0652012 Technical English I

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Reference Books:

1. "Mechanical Engineering Design", J. Shigley and C. Mischke,
2. 'Fundamentals of Machine Elements', B. Hamrock, B. Jacobson, S. Schmid
3. 'Fundamentals of Machine Component Design', R. Juvinall, K. Marshek

Course outline: (Mechanical Engineering Design)

Week	**Subject**
1	1. Shafts i. Shafts loading mechanisms ii. Shaft design
2	2. Keys 3. Bearings i. Rolling bearings
3	ii. Plane surface bearing Lubrication

Grading:

60% Midterm Exams (2 exams) + 40% Final

SHAFTS AND ASSOCIATED PARTS

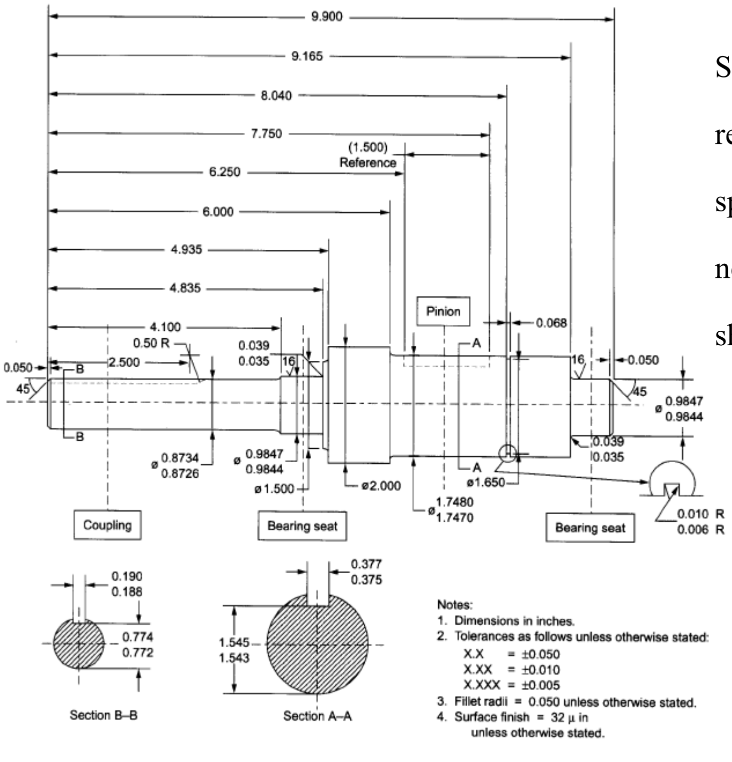
A shaft is a rotating member

usually have circular cross section

used to transmit power or motion

The term shaft usually refers to a relatively long member of round cross section that rotates and transmits power. One or more members such as gears, sprockets, pulleys and cams are usually attached to the shaft by means of pins, keys, splines, snap rings and other devices. These latter members are among the "associated parts" considered here, as are couplings and universal joints, which serve to connect the shaft to its source of power or load.

The geometry of a shaft is generally that of a stepped cylinder. Gears, bearings and pulleys must always be accurately positioned and provision made to accept thrust loads. The use of shaft shoulders is an excellent means of axially locating the shaft elements.



Significant detail is required to completely specify the geometry needed to fabricate a shaft.

Figure 1. Shaft

One or more members such as gears, sprockets, pulleys are usually attached to the shaft by means of pins, keys, snap rings. These latter members are among the ‘associated parts’ which serve to connect the shaft to its source of power or load.

Power transmitting elements are : gears, pulleys, belts, chains, flywheels, rolling element bearings.

