.07 Antifriction bearings differ from sleeve bearings in construction and purpose. They provide rolling contact rather than sliding contact. Also, the total effective contact area is much less in antifriction bearings. Therefore, the starting friction in ball or roller bearings is considerably less than in sleeve or plain bearings.

1.08 The term *race* is applied to the rings or "tracks" of an antifriction bearing on which the rolling elements ride. In a ball bearing, the outer race does not move. The inner race fits tightly on the shaft and turns with the shaft.

1.09 The load is carried by the rolling steel balls, which are held in place by *retainers.* The retainer carries no load, serving only to keep the steel balls properly separated and positioned in the races.

1.10 Antifriction bearings provide several advantages over other bearings. Among them are:

- less power demand because of low starting friction
- less maintenance and lubrication required
- both radial and axial loads can be carried by certain types
- higher-speed operation
- ability to perform under adverse operating conditions.

1.11 Bearings can also be classified by function into three main types. Each type may be plain or antifriction in design, and each type provides its own particular kind of support.

- *Journal bearings* support the radial load on a rotating shaft and confine radial motion.
- *Thrust bearings* support the axial load on a rotating shaft and prevent axial or lateral motion.
- *Guide* or *slipper bearings* are used to guide and support sliding components (in linear motion).

1.12 The importance of bearings can be seen in a gear pump used to provide pressure in a hydraulic system. In Fig. 1-4, the bearings support a heavy load. The bearings also maintain the correct alignment of the shafts on which the driving and driven gears are mounted. If any one of the bearings should fail, the shaft alignment changes, and the gears may jam. Then the whole system will fail.

Bearing Selection

1.13 When selecting bearings for an application, the machine designer must make sure that they are heavy-duty enough to support the load, yet as close to frictionless as possible. High efficiency is needed, because the power delivered to the working point of the equipment must be sufficient to get the job done. That is, the total loss of power due to bearing friction cannot be too great to prohibit the availability of enough usable power for the job.

1.14 Basically, the major requirements to consider in bearing selection are:

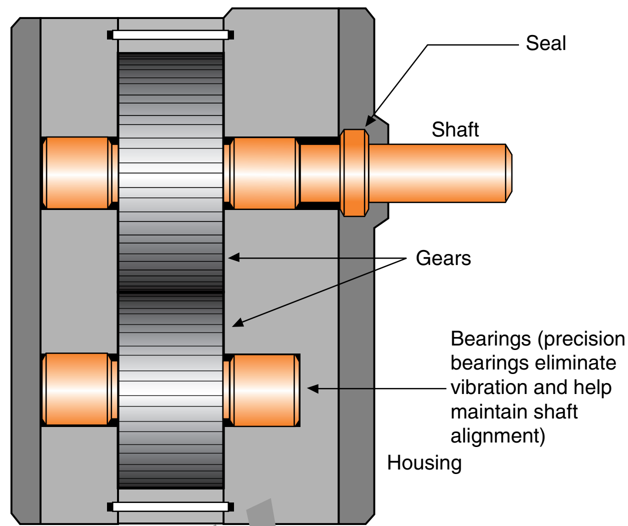
- equipment purpose and type
- power needed
- required bearing life
- equipment location (indoors/outdoors, corrosive or contaminated surroundings)
- load (the amount of weight or pressure the bearings must support)
- type of load (axial, radial, or a combination)
- tolerances and fit
- bearing location within the equipment
- shaft speed (rpm)
- operating temperature
- lubrication.

Other factors may also be considered in unusual circumstances.

1.15 In nearly every application, a *shaft* is involved. The shaft's speed, location, function, and load all have a direct effect on the bearings that support it and confine its motion.

1.16 A missile guidance system shows how critical bearings are in a precision application. High-speed gyroscopes are mounted on bearings that must run vibration free. Spindles must be closely confined and in perfect balance. Bearing loads are light, but tolerances, fit, and perfect uniformity of bearing elements are vital. Because of the operating temperatures, selection of the lubricant is also very important to the success of the system.

