Abu Dhabi Gas Liquefaction Company Ltd

Job Training

Mechanical Technician Course

Module 3

Bearings

ADGAS Personnel & Training Division

Contents

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Pre-Requisite	Completion of A.T.I. Maintenance Programme, ADGAS Induction Course and Basic Maintenance Technician Course.
Course Objectives	The Job Training Mechanical Technician Course is the second phase of the development programme. It is intended specifically for Mechanical Maintenance Developees. On completion of the Course the developee will have acquired an awareness of some of the equipment, terminology, and procedures related to mechanical maintenance of ADGAS LNG plant. Appropriate safety procedures will continue to be stressed at all times.
Module Objectives	On completion of this module, the developee will be able to correctly : • identify types of bearings and, where appropriate, their parts • select the correct bearing type for different load conditions • identify the correct bearing fit for different applications • fit and remove a plain bearing • fit and remove an antifriction bearing • have an awareness of bearing lubrication methods • identify some common causes of bearing failure by visual inspection
Methodology	The above will be achieved through the following: • pre-test • classroom instruction • audio visual support • tasks & exercises • post-test

Abbreviations and Terminology

PTFE	Polytetraflouroethelyne—a polymer (plastic) with very good anti-friction properties.

Additives	Something that is added to a substance, usually to improve its properties.
Alloy	A metal containing two or more metallic *elements* (see below) or carbon to improve its properties.
Brittle	Hard and easily cracked or broken—glass is a brittle material.
Bush	Alternative name used for a plain sleeve bearing. Also ‘bushing’.
Case hardening	A process that hardens only the surface of a component leaving the centre *tough* (see below).
Circumference	The distance around the outside of a circle.
Coefficient of friction (μ)	A measure of the difficulty with which one surface can slide over another. It depends on the materials and the roughness of the surfaces.
Contaminant	An impurity; something unwanted that enters a substance.
Crazing	An irregular pattern of cracks on a surface.
Element	A pure material made up of atoms of only one type.
Erosion	A slow wearing away, usually by a fluid flowing over the surface.
Failure	The point at which a component can no longer perform its job.
Fatigue failure	Failure caused by a continuously changing force over a long time.
Film (oil)	A thin layer.
Housing	Part of a bearing assembly into which the bearing is fitted. It ‘houses’ the bearing.
Hydraulic	Operated by oil pressure (or water pressure).
Journal	The part of a shaft that is supported by and rotates in a plain bearing.
Load	General name used for any kind of force acting on bearings and other support components.
Lubricant	A substance, usually a liquid or semi-liquid, used to reduce friction.
Lug	Part of an object that sticks out and that can be used to fix it in place or to lift it by.
Nip	The amount by which bearing shells are squashed when fitting in a split housing.
Notch	An indentation on the edge of an object. A *lug* (above) can fit into a notch for location.

Overhaul	A major maintenance operation when equipment is taken out of service, dismantled, inspected, repaired if necessary and re-assembled.
Oxidation, oxide	Oxidation is a chemical reaction between a substance and oxygen that forms an oxide.
Pitting	Small, roughly round areas where the surface is broken, forming tiny 'pits'.
Plastigauge	A product used to measure shaft clearance in a split bearing.
Pre-load	Load that is given to something before normal operating loads are applied.
Proud	To stand out from a surface.
Raceway	The track around bearing races in which the rolling elements run.
Radial	In a direction from or towards the centre of a circle—acting along a radius.
Relief	Lowering of a surface to give clearance.
Retaining nut	A nut used to hold something in place.
Root cause	The basic fault that leads to a failure.
Scoring	Scratches, usually quite deep.
Seating	The part of a shaft or housing where a bearing 'sits'. Also used for the surface on which a valve sits when closed.
Seize	When two or more sliding surfaces jam because of lost clearance.
Shims	Thin spacers.
Shock load	The load on an object that results from a sudden impact.
Shrink-fit	The word *shrink* means to make smaller. Shrink-fit describes the method of fitting a bearing into a housing where the bearing is cooled so that it contracts. On warming it expands in the housing providing an interference fit. The term *shrink-fit* is often used to describe the method of fitting a bearing by either cooling or heating it.
Solvent	A liquid that dissolves a solid. Cleaning solvents remove dirt, oil and grease by dissolving them.
Spalling	Surface flaking, often the result of fatigue.
Spherical	Describing the shape of a ball.
Splash lubrication	A method of lubrication that uses oil splashed from a reservoir by a rotating component that dips into it.
Thrust	An axial force.
Toughness	The property that enables a material to be strong without being *brittle* (see above). Able to resist *shock loads* (see above).
Viscosity	A measure of how easily oil flows: low viscosity oil flows easily.

1 Introduction

Bearings are components that allow one part of a machine to move *relative* to another part.

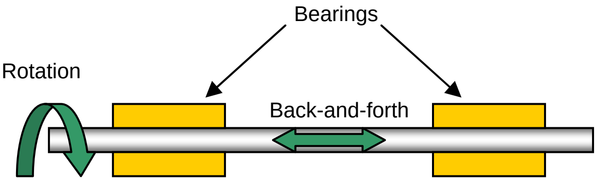
Relative movement happens when one part moves and the other does not, or when two parts move at different speeds.

This relative movement may be:

- sliding back and forth—e.g. when a gear in a gearbox is engaged and disengaged
- rotation—the most common use of bearings in rotating equipment

A bearing does three jobs:

- locates the moving part and guides its motion (**Fig. 1.1(a)**)



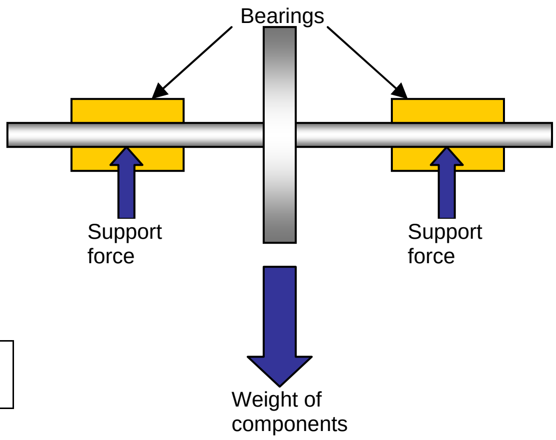
(a) Bearings Used to Locate and Guide

- *supports* the weight of the moving part and the *loads* (or forces) that act on it (**Fig. 1.1(b)**)

To ***support*** is to carry.

- reduces friction between the moving and *stationary* parts

Stationary means not moving.



(b) Bearings Used to Support

Figure 1.1: Location and Support

The first two jobs above can be done quite easily. It is the last job, reducing friction, that makes bearings so important.

Friction between surfaces causes wear. Bearings reduce friction, but they can not *eliminate* it completely. There is always some friction when one surface slides on another, and where there is friction there is always wear.

To ***eliminate*** something is to remove it.

