Lesson One — Principles of Bearings and Shafts

Preface

This lesson explains the general principles of bearing operation. It also includes a section about shafts and their behavior. The importance of shaft action on bearing life and performance is so great that it's one of the controlling factors in the design and selection of bearings. Correct design, selection, and installation of both bearings and shafting are essential to assure proper performance of the equipment where they're used.

Each occupation, sport or profession has its own vocabulary, and the subject of bearings, has, too. As in other units of this series, definitions of terms which may be new are explained.

Bearing Selection

1.01 The word BEARING means any kind of support for a rotating shaft or spindle. (In some areas, the word SPINDLE is used when referring to a small shaft.) It can also be a support or guide for one component of a piece of equipment which slides across another, such as the side rails of an elevator or the slide on a lathe. Nearly all mechanisms have one or both types of unit or surface, and require some kind of bearing.

1.02 Bearing selection for any application depends on the application itself. The factors considered are those which will make certain that the horsepower required at the working-point of the equipment is sufficient to get the job done. Basically, the equipment and machine designers calculate what's required to assure that the bearings will be adequate to support the loads on the various components between the power source and work-delivery point.

1.03 Those factors are as follows:

1. Equipment purpose and type
2. Horsepower needed
3. Required bearing life
4. Equipment location (indoor, outdoor, corrosive surroundings)
5. Load (the amount of weight or pressure which the bearing must support)
6. Type of load (axial, radial, combination)
7. Shafts
8. Tolerances

9. Design of equipment (location of bearing in equipment)
10. Shaft speed (rpm)
11. Operating temperature
12. Lubrication

Other factors may also be considered, of course, but those are the major ones.

1.04 In nearly every one of those considerations, a shaft or way is involved. In the majority of cases it will be a shaft. Its speed, location, function, and the type of load it carries all have a direct relationship to the bearing which will be used to support the shaft or confine its motion. (The reasons will be given later in this lesson and in following lessons.)

1.05 As one example, the bearings in a missile-guidance system control the shafts which must run vibration-free to get the perfect balance required. Precision bearings are used to closely confine the motion of the respective components. The loads are probably light, but balance is vital in order to maintain accuracy of operation. This becomes a bearing design consideration. Because of the temperatures which the unit will operate under, suitable bearing lubricant selection becomes vitally important, too. Because it's an operating mechanism having moving parts, such a critically important unit must be designed and built with particular care. Proper bearing design and installation are all-important to the success of such a system.

1.06 Those same factors are considered in the design of any equipment or machine, because their elements are much the same in principle. About the only real difference among equipment types is the job which each is built to do. This will mean a difference in loads, tolerances, horsepower requirements, and operating speeds. Aside from the physical differences such as size, shape, and type of controls, most of their operating elements and components are much the same. Fortunately, the designer has a wide variety of standard bearings to choose from, and can find a suitable bearing for almost any application.

1.07 An important point to remember is that the bearing used in an application was selected because it met the design requirements of the equipment. That's why it's important to use the same type and class of bearing when it becomes necessary to replace a bearing.

The exercise on the next page covers the material you have just read. Using the REVEAL KEY as explained in the Trainee's Guide, carefully read and answer the first question and check your answer against the printed one before proceeding to the next question. If the answers do not agree, review the material in the paragraph or figure given in the answer frame.

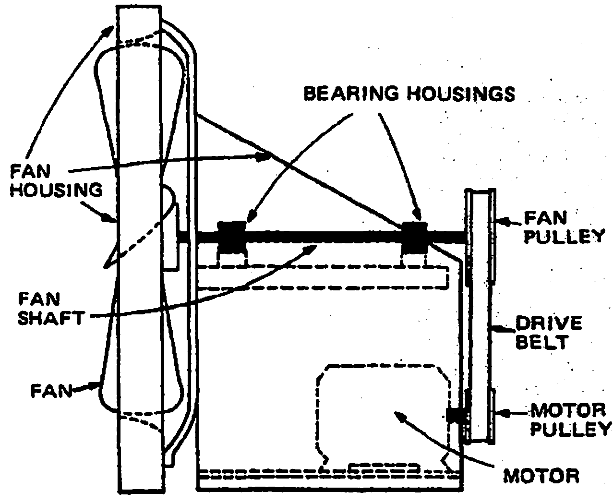


Fig. 1-1. *View of ventilating fan, showing shaft and bearing mountings.*

Shafts and Shafting

1.08 Shafts are used in equipment found in plant facilities of all types. In nearly every case, they are part of a mechanical power transmission system. (Except for electric motors, most electrical equipment doesn't use shafts.) Figure 1-1 shows a familiar example, a ventilating or exhaust fan, driven by an electric motor. The motor shaft turns the fan shaft by a belt and pulley arrangement. The pulleys help produce the speed required to run the fan most efficiently under its operating conditions. The fan has a given job to do. The motor and fan shafts are necessary parts of the arrangement to provide the fan with the needed power to do that job. Both shafts must run in bearings.