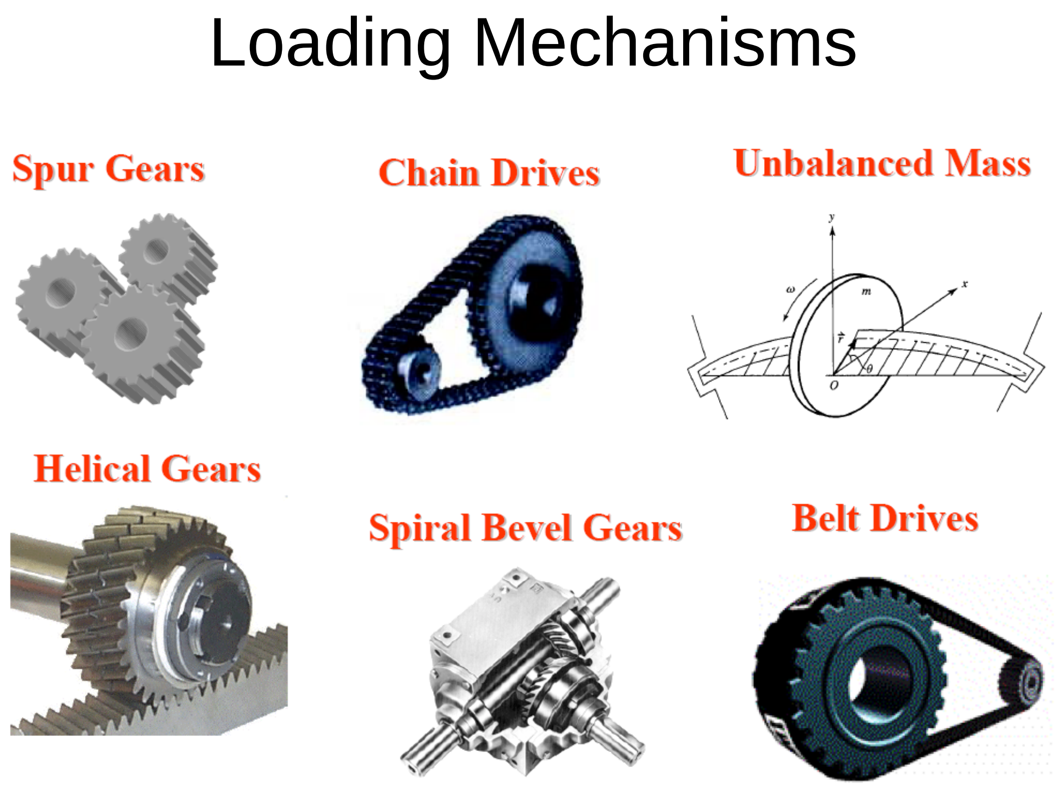


Figure 2. Loading mechanisms [3]

It is apparent that shafts can be subjected to various combinations of axial, bending and torsional loads and that these loads may be static or fluctuating. Typically, a rotating shaft transmitting power is subjected to a constant torque (producing a mean torsional stress) together with a completely reversed bending load (producing an alternating bending stress).

In addition to satisfying strength requirements, shafts must be designed so that deflections are within acceptable limits. Excessive lateral shaft deflection can hamper gear performance and cause objectionable noise. The associated angular deflection can be very destructive to non-self-aligning bearings (either plain or rolling). Torsional deflection can affect the accuracy of a cam- or gear-driven mechanism.

If we summarize:

The loading on the shaft can be various combinations of bending (almost always fluctuating), torsion (may or may not be fluctuating), axial loading and shear.

Design must be studied from the following points of view:

1) Deflection and rigidity
   - Bending deflection
   - Torsional deflection
2) Stress and Strength
   - Static Strength
   - Fatique Strength

PROVISION FOR SHAFT BEARINGS

Rotating shafts carrying gears, pulleys, cams and so on must be supported by bearings. If two bearings can provide sufficient radial support to limit shaft bending and deflection to acceptable values, this is highly desirable and simplifies manufacturing. If three or more bearings must be used to provide adequate support and rigidity, precise alignment of the bearings in the supporting structure must be maintained (as, for example, with the three or more main bearings supporting an engine crankshaft).

Shaft axial positioning and provision for carrying thrust loads normally require that one and only one bearing take thrust in each direction.

OVERALL SHAFT DESIGN

The following general principles should be kept in mind.

1. Keep shafts as short as possible, with bearings close to the applied loads. This reduces deflections and bending moments and increases critical speeds.
2. Place necessary stress raisers away from highly stressed shaft regions if possible. If not possible, use generous radii and good surface finishes.
3. Use inexpensive steels for deflection-critical shafts, as all steels have essentially the same elastic modulus.

4. When weight is critical, consider hollow shafts. For example, propeller shafts on rear-wheel-drive cars are made of tubing in order to obtain the low-weight-stiffness ratio needed to keep critical speeds above the operating range.