Bearing *failure* is a common cause of breakdown in rotating equipment: pumps, compressors, gearboxes, etc. An important task of a mechanical maintenance technician in ADGAS is to replace worn and damaged components. This work often involves the *inspection* and replacement of bearings. In this module you will learn about the different types of bearings used on the ADGAS plant, how to recognise damaged bearings and how to remove and replace them.

Inspection is the action of looking very carefully at something.

2 Friction

The most important job that a bearing does is to allow components to move relative to each other with as little friction as possible. Friction is the force that tries to stop one surface sliding on another.

Before looking at bearings in detail you should understand a little more about friction.

However smooth a surface looks, if you magnify it enough you will see that it has many high and low spots, as shown in **Figure 2.1**.

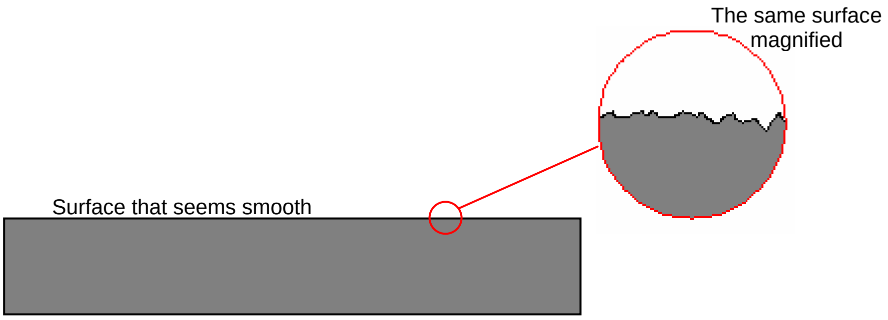


Figure 2.1: Roughness of Apparently Smooth Surface

When one surface slides over another, the small high spots are knocked off. Force is needed to knock them off and this force is equal to the *friction force*. When the high spots are knocked off, the surfaces wear. **Figure 2.2** shows a magnified view of two sliding surfaces.

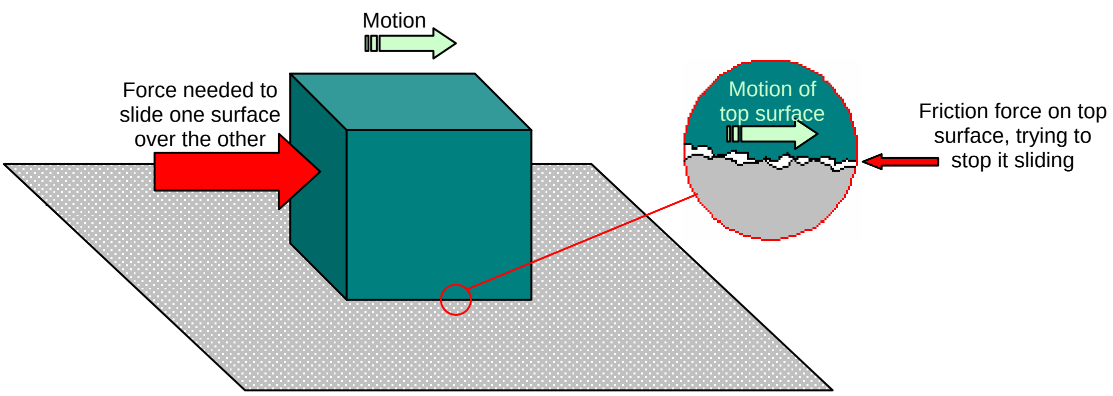


Figure 2.2: Friction between Sliding Surfaces

The type of friction shown in **Figure 2.2** is called *sliding friction.*

The force needed to slide one surface over another depends on:

- the force pressing the two surfaces together
- the roughness of the two surfaces
- the materials the surfaces are made of

All the forces that act on a sliding object are shown in **Figure 2.3**.

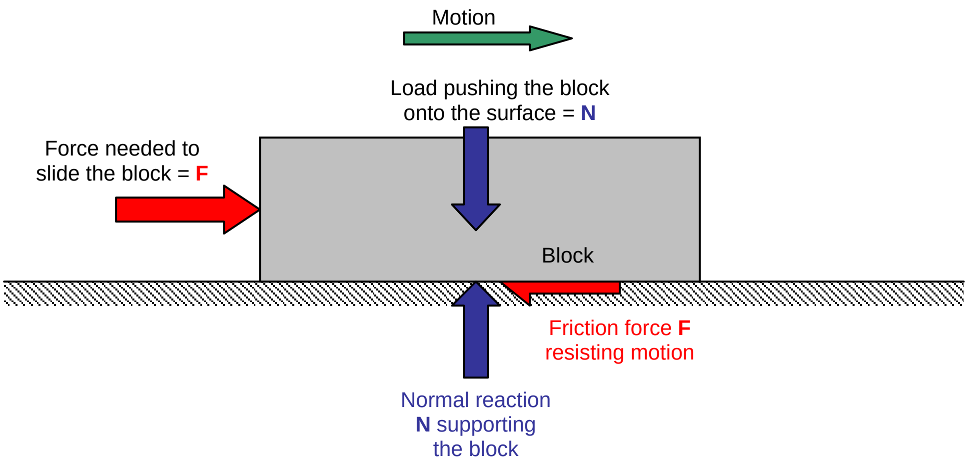


Figure 2.3: Forces on a Sliding Object

The friction force always tries to stop the motion; it pushes against the direction of motion.

Because all the forces on the block must balance:

- the force needed to slide the block = the friction force **F** trying to stop it
- the normal reaction **N** supporting the block = the load pushing down on the sliding surfaces

The greater the load on the sliding surfaces, the greater the friction force, **F**, and the more force needed to push the block. This is easy to see if you try to push something across the floor. The heavier the object you are pushing, the harder it is to push.

The type of material that the sliding surfaces are made of and their roughness is measured by the *coefficient of friction (μ)*. Surfaces that have a big coefficient of friction have a lot of friction between them—they are difficult to slide.

Smooth surfaces have a lower friction force and a lower coefficient of friction than rough surfaces.

Some materials slide more easily than others. Materials that slide easily have a low coefficient of friction.

Friction can be a very useful thing. The brakes of a car only work because of friction between the brake pads and the brake disc. A car only grips the road because of friction between the tyres and the road. You can only stand and walk without slipping and falling because of the friction between your shoes and the ground.

Friction is a bad thing in rotating equipment because it causes wear and wastes power. Bearings are designed to reduce friction as much as possible.

One way to reduce friction is by putting rollers between the surfaces as shown in **Figure 2.4**.