1.09 Figure 1-2 shows what seems to be a complicated arrangement of shafts and gears. It is different from that shown in Fig. 1-1, but is actually no more complicated, because the extra shafts and gears perform a similar function. They are the means used to get the needed horsepower to what we'll call the work-delivery point. If the arrangement shown in Fig. 1-2 is for a lathe, for example, more than one job may have to be done. One set of gears and shafts will transmit power to move the tool slide. The machine spindle itself is a shaft on which the work-holding chuck is mounted. It is driven by a chain and sprocket at the speed found to be the most efficient for making the cut which is being taken. The amount

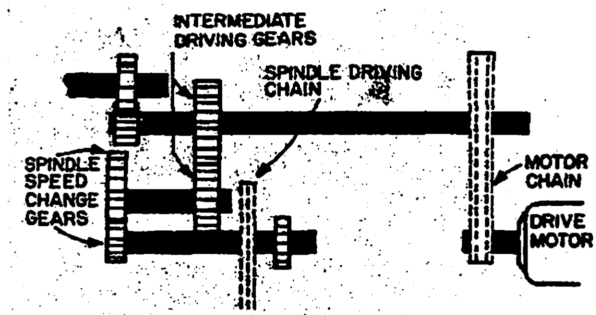


Fig. 1-2. *Motor, shafts, and gears of a typical power transmission arrangement in a machine tool.*

of horsepower available from the motor is absolutely useless, however, unless it can be delivered to the point where the actual machining is done. The arrangement is different from the ventilating fan, but only because the job of the lathe is different. 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.

Shaft Materials

1.10 Because shafting is so widely used in mechanical power transmission, the success of such a system may well depend on proper selection of shaft size and shaft material. Shafting made by the best manufacturing methods has a smooth, clean surface and is free from irregularities. For most uses, the shafts are made from plain, low-carbon steels. As a rule, shafting in diameters up to 2-5/16" is cold-rolled. Shafting 2-5/16" in diameter and above is usually turned and polished.

1.11 Some applications may require special shafting, different in form, heat treatment, or type of material. Examples include shafts for operations at higher temperatures, or for conditions where the shafting will have to resist corrosion or other chemical action. In other cases, limitations in diameter, service requirements, or the need for more exact tolerances may be the reasons that special shafting is required.

1.12 Special-analysis materials include bronze, stainless steel, high-carbon steel, or any of the alloy steels. Heat treatment provides the properties required for certain applications.

1.13 Shafts having special forms or shapes (square, hexagonal, or hollow) may be required in some cases. That type of shafting is either already available, or can be made up to meet the needs of the application.

1.14 One reason for using special materials is that the physical characteristics of cold-rolled steel can vary. Shafts requiring uniform physical characteristics or of large diameters are quite often hot-rolled or forged, and turned down to finished size. Table 1-1 shows the tolerances of standard shaft diameters up to 6 inches. You will note that in no case is the shafting allowed to be oversize. (Note: It is always good practice to check the diameter and other dimensions of a shaft before using it, on the off-chance that the wrong size was supplied. Checking beforehand can often save you considerable time and effort later on.)

1.15 Shafting is subject to the action of forces called STRESSES. Stresses on shafts are of three main types, as follows:

1. Torsional, or twisting (taken from the word TORQUE, which is defined as being "that which produces rotation or torsion").
2. Bending stress.
3. Axial stress (parallel to the center line of the shaft).

Figures 1-3 and 1-4 show how such stresses affect a shaft. If any of the stresses are excessive, the shaft will fail. Shaft failure is uncommon, however, because any given shaft has been designed with consideration of the stresses expected in its use. Again, many of the same factors which determine bearing selection are considered in shaft design. Typical examples would be speed and horsepower required. If and when a plant engineer has to choose a round shaft size, he usually knows both how much horsepower will be required, and the speed. He then has to consider the stresses involved, so that the proper shaft diameter will be chosen. Standard formulas and tables will provide him with the figures he'll need.