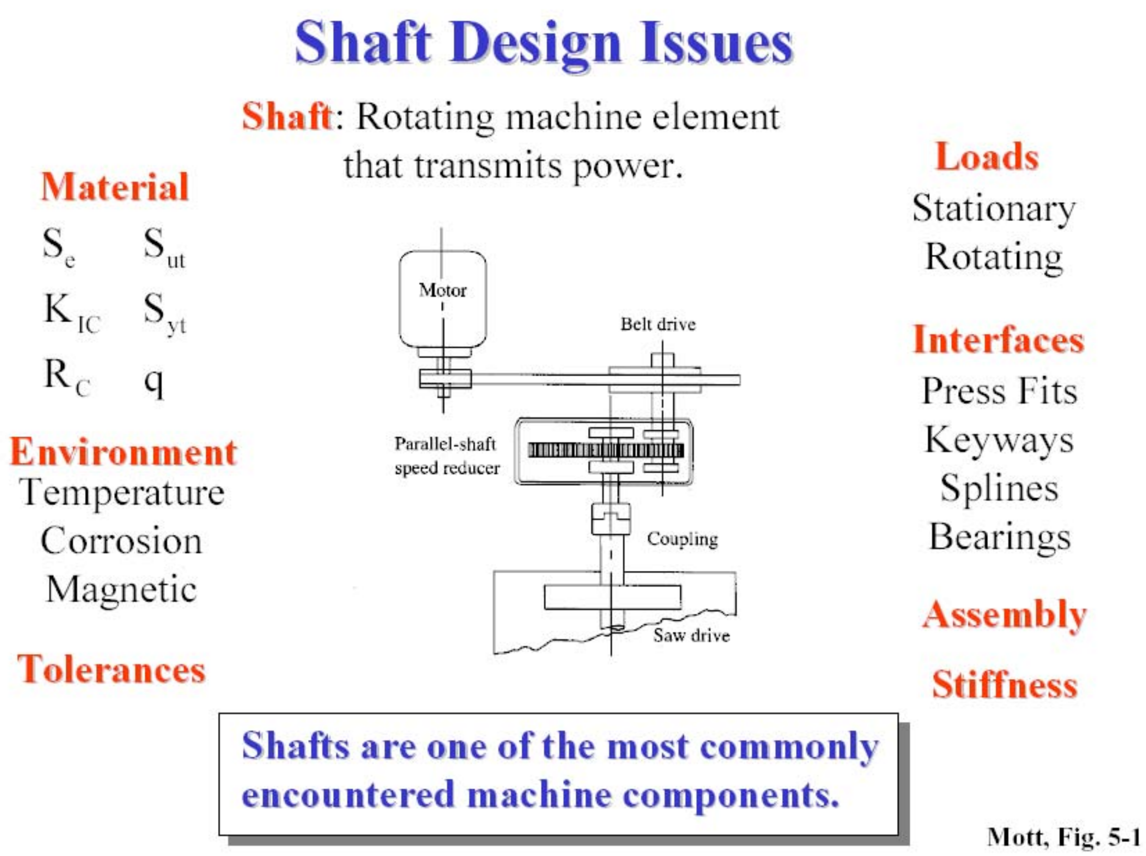


Figure 3. Shaft design issues

MOUNTING PARTS ONTO ROTATING SHAFTS

KEYS

A variety of power-transmitting elements, such as gears, pulleys and cams, are mounted on rotating shafts. Sometimes members like gears and cams are made integral with the shaft, but more often such members (which also include pulleys, sprockets, etc.) are made separately and then mounted onto the shaft. The portion of the mounted member in contact with the shaft is called the **hub**. The hub is attached to the shaft in a variety of ways. The gear is gripped axially between a shoulder on the shaft and a spacer, with torque being transmitted through a key. Figure

4 illustrates a variety of keys. The grooves in the shaft and hub into which the key fits are called keyways or keyseats.

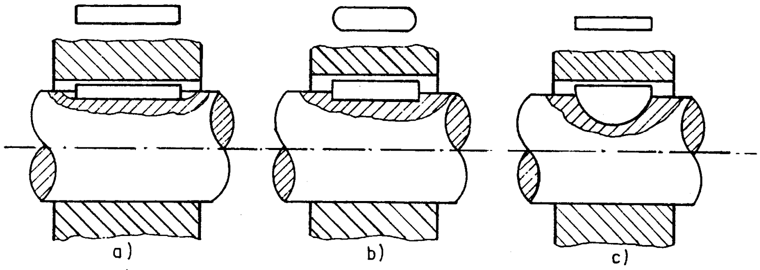


Figure 4. Types of keys, a and b : rectangular parallel keys, c: woodruff, [2]