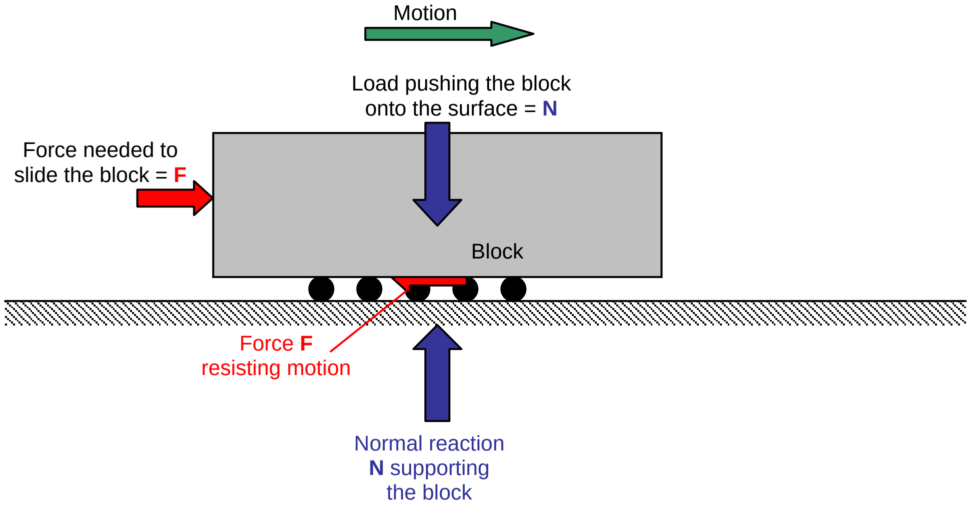


Figure 2.4: Rolling Friction

If you put rollers under an object it is much easier to push.

The load **N** on the rollers in **Figure 2.4** is the same as the load **N** shown in **Figure 2.3** but the friction force **F** resisting motion is much less for the rollers. This type of friction is called *rolling friction*.

rolling friction is less than sliding friction

Another way of writing this is:

rolling friction < sliding friction

Using a liquid between the sliding or rolling surfaces reduces friction even more. Something that is supported on a liquid is much easier to move. Pushing a boat through the water is much easier than trying to push it on the beach, even on rollers. Friction in a liquid is called *fluid friction*.

fluid friction < rolling friction <sliding friction

Figure 2.5 shows the forces acting on a block supported by a liquid.

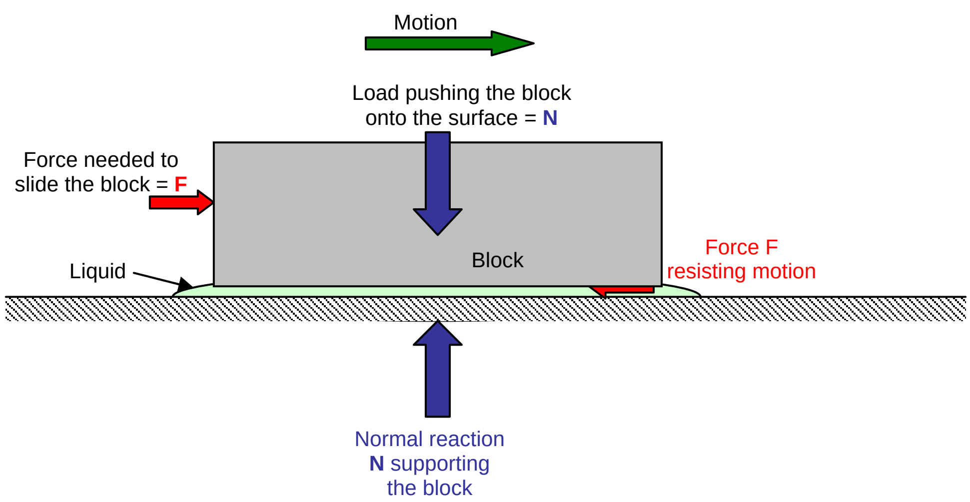


Figure 2.5: Fluid Friction

The load **N** in **Figure 2.5** is the same as the load **N** shown in **Figures 2.3** and **2.4** but the friction force **F** resisting motion is now much less than in either of those two figures.

The liquid used between bearing surfaces is called *lubricant*.

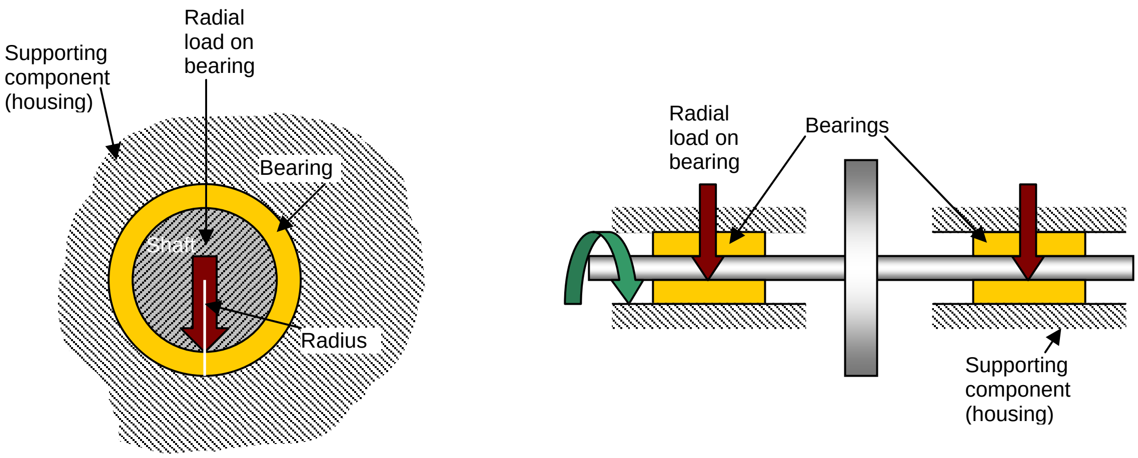
It has already been said that friction causes wear when the high spots on the sliding surfaces are knocked off. Friction between surfaces also produces heat. Rub your hands together and you will feel the friction force. Keep rubbing them for a while and you will feel the heat produced by friction. Too much heat produced in a machine can cause problems. Using bearings and lubricants helps to reduce the amount of unwanted heat produced, as well as reducing friction.

3 Bearing Loads

The loads that can act on bearings in operation are:

- radial
- axial or thrust

Radial loads act along a *radius* of the bearing and shaft as shown in **Figure 3.1**.