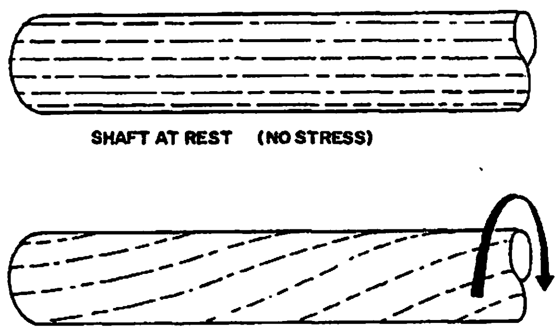


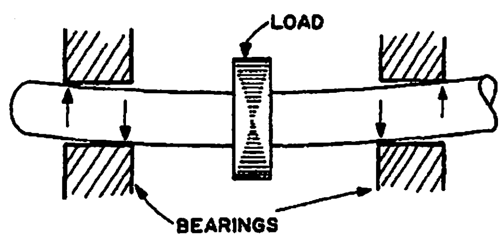
Fig. 1-3. How a shaft is affected by torsional or twisting stress.

Table 1-1. Tolerances for Standard Shaft Diameters		
Shaft Diameters in inches	**Diameter Tolerance in inches**	
	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

Torsional Stress

1.16 In Fig. 1-3, you saw that the shaft will actually twist when torque is applied. You may not be able to see it, but it does occur. Whenever the shaft is rotating, it is twisted to some degree when the amount of stress is steady. When the shaft stops rotating, the torsional stress is removed.

Fig. 1-4. An example of how bending stress affects a shaft.



and the shaft returns to its original position. When a motor is started, there's an extra starting torque, which causes additional stress. As other loads are introduced into the system additional torsional stresses are applied to the motor shaft. All these stresses are calculated for the whole power transmission system and seldom present problems.

Bending Stress

1.17 A shaft, although supported by bearings, may also have pulleys or gears mounted on it at points between the bearings. The weight and load of these units will naturally pull on the shaft, causing it to bend. This effect, where it occurs, is called bending stress. While Fig. 1-4 has been slightly exaggerated to better illustrate the point, the effect of bending stress on bearings is very much a fact. In time, that effect is made obvious by excessive bearing wear, particularly with certain types of bearings, such as sleeve bearings (to be described in Lesson Two).

Axial Stress

1.18 Axial stress, in which pressure is along the center line of the shaft, isn't much of a problem in shafting used for power transmission. Thrust bearings are used to prevent endwise motion of the shaft, however, as will be explained later in this lesson.

Combination Stresses

1.19 In practice, most shafts are subject to a combination of both torsional and bending stresses. Design engineers make the necessary allowances for the stresses involved in any given application in order to minimize the effect of shaft deflection. One way of accomplishing this is to choose shaft diameters on the large side, although the added cost must be considered. Doing so helps increase bearing life, as well. Resistance to shaft deflection is determined by the size of the shaft, and by the shaft material itself.

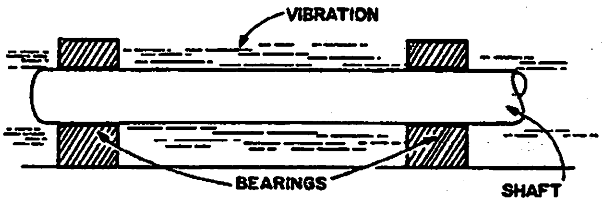


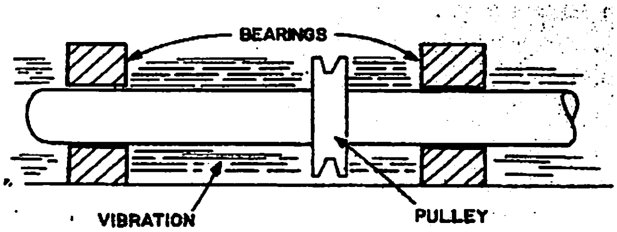
Fig. 1-5. When struck, a well-supported shaft will vibrate at a given rate.

Other Factors

1.20 In addition to the various stresses which cause shaft deflection, other forces have a definite influence on shaft behavior. For practical purposes, two are considered. One is vibration. The other is what's called critical speed, which will be defined shortly.