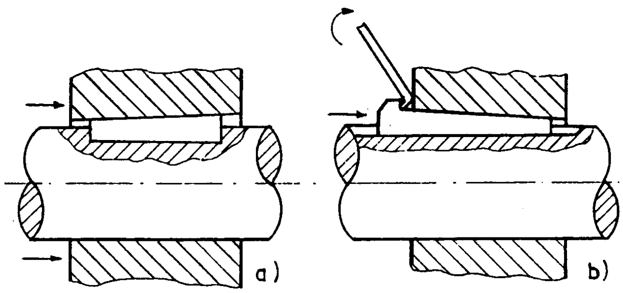


Figure 5. a: Tapered keys (friction will help transmit torque and provide resistance to axial motion of the hub relative to the shaft),
b: Gib head key [2]

There are a great variety of keys, but here the simplest type is analyzed. The main purpose of the keys is to prevent motion between the shaft and the connected machine element through which torque is being transmitted. The purpose of using the key is to transmit the full torque.

Standard sizes of these, together with the range of applicable shaft diameters are listed in Tables. The length of the key is based on the hub length and the torsional load to be transferred.

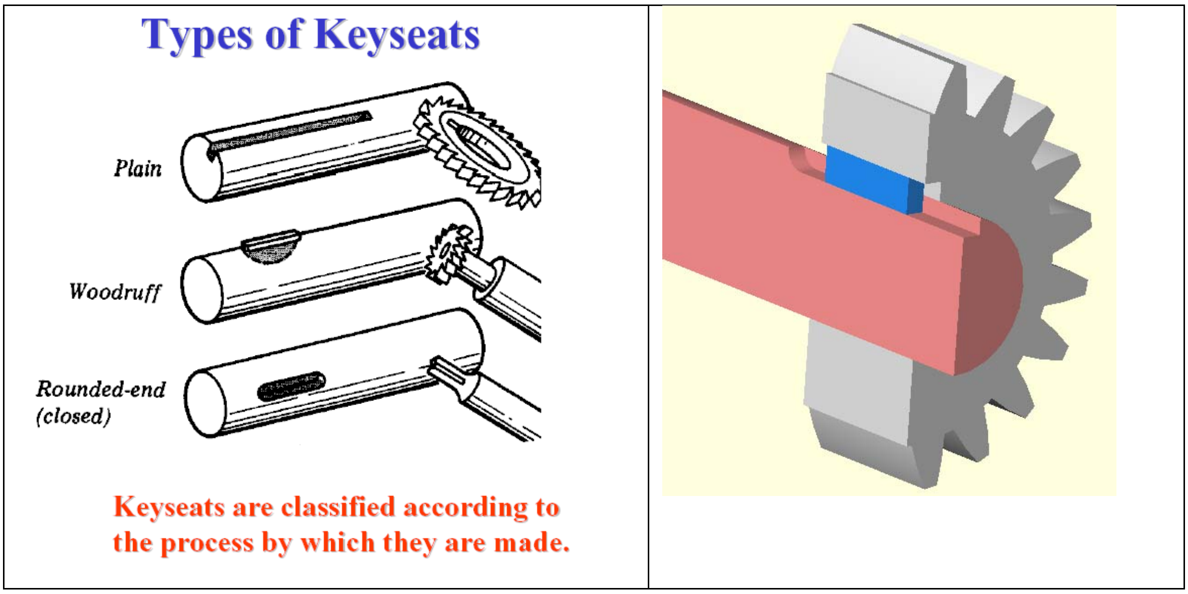


Figure 6. Keys and keyseats [3]

A simpler attachment for transmitting relatively light loads is provided by pins, such as the types illustrated in Figure 6. Pins provide a relatively inexpensive means of transmitting both axial and circumferential loads.