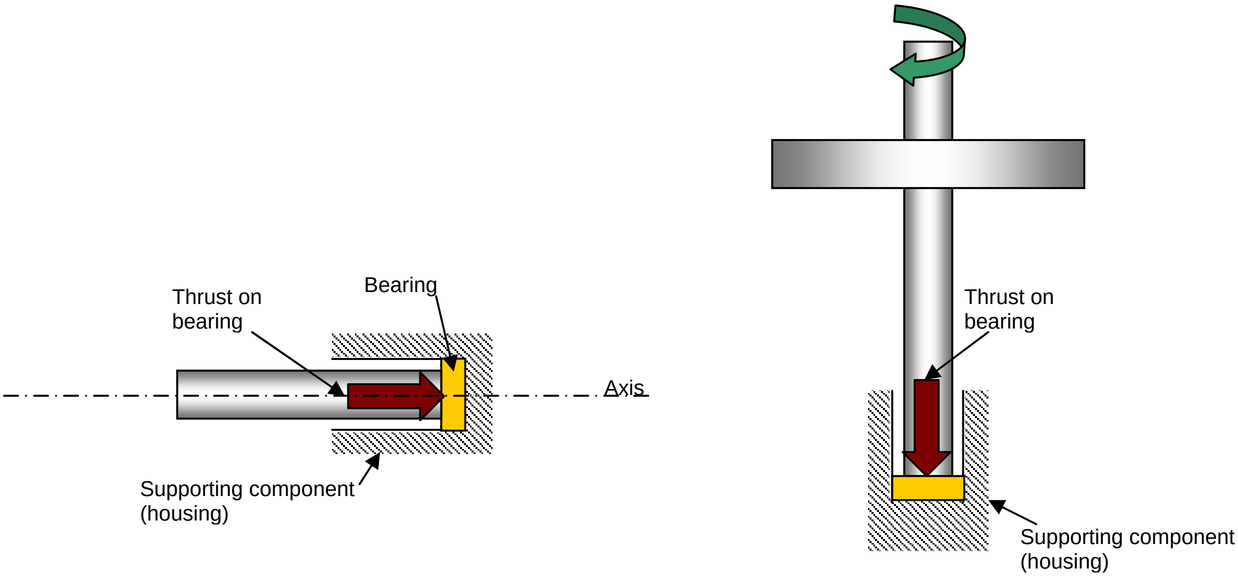


(a) End View Showing Radial Load Direction (b) Typical Arrangement Giving Radial Loads

Figure 3.1: Radial Loads

Note that **Figure 3.1** only shows the forces that push on the bearings. These forces, or loads, are the result of the weight, etc., of the shaft and components attached to it.

Axial loads act along the axis of the bearing and shaft as shown in **Figure 3.2**. Axial load is often called *thrust*.



(a) Side View Showing Thrust Load Direction

(b) Typical Arrangement Giving Thrust Load

Figure 3.2: Thrust Loads

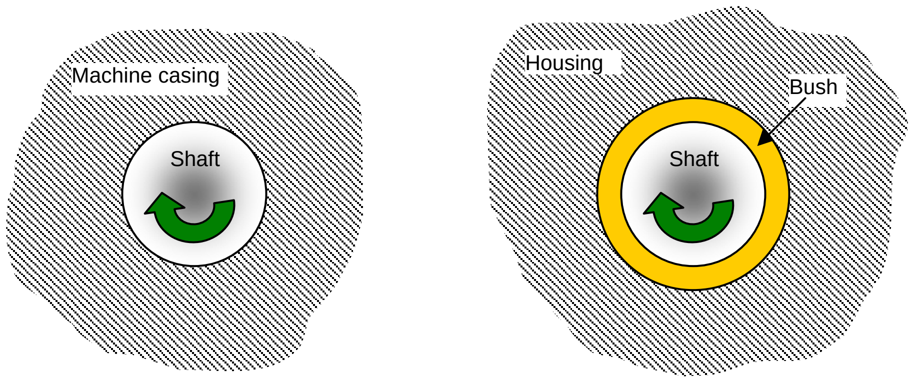
Note that **Figure 3.2** only shows the forces that push on the bearing. These forces, or loads, are the result of the weight, etc., of the shaft and components attached to it.

Most bearings are either designed to take radial loads or thrust loads. There are some bearings that are specially designed to take both types of load. These different bearing designs are described later in this module.

4 Plain Bearings

Plain bearings have sliding contact between the shaft and the bearing surfaces.

The simplest type of bearing is made by supporting the shaft directly in a hole in the supporting component as shown in **Figure 4.1(a)**. The supporting component is often the casing of the machine. The problem with this very simple bearing is that the shaft, the machine casing or both will wear as the shaft turns. These components are often expensive to repair or replace. This simple bearing is not used in industrial equipment found on the ADGAS plant.



(a) Simplest Plain Bearing (b) Plain Bearing Bush or Sleeve

Figure 4.1: Plain Bearings

Nearly all modern plain bearings use a sleeve or bush fitted into the supporting component as shown in **Figure 4.1(b)**. The part of the supporting component that holds a bearing is called a *housing*. Bushes are made of materials that have a low coefficient of friction between the bearing surface and the shaft. This reduces friction and wear. A bush is also easier and cheaper to replace than the shaft or the housing.

4.1 Types of Plain Bearings

Four types of plain bearings are described in this module.

There are two main types of bearings:

- radial or journal bearings
- thrust bearings

Some bearings are designed to carry both types of load:

- combination radial/thrust bearings

The fourth type of bearing is designed to allow for small changes in alignment of the shaft in its bearings:

- self-aligning or spherical bearings

4.1.1 Plain Radial Bearings

The simplest plain bearing bush is a cylinder or tube that is usually cast or machined from solid material as shown in **Figure 4.2(a)**. Casting is a method of making a component by melting the metal and pouring it into a *mould*.

A ***mould*** is a specially shaped container.

(a) Machined or Cast Bushes

(b) Wrapped Bushes

Figure 4.2: Sleeve Bearings or Bushes

Some simple bushes are made by wrapping a strip of the bush material into a cylinder, as shown in **Figure 4.2(b)**.

These bushes can only take radial loads. Radial-load plain bearings are often called *journal* bearings.

The *journal* is the part of the shaft supported by a bearing as shown in **Figure 4.3**.

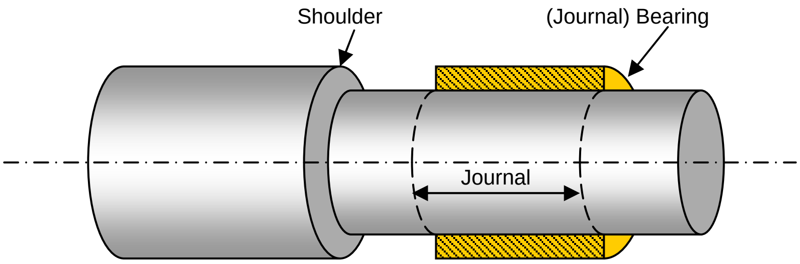
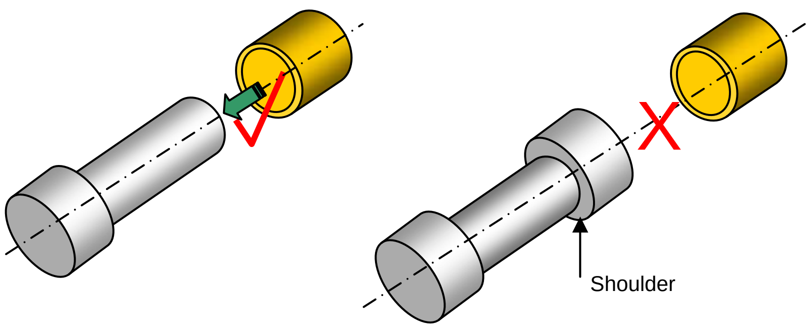


Figure 4.3: Shaft Journal and Shoulder

Figure 4.3 shows another *feature* of a shaft: an increased diameter called a *shoulder*.

A ***feature*** is something you notice about an object. You can identify something by its features

If the journal is on the end of a shaft or there are no shoulders, etc., in the way, you can fit a simple one-piece bush as shown in **Figure 4.4(a)**. **Figure 4.4(b)** shows a bush that can not be fitted because the journal is between two shoulders.