1.21 Vibration is common enough to require no lengthy explanation or definition. Nearly everyone is familiar with it, but few people can tell you you how it happens and what it really is. Figure 1-5 shows a rod or shaft of steel supported at both ends. If you were to tap it lightly, the rod would vibrate. It would do so at a given rate, depending on the size and length of the rod, as well as the material. If you were to strike the rod a second time, but much harder, it would bounce or vibrate much more noticeably than it had the first time. The rate of bounce, or number of vibrations per second, would remain exactly the same, however. You would refer to the frequency of vibration, meaning the number of vibrations per second. If we change the setup, as in Fig. 1-6, by adding a pulley or gear, the frequency of vibration will be lower. The bearings at both ends of the rod will also be affected by the vibration. The amount of

Fig. 1-6. With pulley mounted on shaft shown in Fig. 1-5, the vibration rate will change.



shaft deflection will have an effect on the frequency of vibration, making it still lower.

1.22 If the shaft is rotated at an increasing speed, a point will be reached where the whole setup will begin to shake violently. That's because the shaft is deflecting uncontrollably.

1.23 The speed of shaft rotation which is equal to the shaft's frequency of vibration is known as the CRITICAL SPEED. To avoid the destructive effect of critical speed, the designer will specify a shaft which will operate at a speed well below the critical speed.

1.24 It's because these conditions do exist that they're mentioned here. Both vibration and critical speed are to be avoided because of their effect on bearings. You're more likely to see the effects of vibration when a bearing fails or wears excessively. The path of the shaft movement which is ordinarily controlled or confined by a bearing will change if and when the bearing fails. When that does happen, the results don't take long to show up. You very probably will hear the trouble first, depending on the location of the bearing in the equipment.

Fits and Clearances

1.25 Basically, there are three classes of fits, which are allowances for variation in dimensions of shafts and holes. The object of setting up standards for such fits is to make selection of the proper components that much easier. The three general groups of fits are (1) running and sliding fits; (2) locational fits; and (3) force fits. Each type is broken down further, in accordance with a standard numbering system.

1.26 Running and sliding fits are those which allow rotation or movement with proper allowance having been made for lubrication. This will be true for each of the nine classes of running fit. RC_3 is an example of the numbering system used. The letters RC identify it as a Running and Sliding fit. The number 3 identifies the class called a PRECISION RUNNING FIT, meaning that parts made to this fit are as close as can be matched together and still run freely. That fit is intended for precision work which will run at slow speeds, where the journal pressures will be light, and temperatures aren't likely to change much. (Too great a temperature difference will result in enough expansion of the shaft to cause seizing.)

1.27 An RC_1 fit is a CLOSE SLIDING FIT used for accurately locating parts in assemblies which must have a minimum of free movement. An RC_8 or RC_9 is a LOOSE RUNNING FIT used for applications where materials made to commercial tolerances are involved. In other words, the lower the number of the class, the tighter the fit.

1.28 Locational fits are divided into three types all three of which are intended only to locate mating parts. Locational Clearance fits (identified by the initials LC) are for parts which normally don't move, but which can be easily assembled or disassembled. They can provide a snug, medium, or loose clearance, depending on the application.

1.29 The second type of Locational fit is identified by the letters LT, standing for Locational Transition fits. They're a compromise between Locational Clearance fits and the third type, Locational Interference fits, which are identified by the letters LN.

1.30 Locational interference fits are used when accuracy of location is essential, and for parts requiring rigidity and alignment. These fits aren't intended, however, for applications where the transmission of motion depends on the fit.

1.31 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 FN_1 (light drive fits) to FN_4 and FN_5, which can be used for shrink fits.

1.32 The shafts and bearings you'll work with have been chosen with those considerations in mind. It's one more reason for the importance of using the correct bearing as a replacement, when replacement is necessary.

Principles of Bearing Operation

1.33 When two surfaces roll or slide over one another, friction develops. Friction, which is resistance to movement, generates heat, increases horsepower requirements, and has other undesirable effects. Reducing or eliminating friction is accomplished in two ways. One is lubrication, which provides a lubricant film between moving components. The object is to provide a smooth surface for the sliding or rolling members to travel on. The film of lubricant actually does separate the moving parts, under ideal conditions, and takes the load or pressure.

1.34 The other means of reducing friction is the use of bearings which themselves must be lubricated. The bearings also help take the load or pressure of the application.