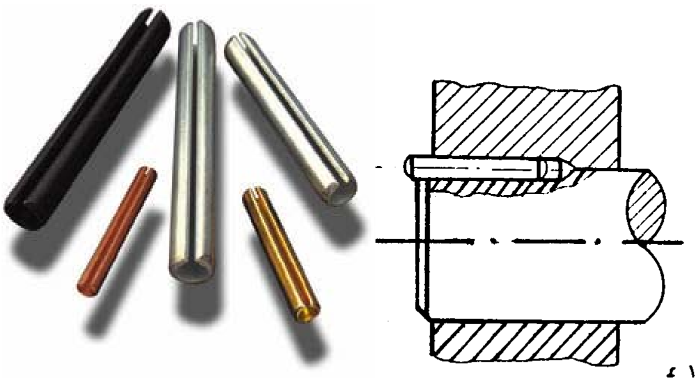


Figure 7. Pins

An excellent and inexpensive method of axially positioning and retaining hubs and bearings onto shafts is by retaining rings, commonly called snap rings. Figure 8 illustrates a few of the numerous varieties available.

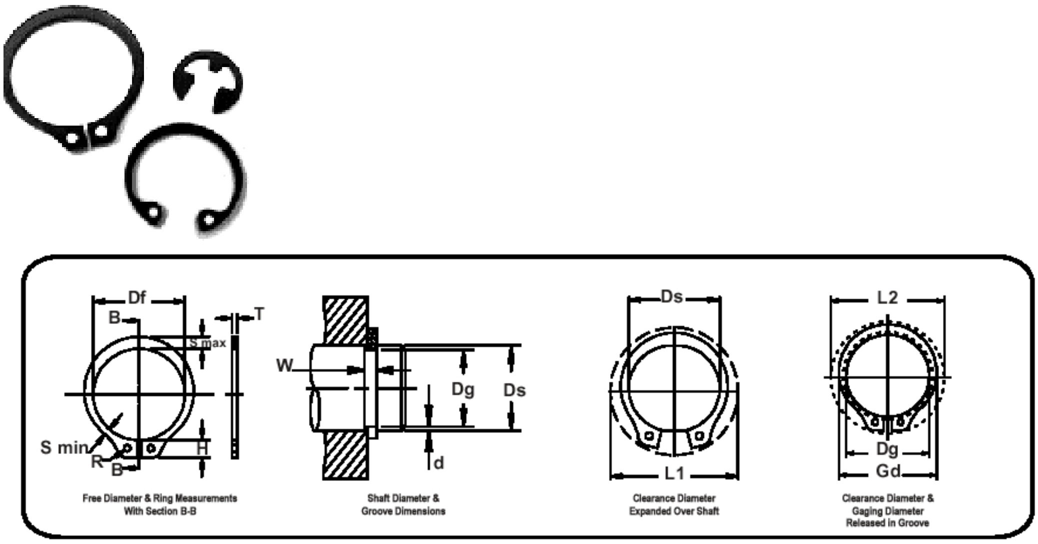


Figure 8. Snap rings which provide a removable shoulder to lock the components on shafts.

Perhaps the simplest of all hub-to-shaft attachments is accomplished with an interference fit wherein the hub bore is slightly smaller than the shaft diameter. Assembly is done with force exerted by a press, or by thermally expanding the hub-sometimes also by thermally contracting the shaft, as with dry ice-and quickly pressing the two parts together before the temperatures of the parts equalize. Sometimes a combination of pin and interference fit is used [1].

BEARINGS

Rotating shafts carrying gears, pulleys must be supported by bearings. Bearing will provide radial support to limit shaft bending and defection to acceptable values.

There are two types of bearing

1. Rolling element bearing
2. Sliding bearing

1. ROLLING ELEMENT BEARING

HISTORY OF ROLLER-ELEMENT BEARINGS

The first recorded use of rolling elements to overcome sliding friction was by Egyptian construction workers, to move heavy stone slabs, probably before 200 B.C. [1], and possibly by the Assyrians in about 650 B.C. It is believed that some early chariot wheels used crude roller bearings made from round sticks. Around A.D. 1500 Leonardo da Vinci is considered to have invented and partially developed modern ball and roller bearings. A few ball and roller-type bearings were constructed in France in the eighteenth century. The builder of a roller-bearing carriage claimed, in 1710, that his roller bearings permitted one horse to do work otherwise hardly possible for two horses. But it was not until after the invention of the Bessemer steel process in 1856 that a suitable material for rolling-element bearings was economically available. During the remainder of the nineteenth century, ball bearings were rapidly developed in Europe for use in bicycles, [1]

The main load is transferred through elements in rolling contact rather than in sliding contact.

Bearings are manufactured to take pure radial loads, pure thrust loads, or a combination of the two kinds of loads. A ball bearing is illustrated in Fig. 9 which also shows the four essential parts of a bearing. These are the outer ring, the inner ring, the balls or rolling elements, and the separator. In low-priced bearings, the separator is sometimes omitted, but it has the important function of separating the elements so the rubbing contact will not occur.