Fig. 1-4. Typical bearing and gear application



1.17 Similar factors are considered in the design of any piece of equipment or machine, because their elements are much the same in principle. The only real differences among equipment types are differences in loads, tolerances, power requirements, and operating speeds. However, these four factors can combine in many different ways, creating many different bearing requirements. Fortunately, the designer has a wide variety of standard bearings to choose from and can find a suitable bearing for almost any application.

Principles of Bearing Operation

1.18 When two surfaces roll or slide over each other, friction develops. *Friction,* which is resistance to movement, generates heat, increases power requirements, and has other undesirable effects. Friction can be reduced in two ways. One is lubrication, which provides a lubricant film between moving components. The film creates a smooth surface on which the sliding or rolling elements can travel. The other means is to use bearings, which themselves must be lubricated.

1.19 In addition, bearings confine or restrain the movement of shafts and slides. By acting as guides, bearings help control the motion of the parts they are supporting. In that way, bearings also help reduce or eliminate vibration, which can be extremely destructive to an operating mechanism.

1.20 By confining the motion of a shaft, bearings assure smoother and more efficient shaft operation.

Fig. 1-5. Motor-driven fan

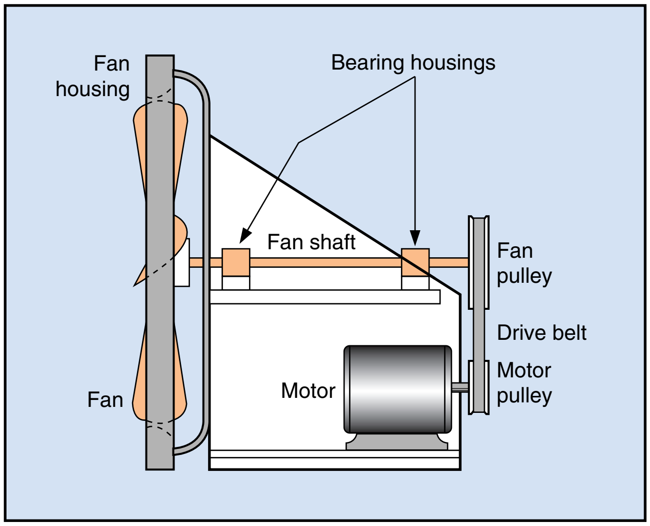
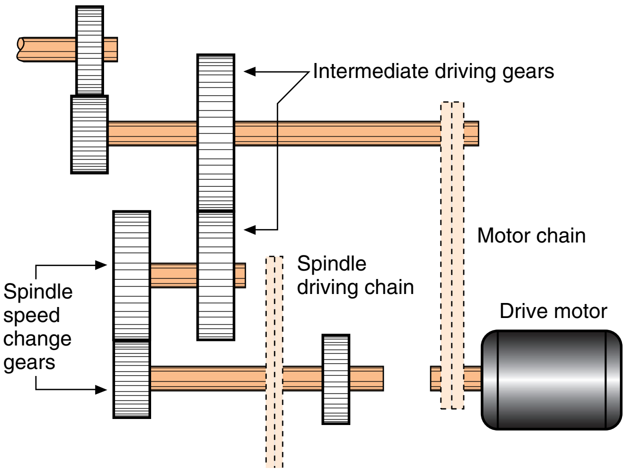


Fig. 1-6. Power transmission in a lathe



That, in turn, makes the whole power transmission system more efficient by helping the required power reach the work-delivery point with a minimum of loss.

1.21 An important point to remember is that the bearings used in any application were carefully selected to meet the design requirements of that application. That is why you should always use the same type and class of bearing when it comes time to replace a bearing.

Shafts and Shafting

1.22 Shafts are used in equipment found in plant facilities of all types. In nearly every case, the shafts are part of mechanical power transmission systems. Figure 1-5 shows a familiar example—a ventilating or exhaust fan driven by an electric motor.

1.23 The motor shaft turns the fan shaft through a belt drive. The pulleys determine the final speed of the fan blades. The fan has a given job to do—to circulate air. In addition to the belt, the motor and fan shafts are necessary transfer links to provide the fan with the power to do the job. Both shafts run in bearings, which also become critical in the power transfer process.