(a) Bush can slide over end of shaft for assembly

(b) Bush can not slide over end of shaft

Figure 4.4: Assembly of Simple Bushes

Split bearings are used where a one-piece bush can not be fitted. Most split bearings come in two halves, often called bearing *shells*. **Figure 4.5** shows two examples of a pair of bearing shells.

Figure 4.5: Split Bearing Shells

ADGAS uses split bearings on a lot of the equipment in the plant. Bearing shells are held in a housing that is made in two parts. Bearing housings are described in **Section 9** of this module but an example is shown in **Figure 4.6**.

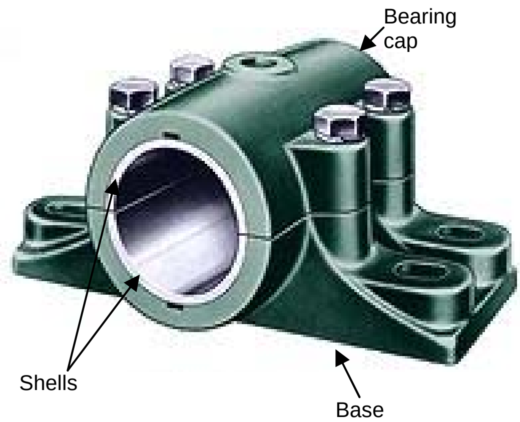


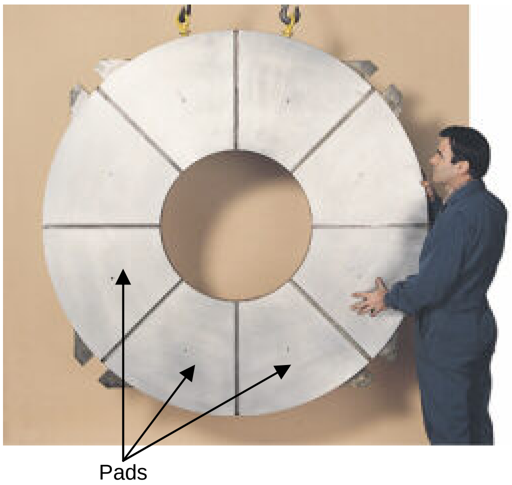
Figure 4.6: Split Bearing and Housing

Most split bearings have two halves but you can get multi-part bearings that have more than two parts.

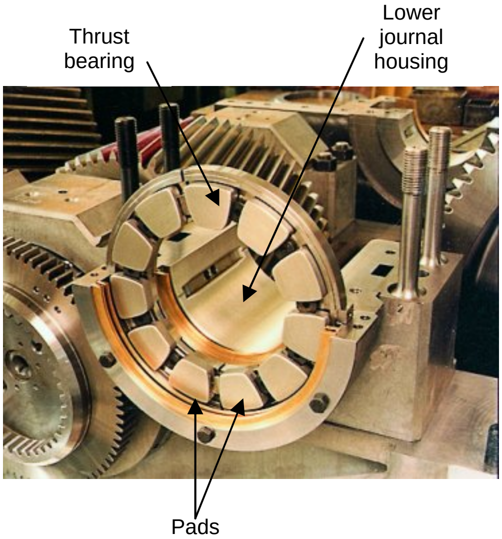
The plain bearings described so far are designed to support radial loads only

4.1.2 Plain Thrust Bearings

Plain thrust bearings have a pad, or pads, on which a shoulder or the end of the shaft can push. **Figure 4.7(a)** shows a plain thrust bearing for a large turbine.



(a) Large Turbine Plain Thrust Bearing



(b) Gearbox Thrust Bearing

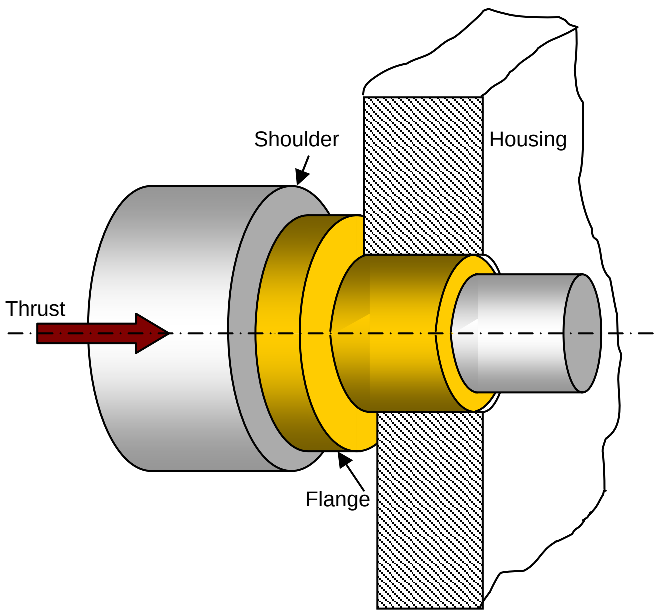
Figure 4.7: Plain Thrust Bearings

Figure 4.7(b) Shows a thrust bearing mounted in front of a journal bearing. These two bearings together take radial and thrust loads.

4.1.3 Combination Radial/Thrust Bearings

Some bearings are designed to take radial and thrust loads. This saves having two separate bearings. The simplest plain bearing that can take some thrust load as well as radial load is a flanged bush. **Figure 4.8(a)** shows a pair of flanged bushes.

(a) Flanged Bushes



(b) Thrust Load on Flanged Bush

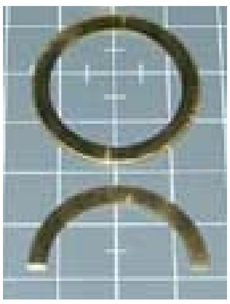
Figure 4.8: Flanged Bushes

Flanged bushes can take some thrust load in one direction as shown in **Figure 4.8(b)**. These bushes can also take the normal radial load.

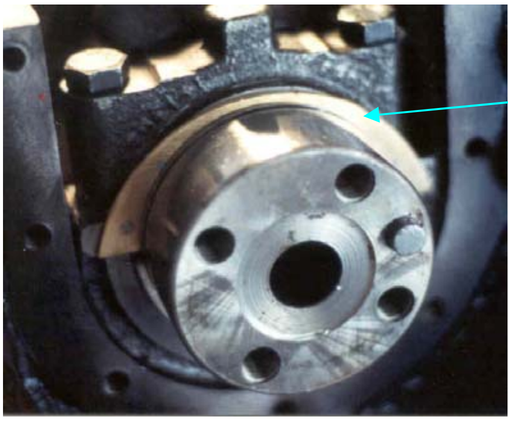
Some split-bearing shells have flanges to take thrust loads on the shaft. A pair of flanged shells is shown in **Figure 4.9**.

Figure 4.9: Flanged Shells

Thrust washers are often used to support thrust loads. They are full or half-washers, often coated with a bearing material to reduce friction. Half-washers are used where you can not assemble a full-washer onto the shaft. Examples of typical thrust washers are shown in **Figure 4.10(a)**.