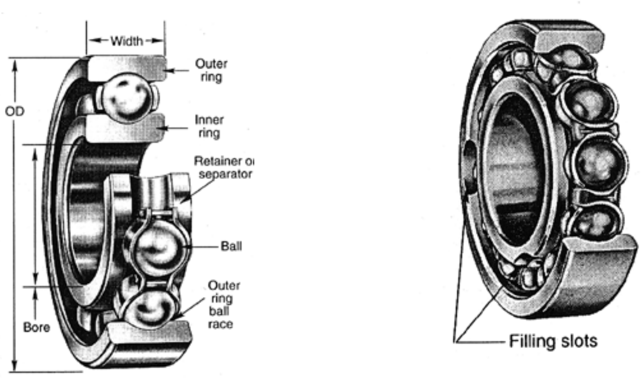


Figure 9. Ball bearing components

Rolling Element Bearing Types

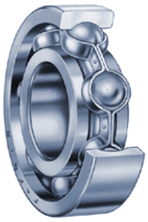
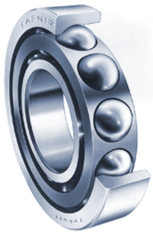
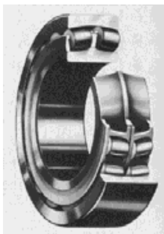
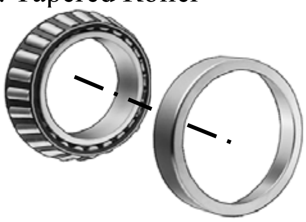
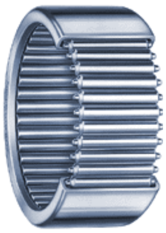
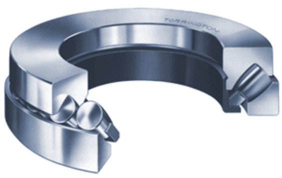
1. Single-row Radial Ball 	2 . Radial Roller 	3. Angular Contact Ball 
4. Angular Roller 	5. Spherical Roller 	6. Tapered Roller 
7. Needle 	8.Thrust 	

Figure 10. Rolling element bearing types

Rolling-element bearings are either ball bearings or roller bearings. In general, ball bearings are capable of higher speeds, and roller bearings can carry greater loads. Most rolling-element bearings can be classed in one of three categories:

(1) radial for carrying loads that are primarily radial; (Fig.10.1)

(2) thrust, or axial-contact for carrying loads that are primarily axial; and (Fig. 10.8)

(3) angular-contact for carrying combined axial and radial loads. (Fig. 10.3).

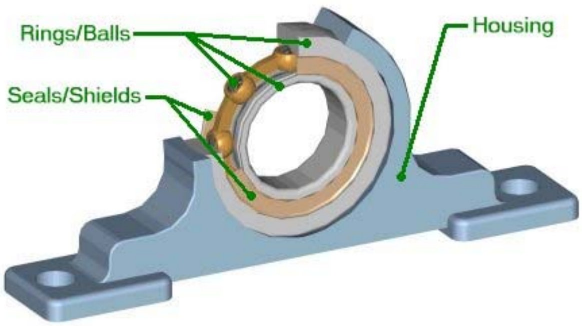
Roller bearings are also classified by roller configuration into the four types shown in Figs. 10.2, 10.5, 10.6 and 10.7: (I) cylindrical, (2) spherical, (3) tapered, and (4) needle. Needle bearings can be regarded as a special case of cylindrical roller bearings in which rollers have a length-to-diameter ratio of four or greater.

Angular-contact bearings, as shown in Fig. 10.3, have substantial thrust capacity in one direction only. They are commonly installed in pairs, with each taking thrust in one direction. The double-row ball bearing incorporates a pair of angular-contact bearings into a single unit.