1.24 Figure 1-6 shows a system of shafts and gears used to drive a lathe. It is different from the drive unit shown in Fig. 1-5 in the number of shafts involved, but no more complicated in principle. The shafts and gears in both systems are used to get the needed power to the work-delivery point.

1.25 A lathe needs several shafts, because it has several different jobs to do. One set of gears and shafts transmits power to move the cutting tool axially. Another drives the crossfeed screw. The machine spindle itself is a shaft on which the workholding chuck is mounted. In the system shown in Fig. 1-6, the spindle is driven by a chain and sprocket drive.

1.26 The power available from a lathe motor is useless unless it can be delivered to the point at which the actual machining is done. The shafting on a lathe is different from that on a ventilating fan, because each has a different job to do. Common to both pieces of equipment is the need for enough power to do their respective jobs, and the need for components to transmit that power efficiently.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of the book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. Rotating or sliding components in equipment are supported by ________.	1-1. BEARINGS Ref: 1.01
1-2. The two basic kinds of machinery bearings are ________ and ________ bearings.	1-2. PLAIN, ANTIFRICTION Ref: 1.03
1-3. In a plain bearing installation, the component that is made of the softer material is the ________.	1-3. BEARING Ref: 1.04
1-4. In antifriction bearings, the tracks on which the balls or rollers move are called ________.	1-4. RACES Ref: 1.08
1-5. Can antifriction bearings carry both radial and axial loads?	1-5. YES Ref: 1.10
1-6. Components that slide in a linear motion are guided and supported by ________ bearings.	1-6. GUIDE or SLIPPER Ref: 1.11
1-7. Two of the main reasons bearings are used are to reduce ________ and ________.	1-7. FRICTION, VIBRATION Ref: 1.18, 1.19
1-8. In machines, shafts normally serve to ________ power.	1-8. TRANSFER or TRANSMIT Ref: 1.22

Shaft Materials

1.27 The success of a mechanical power transmission system depends on having properly selected shafts. Good shafting should have smooth, clean surfaces that are free from nicks, gouges, burrs, and other irregularities. They should be sized correctly and made of the proper material.

1.28 Most shafts are made from plain, low-carbon steels. As a rule, shafting is cold rolled in diameters up to 2⁵⁄₁₆ in. Shafting is turned and polished in diameters over 2⁵⁄₁₆ in.

1.29 Some applications may require special shafting that is different in form, shape, heat treatment, or material. Examples include shafts for operation at high temperatures or in corrosive environments. Special shafting is required in other cases that involve limitations in diameter, service requirements, or close tolerances.

1.30 Shafts with special shapes may be called for in some applications. Square, hexagonal, and hollow shafts are available commercially, or they can be custom made for specific applications.

1.31 Special shafting materials include bronze, stainless steel, high-carbon steel, or any of the alloy steels. Heat treatment provides the properties required for special applications. One reason for using special materials is that the physical characteristics of cold-rolled steel can vary. Shafts requiring uniform physical characteristics or large diameters are often hot rolled or forged, and then turned on a lathe to finished size.

Table 1-1. Tolerances for standard shaft diameters

	Diameter tolerance (in.)	
Shaft diameters (in.)	Oversize	Undersize
Up to 1	0.000	0.002
1 1/16 to 2	0.000	0.003
2 1/16 to 4	0.000	0.004
4 1/16 to 6	0.000	0.005

1.32 Table 1-1 shows the tolerances of standard shaft diameters up to 6 in. Note that the shafting is never allowed to be oversize. It is always good practice to check the diameter and length of a shaft before attempting to install it. Checking beforehand can often save time and effort later on.

Shaft Stresses

1.33 Shafting is subject to the action of forces called *stresses.* Three different stresses act on shafts:

- *Torsional stress* is the result of twisting.
- *Bending stress* is the result of radial loading.
- *Axial stress* is the result of end loading and acts parallel to the length of the shaft.