(a) Full- and Half-washers



(b Half-washer in Place

Figure 4.10: Thrust Washers

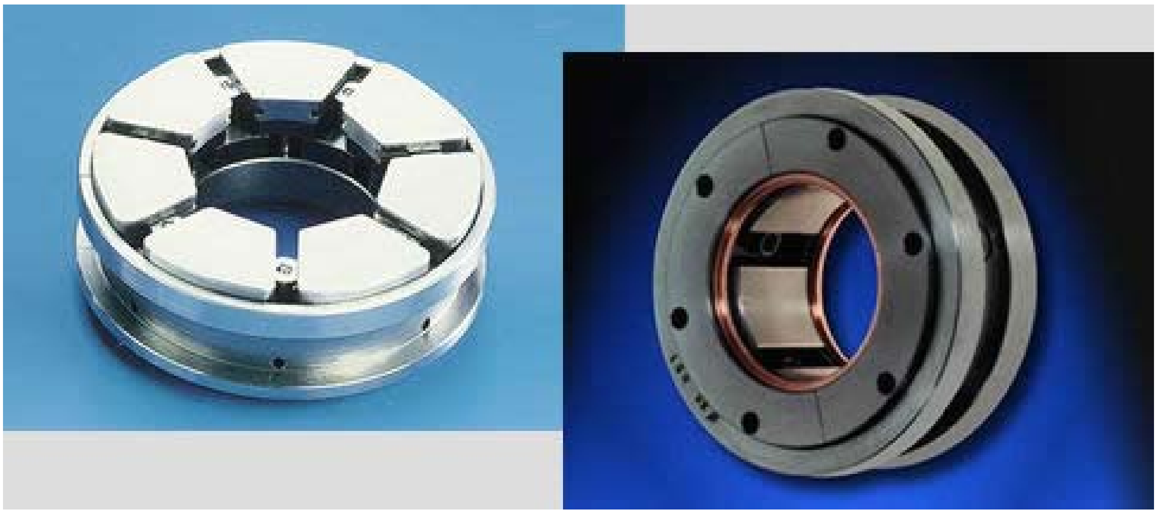
Figure 4.10(b) Shows a half-washer in place at the main bearing of an engine crankshaft.

4.1.4 Tilting-pad Bearings

Tilting-pad bearings are a more advanced design of plain bearing. The pads in these bearings can *tilt* through a small angle.

To ***tilt*** is to lean or tip.

In **Figure 4.11** you can see examples of three types of tilting-pad bearings.



(a) Thrust Bearing (b) Radial or Journal Bearing

(c) Combination Radial and Thrust Bearing

Figure 4.11: Tilting-pad Bearings

Tilting pads allow better lubrication. They are used for high-speed operation but can only take low to medium loads.

4.1.5 Self-aligning (Spherical) Plain Bearings

Self-aligning bearings allow an angular difference between the axis of the shaft and that of the housing. This may be because of misalignment between bearing housings on the same shaft as shown in **Figure 4.12**.

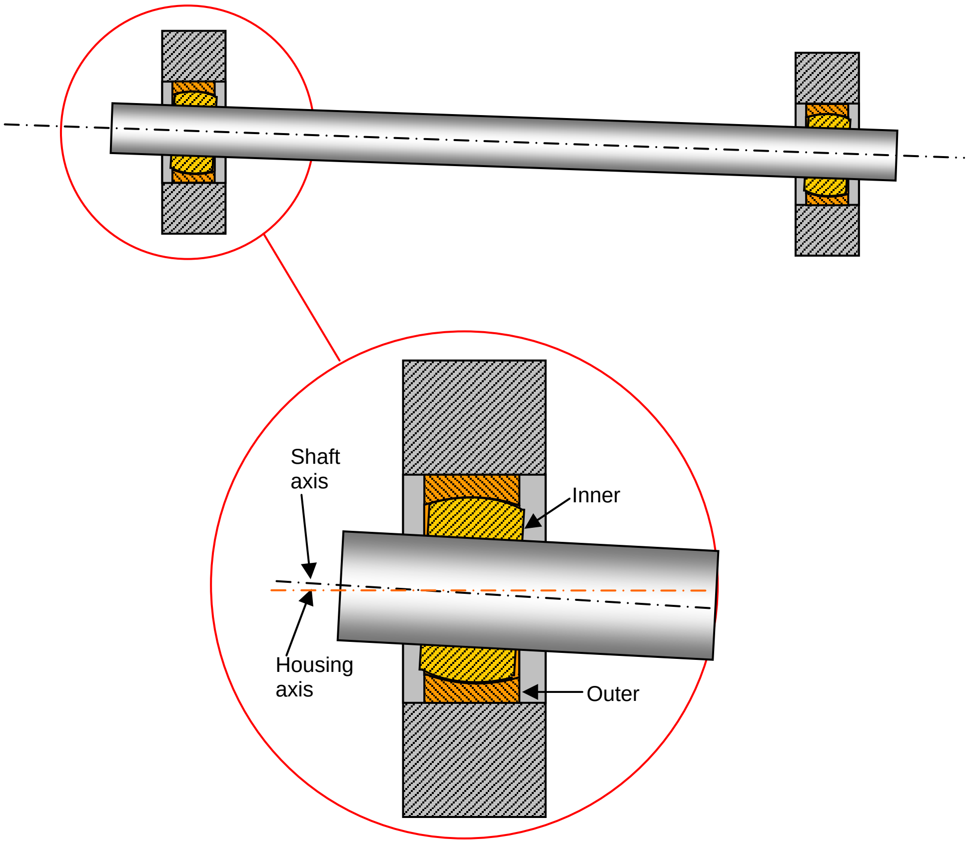


Figure 4.12: Housing Misalignment

They also allow for some bending of the shaft as a result of vibration, etc. Misalignment is described in more detail in **Sections 5.6** and **7.3** of this module.

Self-aligning bearings have two parts: the inner part fits onto the shaft and the outer fits into the housing. Sliding is between the inner and outer parts of the bearing.

These bearings are often called *spherical bearings*. A *sphere* is a ball-shape. The sliding surfaces on the inner and outer parts of the bearing are part of the surface of a sphere, as shown in **Figure 4.13**.