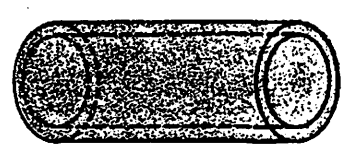
1.35 In addition, bearings confine or restrain the movement of shafts and slides. By acting as guides, bearings help control the motion of the parts they're supporting. In that way, bearings also help reduce or eliminate vibration, which can be extremely destructive to an operating mechanism. One familiar example of vibration is evident in an automobile having wheels badly out of balance. If it's not controlled or eliminated, vibration can shake almost any equipment apart.

1.36 By confining the motion of a shaft, bearings assure smoother and more efficient shaft operation. That, in turn, makes the whole power transmission system more efficient, by helping the required horsepower reach the work-delivery point with a minimum of power loss.

Types of Bearings

1.37 Bearings fit into either of two main categories. One, the PLAIN BEARING (see Fig. 1-7), is a solid surface on which a moving part slides or rolls. The second type is the ANTIFRICTION BEARING (see Fig. 1-8), which depends on races containing rotating balls or rollers to make contact

Fig. 1-7. Typical sleeve-type plain journal bearing.



TYPICAL PLAIN JOURNAL BEARING

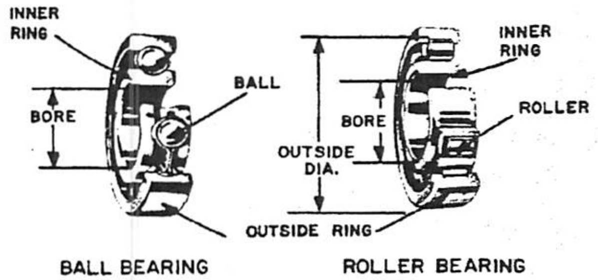


Fig. 1-8. *Cutaway view of common types of antifriction bearings.*

with the revolving or sliding surfaces which it's supporting.

1.38 Each category is further broken down into three main types, each type being designed to provide a particular kind of support. They are as follows:

1. Journal bearings, which support a rotating shaft. (The section of a shaft which revolves within a bearing is called the journal.) They confine radial motion.

2. Thrust bearings, which prevent endwise (axial) motion of a shaft.

3. Guide or slipper bearings, which are used for guiding or supporting sliding components.

1.39 As will be fully explained in the following lessons, plain and antifriction bearings differ considerably from one another. Both types, however, and their numerous variations, perform the same basic function: support and guidance of moving elements in machines and equipment.

1.40 Plain bearings are softer than the material of the shaft or slide which they support. This means that the bearing will wear out before the more expensive shaft does. The supported surfaces ride on the surface of the bearing itself. Most of the wear which occurs will be on the bearing, which is easier and less expensive to replace than a shaft or slide.

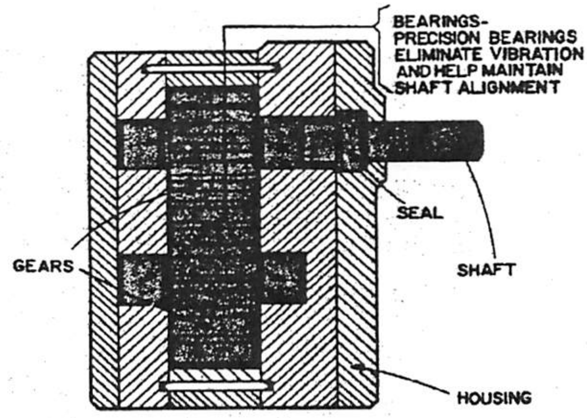


Fig. 1-9. *The bearings in this rotary gear pump are a typical application.*

1.41 Antifriction bearings are so called because the friction developed in their operation is relatively low. That's because the load on the bearing is taken by the small contact area between the races and the ball or roller (see Fig. 1-8). Because the full load of the application is taken on small contact surfaces, the balls and rollers of antifriction bearings are made of hardened alloy steels, to provide the maximum resistance to wear and pressure.

1.42 A common practical example of the important relationship between shafts and bearings is found in the type of gear pump used to provide pressure in a hydraulic system. See Fig. 1-9. In the pump shown, the bearings support a heavy load. They also maintain correct alignment of the shafts which the driving and driven gears are mounted on. If any of the bearings should fail, the whole system will fail, almost simultaneously, because the pump will stop. It will stop because the shaft alignment will change, and the gears may jam. As a result, the pump will no longer provide the pressure needed to operate the system, and the whole unit will have to be shut down.