1.34 In Fig. 1-7 and 1-8, you can see how torsion and radial loading affect a shaft. If any of the stresses is excessive, the shaft will fail. Shaft failure is uncommon, however, because machines are designed with

Fig. 1-7. Applying a torque load to a shaft

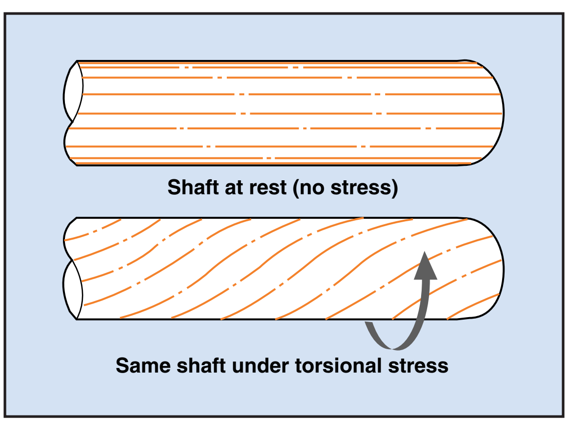
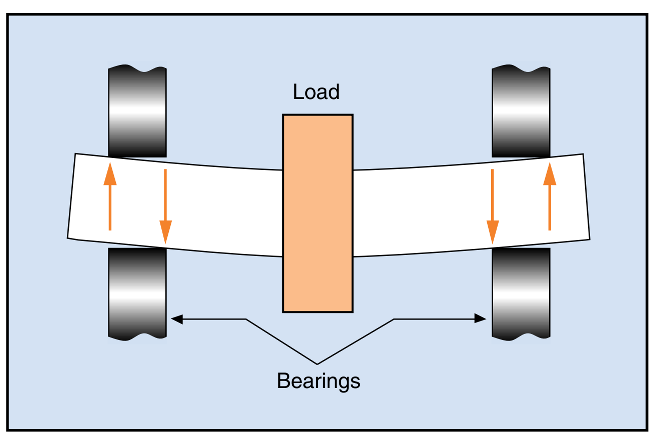


Fig. 1-8. Bending stress on a shaft



consideration of the expected shaft stresses, with a built-in margin of error for safety. Many of the factors that determine bearing selection are also considered in shaft selection. Typical examples are the speed and power requirements.

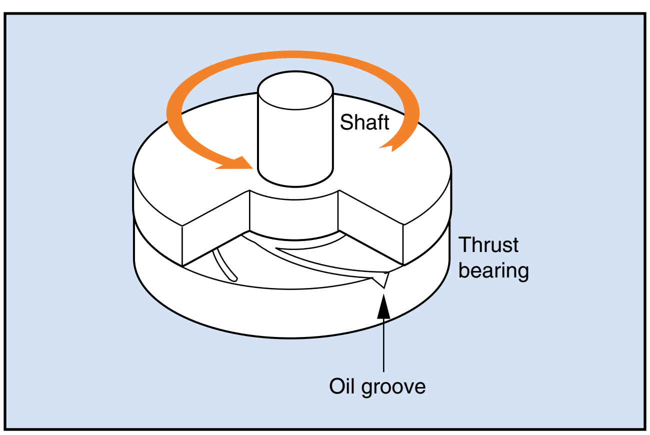
1.35 **Torsional stress.** A steel shaft actually twists when torque is applied, as shown in Fig. 1-7, although you probably will not be able to see it in a real shaft in operation. Whenever a shaft transfers power, it is twisted to some degree by the torsional load of operation. When the shaft stops rotating, the torsional load usually drops to zero. The shaft then returns to its original, untwisted condition.

1.36 At the instant power is applied, an extra starting torque causes an additional amount of loading to come to bear on the shaft. As more loads are added, additional torsional stress is applied to the shaft.

1.37 **Bending stress.** Although a shaft is supported by bearings, it may also have pulleys or gears mounted at various places between the bearings, or even outboard of the bearings. The weight of these components and the tension of belts on pulleys cause radial loads on the shaft. The result is bending stress in the shaft. Figure 1-8 exaggerates the bending to illustrate the effect on the bearings. Notice how the bend causes excessive pressure at the edges of the bearings. In time, the effects of bending show up as spotty, uneven wear, especially in sleeve bearings.