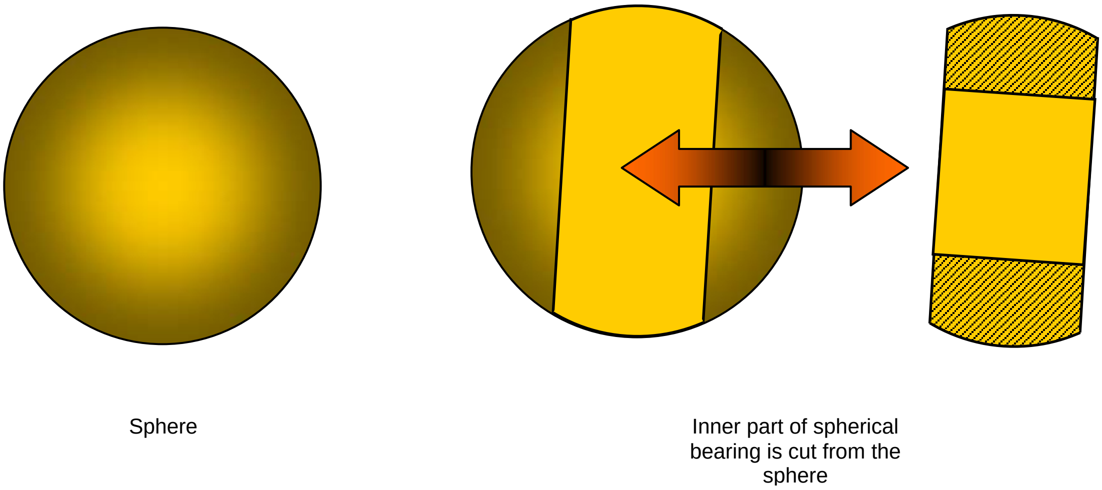
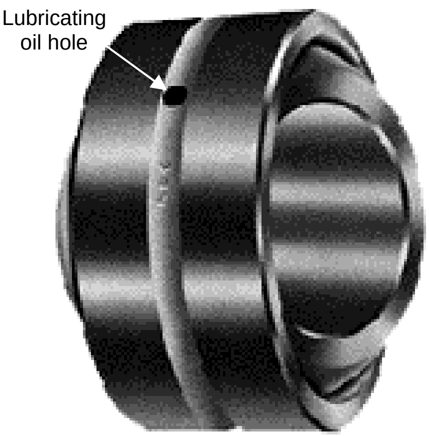


Figure 4.13: Inner Part of a Spherical Bearing

Because the sliding surfaces in both parts of the bearing are spherical, the inner can turn in any direction in the outer. Joints with this kind of freedom of motion are often called *ball and socket* joints. **Figure 4.14** shows two types of spherical plain bearings.



(a) Oil-lubricated Spherical Plain Bearing

(b) Self-lubricating Spherical Plain Bearing

Figure 4.14: Spherical Plain Bearings

Lubricant is supplied to the sliding surfaces of the bearing shown in **Figure 4.14(a)** through the oil hole shown. The sliding surface of the outer part of the bearing shown in **Figure 4.14(b)** is coated with a low-friction material and does not need lubrication. Materials used for self-lubricating bearings are described in **Section 4.3.2** of this module.

Now try **Exercise 1**

4.2 Plain Bearing Fits

Fits between shafts and holes were described in an earlier module in this course: *Precision Measurement*.

The three main types of fit are shown in **Figure 4.15**:

- clearance
- transition
- interference (or *press fit*)

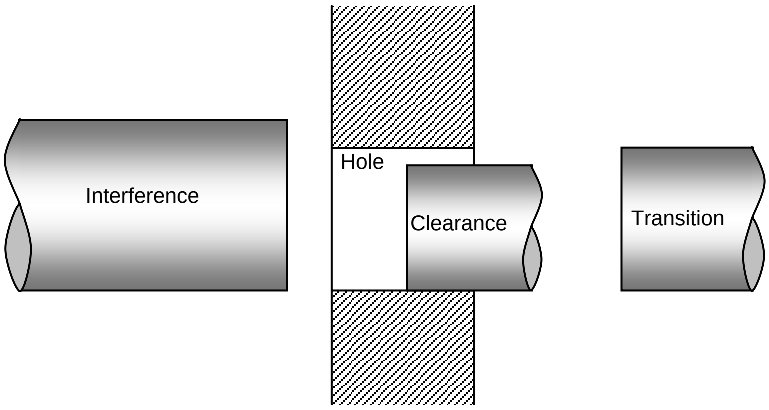
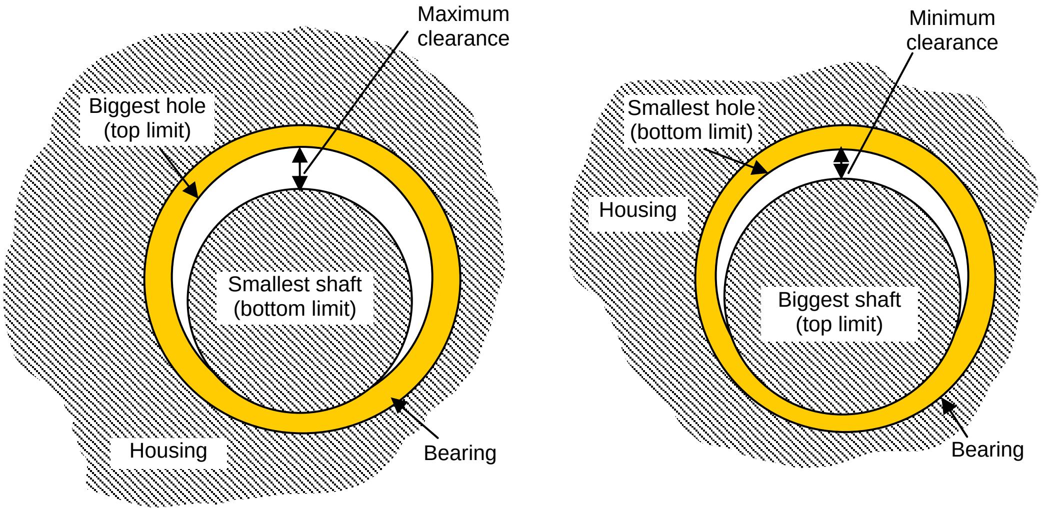


Figure 4.15: Shaft and Hole Fits

There must always be some clearance between a shaft and a plain bearing. This clearance may be very small, only a few hundredths of a millimetre, but there must be some.

The limits of size for the shaft and bearing must always give clearance, even when the shaft is on top limit and the bearing hole on bottom limit as shown in **Figure 4.16**.

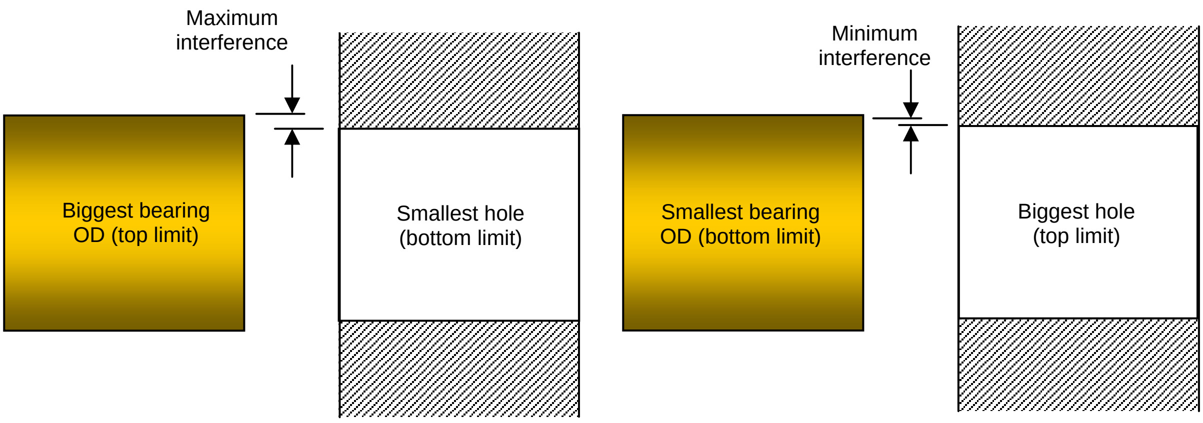


(a) Maximum Clearance (b) Minimum Clearance

Figure 4.16: Shaft/Bearing Clearance Fit

Without clearance, the shaft can not turn in the bearing.