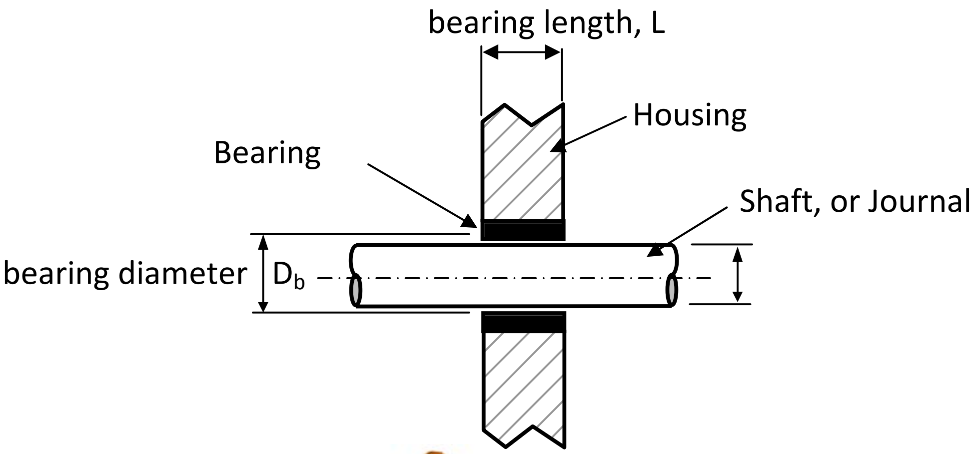
Most bearing manufacturers provide engineering manuals and brochures containing lavish descriptions of the various types available.

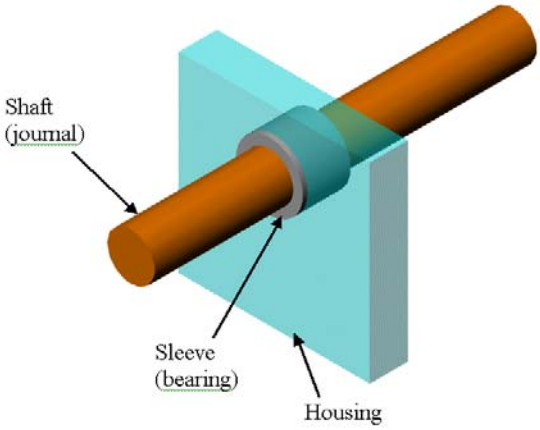
Mounted Ball Bearings

Bearing is inserted into a cast housing, with base or flange slots, which can be readily attached to a machine base.



2. SLIDING BEARING (PLAIN SURFACE BEARINGS)





Sliding bearings require direct sliding of the load-carrying member on its support, as distinguished from rolling-element bearings, where balls or rollers are interposed between the sliding surfaces.

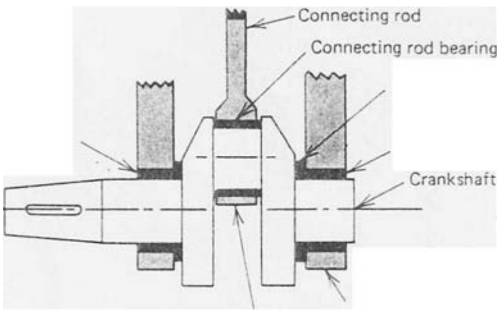


Figure 11. Crankshaft and plain bearing

Sliding bearings (also called plain bearings) are of two types:

(1) journal or sleeve bearings, which are cylindrical and support radial loads. (those perpendicular to the shaft axis; and

(2) thrust bearings, which are generally flat and in the case of a rotating shaft, support loads in the direction of the shaft axis.

LUBRICATION AND SLIDING BEARINGS

The word bearing, applied to a machine or structure, refers to contacting surfaces through which a load is transmitted. When relative motion occurs between the surfaces, it is usually desirable to minimize friction and wear. Any interposed substance that requires friction and wear is a lubricant. Lubricants are usually liquid but can be solid, such as graphite or molybdenum disulfide, or a gas, such as pressurized air.

Liquid lubricants that are oils are characterized by their viscosity, but other properties are also important. Oil lubricants have names designating these properties. Modern oils usually contain one or more additives designed to cause the oil to flow at lower temperatures-the pour-point depressants; have less variation of viscosity with temperature-the viscosity index improvers; resist foaming when agitated by high-speed machinery-the defoamants; resist oxidation at high temperatures-the oxidation inhibitors: prevent corrosion of metal surfaces-the corrosion inhibitors: minimize the formation of engine deposits and reduce the rate at which they deposit on metal surfaces-the detergents and dispersants; and reduce friction and wear when full lubricating films cannot be maintained-the anti wear additives.