1.38 **Axial stress.** Loading parallel to the centerline of the shaft causes axial stress. The load may be a compression or a tension on the shaft. In shafting used for power transmission, axial stress is not a serious problem. Thrust bearings, such as the one pictured in Fig. 1-9, are used to bear the axial compressions on a shaft. They also contain the shaft effectively, preventing it from moving back and forth.

Fig. 1-9. Plain thrust bearing



1.39 In practice, most shafts are subject to a combination of torsional, bending, and axial stresses. All these stresses are taken into account by the engineer in specifying components. The specification makes the necessary allowances for the maximum loads that may be encountered, while keeping shaft *deflection* to an absolute minimum. Excessive shaft deflection wastes energy and accelerates wear.

1.40 One way of controlling shaft deflection is to choose shaft diameters on the large size, although cost must be considered. A larger shaft helps increase bearing life as well. Remember that the shaft's resistance to deflection is determined by the size of the shaft and the strength of the component material.

Vibration and Critical Speed

1.41 In addition to the various stresses that cause shaft deflection, several other factors also influence shaft behavior. For practical purposes, only the two most prominent will be considered here. One is *vibration.* The other is *critical speed,* which will be defined shortly.

1.42 Vibration is common enough to require no lengthy explanation. Nearly everyone is familiar with it, but few people can tell you how it happens and what it really is. Figure 1-10 on the following page shows a rod or shaft of steel supported at both ends. If you were to tap it lightly, the rod would vibrate at a fixed *frequency*. The frequency depends on the size and length of the rod, as well as on the material.

1.43 If you were to hit the rod again harder, it would vibrate harder, but at the same frequency. This frequency is called the rod's *natural frequency,* or *resonant frequency.* If you change the setup by adding a pulley or a gear (see Fig. 1-11 on the following page), the natural frequency of vibration will be lowered. The natural frequency for each shaft is significantly affected by the parts attached to the shaft and their arrangement.

1.44 As the shaft is rotated at an increasing speed, a point will be reached at which the whole machine

Fig. 1-10. Shaft vibrating after being struck

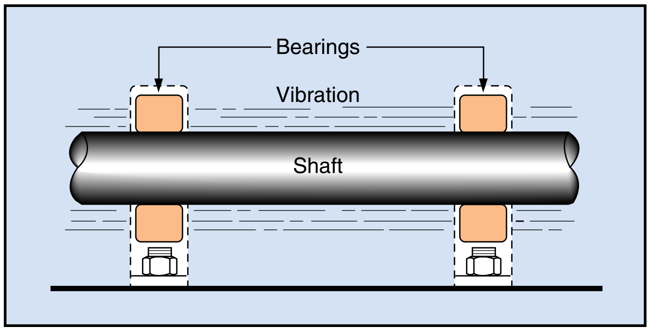
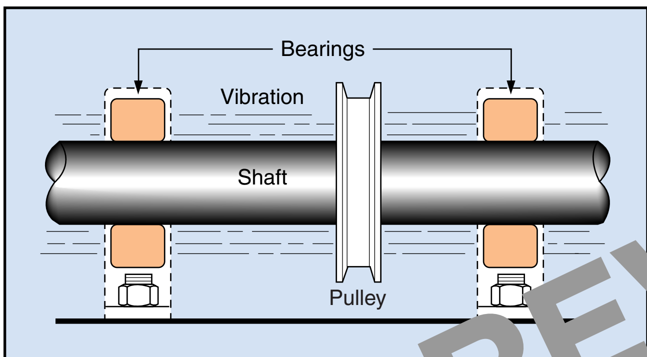


Fig. 1-11. Shaft vibrating at a lower frequency



begins to shake violently. The shaft is deflecting uncontrollably, with the strong vibrations occurring at its natural frequency.

1.45 When the speed of shaft rotation equals the shaft's natural frequency of vibration, a condition known as *critical speed* is reached. To avoid the severe shaking and destructive effects of critical speed, the machine designer will specify a shaft that has a natural frequency much higher than its expected operating speed.

1.46 Vibration at critical speeds must be avoided, because of its harmful effect on bearings. Vibration is a very common cause of excessive wear and bearing failure. When a bearing fails, it no longer controls the shaft's movement. The shaft and its attachments will then wear excessively without the guidance of the bearing.

1.47 When a bearing fails, the results show up quite quickly. If you are standing nearby when it happens, you cannot mistake the sound. It changes from the soft purr of a smooth-running bearing to a loud knocking or rattling sound.

Fits and Clearances

1.48 A *fit* is an allowance for variation in the dimensions of a shaft, bearing, fastener, or opening. Fits are applied mostly to mating parts. Basically, there are three classes of fits. They are:

- running and sliding fits
- locational fits
- force fits.

Each type is broken down further, in accordance with a standard numbering system. The standards are set up to make it easier to select components that will mate properly.

1.49 *Running and sliding fits* are those that allow freedom of rotation or movement, while also allowing proper clearances for lubrication of the surfaces. This class is divided into nine subclasses, numbered 1 through 9. The lower the number, the tighter the fit.

1.50 RC3 is an example of the code that is used. The letters RC identify it as a running and sliding fit. The number 3 identifies the subclass as a *precision running fit*, meaning that parts made to this fit are as close as can be matched together and still run freely. This fit is intended for precision work that runs at slow speeds, where the journal pressure is light, and temperatures are not likely to change much. Too great a temperature increase would result in enough expansion to cause seizing.

1.51 An RCl fit is a *close sliding fit* used for accurately positioning parts in assemblies that must have a minimum of free movement. RC8 and RC9 indicate *loose running fits* used in applications where materials are mass produced to commercial tolerances.

1.52 *Locational fits* are divided into three subclasses, all three of which are intended only to locate mating parts. Letters are used instead of numbers to identify the subclasses. The first subclass, locational *clearance fits* (identified by the letters LC), is for parts that normally do not move, but can be easily assembled and disassembled. They can provide a snug, medium, or loose clearance, depending on the application.

1.53 The second type of locational fit is identified by the letters LT, which stand for locational *transition fits*. They are a compromise between locational clearance fits (LC), and the third subclass, locational *interference fits*, which are identified by the letters LN.

1.54 Locational interference fits (LN) are used for applications in which accuracy of location is essential, and for parts requiring rigidity and alignment. However, these fits are not intended for applications in which the transmission of motion depends on the fit.

1.55 *Force fits* are a special type of interference fit used to maintain bore pressures. Identified by the letters FN, force fits are furnished in any of five classes, ranging from FN1 (light drive fits) to FN4 and FN5 (shrink fits).

1.56 The shafts and bearings you will be working with have been chosen with a specific fit in mind. The worn bearings you will be replacing and the fits required to do the job are the best ones to handle the stresses, speeds, loads, conditions, and temperatures of the particular application. Make sure you maintain the proper fits in the equipment you service.

1-9. Unless they must serve a special purpose, most machine shafts under 2 5/16 in. in diameter will be made of cold-rolled ________ steel.	1-9. LOW-CARBON Ref: 1.28
1-10. Name at least two shaft materials used for special applications.	1-10. BRONZE, STAINLESS STEEL, HIGH-CARBON STEEL, ALLOY STEEL Ref: 1.31
1-11. The type of shaft stress that results from end loading is called ________ stress.	1-11. AXIAL Ref: 1.33
1-12. When torque is applied to a shaft, it causes the shaft to ________.	1-12. TWIST Ref: 1.35, Fig. 1-7
1-13. Loading along the centerline of a shaft is called ________ stress.	1-13. AXIAL Ref: 1.38
1-14. The frequency at which a shaft, under given conditions, vibrates, is called its ________ frequency.	1-14. NATURAL or RESONANT Ref: 1.43
1-15. When the speed of shaft rotation equals the shaft's natural frequency, the shaft's ________ is reached.	1-15. CRITICAL SPEED Ref: 1.45
1-16. Force fits are identified by the letters ________.	1-16. FN Ref: 1.55

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. The basic purpose of bearings is to

- ☐ a. lubricate moving machine parts
- ☐ b. protect journals from grit and contaminants
- ☐ c. provide unconfined axial movement
- ☐ d. support moving shafts and slides

1-2. The major categories of machine bearings are

- ☐ a. journal and guide
- ☐ b. plain and antifriction
- ☐ c. plain and sleeve
- ☐ d. thrust and journal

1-3. Suppose a shaft is supported at each end by a ball bearing. As the shaft rotates, what happens to the bearing races?