Greases are liquid lubricants that have been thickened in order to provide properties not available in the liquid lubricant alone. Greases are usually used where the liquid lubricant is required to stay in position, particularly when frequent lubrication is difficult or costly. Often, by remaining in place to provide lubrication, grease also serves to prevent harmful contaminants from entering between the bearing surfaces. Unlike oils, greases cannot circulate and thereby serve a cooling and cleaning function. Except for this, greases are expected to accomplish all functions of fluid lubricants.

COMPARISON OF ALTERNATIVE MEANS FOR SUPPORTING ROTATING SHAFTS

In rolling-element bearings the shaft and outer members are separated by balls or rollers, and thus rolling friction is substituted for sliding friction. Since the contact areas are small and the stresses high, the loaded parts of rolling-element bearings are normally made of hard, high-strength materials, superior to those of the shaft and outer member. These parts include inner and outer rings and the balls or rollers. An additional component of the bearing is usually a retainer or separator, which keeps the balls or rollers evenly spaced and separated.

Both sliding and rolling-element bearings have their places in modern machinery. A major advantage of rolling-element bearings is low starting friction. Sliding bearings can achieve comparably low friction only with full-film lubrication (complete surface separation). This requires hydrostatic lubrication or hydrodynamic lubrication, which cannot be achieved during starting.

Roller bearings are ideally suited for applications with high starting loads. For example, use of roller bearings to support rail car axles eliminates the need for an extra locomotive to get a long train started. On the other hand, fluid-film bearings are well suited for high rotating speeds with impact or momentary overloads. The higher the rotating speed is, the more effective the hydrodynamic pumping action. Moreover, the fluid film effectively "cushions" impact, for the duration of the impact is not long enough for the impact load to squeeze out the film. High rotating speeds are generally disadvantageous to rolling-element bearings because of the rapid accumulation of fatigue cycles and the, high centrifugal force on the rolling elements.

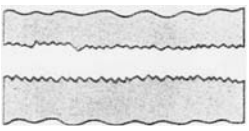
Rolling-element bearings take up more radial space around the shaft, but plain bearings usually require greater axial space. Rolling-element bearings generate and transmit a certain amount of noise, whereas fluid-film bearings do not normally generate noise and may dampen noise from other sources. Sliding bearings are less expensive than ball or roller bearings for simple applications requiring minimal lubrication provisions. When sliding bearings require a forced lubrication system, the overall cost of rolling-element bearings may be lower.

Rolling-element bearings are also known as "antifriction" bearings. This term is perhaps unfortunate because these bearings do not in all cases provide lower friction than fluid-film bearings. With normal operating loads, rolling-element bearings (without seals) typically provide coefficients of friction between 0.001 and 0.002.

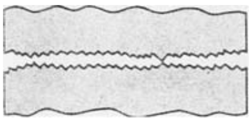
TYPES OF LUBRICATION

Lubrication is commonly classified according to the degree with which the lubricant separates the sliding surfaces, Figure 12.

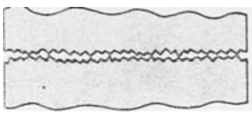
1. In hydrodynamic lubrication the surfaces are completely separated by the lubricant film. The load tending to bring the surfaces together is supported entirely by fluid pressure generated by relative motion of the surfaces (as journal rotation). Surface wear does not occur, and friction losses originate only within the lubricant film. Typical film thicknesses at the thinnest point (designated h_o) are 0.008 to 0.020 mm (0.0003 to 0.0008 in.). Typical values of coefficient of friction (f) are 0.002 to 0.010.



(a) Hydrodynamic (surface separated)



(b) Mixed film (intermittent local contact)



(c) Boundarv (continuous and extensive local contact)

Figure 12. Three basic types of lubrication. The surfaces are highly magnified.

2. In mixed-film lubrication the surface peaks are intermittently in contact, and there is partial hydrodynamic support. With proper design, surface wear can be mild. Coefficients of friction commonly range from 0.004 to 0.10.
3. In boundary lubrication surface contact is continuous and extensive, but the lubricant is continuously "smeared" over the surfaces and provides a continuously renewed adsorbed surface film that reduces friction and wear. Typical values of f are 0.05 to 0.20.

REFERENCES:

[1] Shigley, J. E., ‘Mechanical Engineering Design’, 1986.

[2] Bozacı, A., Koçaş, İ. And Çolak Ö. Ü., ‘ Makina Elemanlarının Projelendirmesi’, 2001.

[3] Various internet sources.