- ☐ a. All four races rotate, but at a speed slightly slower than the shaft
- ☐ b. Both inner and outer races rotate with the shaft
- ☐ c. The outer races rotate, the inner races are stationary
- ☐ d. The two inner races rotate with the shaft, the outer races are stationary

1-4. What kind of motion is restricted or prevented by a journal bearing?

- ☐ a. Axial
- ☐ b. Radial
- ☐ c. Rotational
- ☐ d. Torsional

1-5. Bearings are most often selected on the basis of

- ☐ a. how well they match the equipment requirements
- ☐ b. the hardness of their load-carrying surfaces
- ☐ c. their frequency of replacement
- ☐ d. their original cost

1-6. It is important to reduce bending stresses on shafts, because

- ☐ a. a great percentage of power is lost in the bending action
- ☐ b. bearings can wear unevenly, due to the bending action
- ☐ c. shaft journals can lose their supporting strength
- ☐ d. shafts may become brittle and break

1-7. Loading along the centerline of a shaft produces _________ stress.

- ☐ a. axial
- ☐ b. lateral
- ☐ c. radial
- ☐ d. torsional

1-8. Violent shaft vibration occurs when the

- ☐ a. critical mass of the shaft equals its critical speed
- ☐ b. frequency of the bearing matches the frequency of the shaft
- ☐ c. rotational speed of the shaft equals its natural frequency
- ☐ d. shaft speed exceeds the harmonic frequency of the bearing

1-9. The letters RC3 identify what type of fit?

- ☐ a. Close sliding
- ☐ b. Light drive
- ☐ c. Precision running
- ☐ d. Shrink

1-10. The tightest locational fit, used where parts must be aligned most accurately and rigidly, is the ________ fit.

- ☐ a. LC1
- ☐ b. LN
- ☐ c. LT
- ☐ d. RC9

SUMMARY

This lesson has provided an explanation of the basic purpose and operating principles of bearings. The main function of a bearing is to support and guide the moving elements of a machine. Some bearings support rotating shafts, others support frames or carriages that slide in a linear fashion.

The choice of bearings is related to the demands of a particular application. Plain bearings do a good job of supporting low-speed shafts with heavy radial loading. Antifriction bearings are better for high-speed shafts, or for applications where low starting friction is required. Some bearings must bear an axial load in addition to the usual radial load. All bearings should confine the shaft, as much as possible, strictly to rotational motion.

Shaft selection is as critical as bearing selection, since a shaft may be subject to several kinds of stresses. Torsional stress occurs when power is applied. Bending stress may be caused by belt tension on a pulley or the sheer weight of a heavy impeller. If a shaft flexes too much, its bearings will wear excessively. Bearing life can also be shortened when a shaft vibrates violently, as it does when the shaft reaches its critical speed of rotation.

There are three classes of fit for mating parts. Running and sliding fits, comprised of nine subclasses, include all those fits that can be assembled and disassembled by hand. The next class is the locational-fit class, where parts fit together snugly, with no movement allowed. Finally, the closest fits of all are the force fits, including those where the fit must be tight enough to transfer rotational motion without slippage.

Answers to Self-Check Quiz

1-1. d. Support moving shafts and slides. Ref: 1.01

1-2. b. Plain and antifriction. Ref: 1.03

1-3. d. The two inner races rotate with the shaft, the outer races are stationary. Ref: 1.08

1-4. b. Radial. Ref: 1.11

1-5. a. How well they match the equipment requirements. Ref: 1.17, 1.21

1-6. b. Bearings can wear unevenly, due to the bending action. Ref: 1.37

1-7. a. Axial stress. Ref: 1.38

1-8. c. Rotational speed of the shaft equals its natural frequency. Ref: 1.44, 1.45

1-9. c. Precision running. Ref: 1.50

1-10. b. LN fit. Ref: 1.54