In nearly all cases, the bearing must not turn in its housing. An interference fit holds the bearing securely in its housing. The interference may be only a few hundredths of a millimetre. The size limits of the housing and bearing must always give an interference fit, even when the outside diameter (OD) of the bearing is on bottom limit and the housing hole on top limit as shown in **Figure 4.17**.



(a) Maximum Interference (b) Minimum Interference

Figure 4.17: Bearing/Housing Interference Fit

The interference fit crushes the bush, making its outside diameter (OD) smaller. Crushing also makes the ID smaller, reducing the clearance between shaft and bearing surfaces. This happens to any bearing that is an interference fit in its housing, whatever method of assembly you use. The crushing effect is shown in **Figure 4.18**.

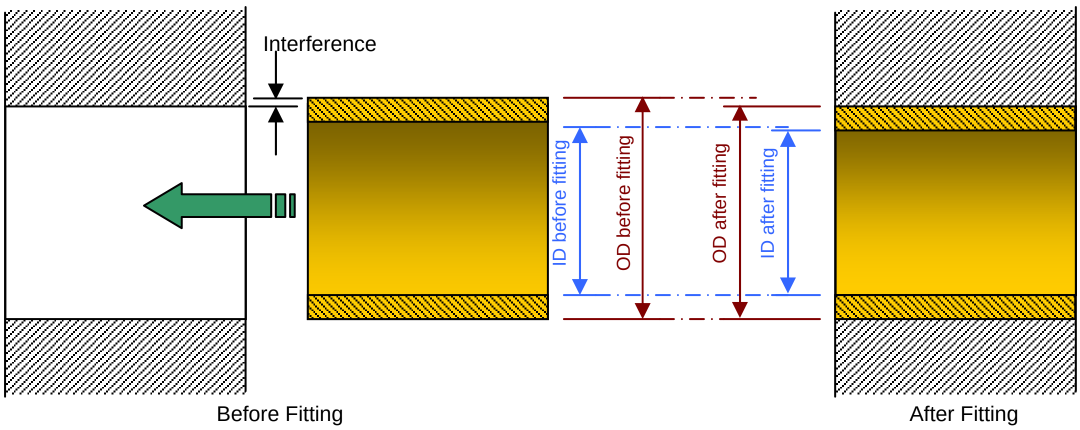


Figure 4.18: Bearing Crush

Always take final measurements of the inside diameter (ID) **after** fitting the bush into its housing.

In **Figure 4.18** you can see that the OD and the ID of the fitted bush are smaller than they were before fitting. If the clearance is now too small, you can ream smaller bushes to the correct ID. Larger bushes must be scraped to size, but this is not a job that you will have to do on the plant.

Split bearings have the same fits as described above. The difference is in the way they are assembled.

Before assembly, the shells are fitted into the lower housing and cap as shown in **Figure 4.19(a)**.

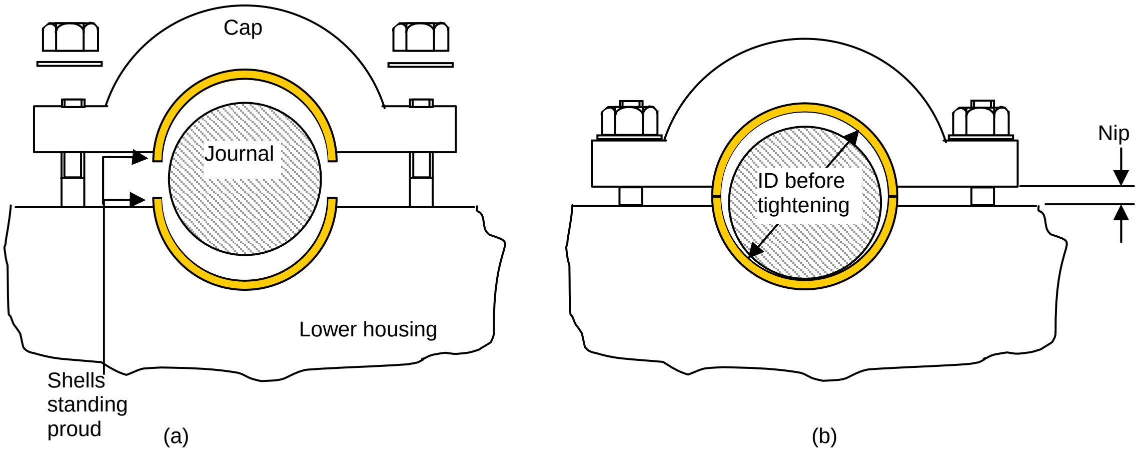


Figure 4.19: Split-bearing Nip

The ends of the shells are slightly *proud* of the bottom of the cap and the top of the housing.

The cap is assembled onto the lower housing and the nuts finger tightened. When the shells touch there is still a gap between the cap and the housing. This gap is called the *nip*, shown in **Figure 4.19(b)**.

Tightening the nuts crushes the shells as shown in **Figure 4.20**.

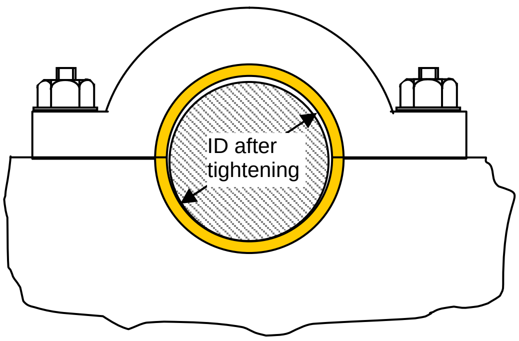


Figure 4.20: Split-bearing Crush

This gives an interference fit between the shells and the housing. It also reduces the inside diameter of the bearing surfaces.

Only assemble and tighten the bearing cap when the shaft journal is in place. This means that you can not measure the inside diameter of the bearing after tightening and crushing in the normal way.

> Note: The clearances, interferences and nips in the figures in this module are shown much bigger than they really are. It would be very difficult or impossible to see the actual size.

One way of measuring split-bearing clearance is by using a product called *Plastigauge*. Plastigauge is a thin circular-section strip of soft plastic. It comes in a packet that has a scale printed on it.

To measure bearing clearance using Plastigauge:

1. With the bearing cap removed, place a length of Plastigauge strip on the shaft journal or the top bearing shell (**Fig. 4.21**).

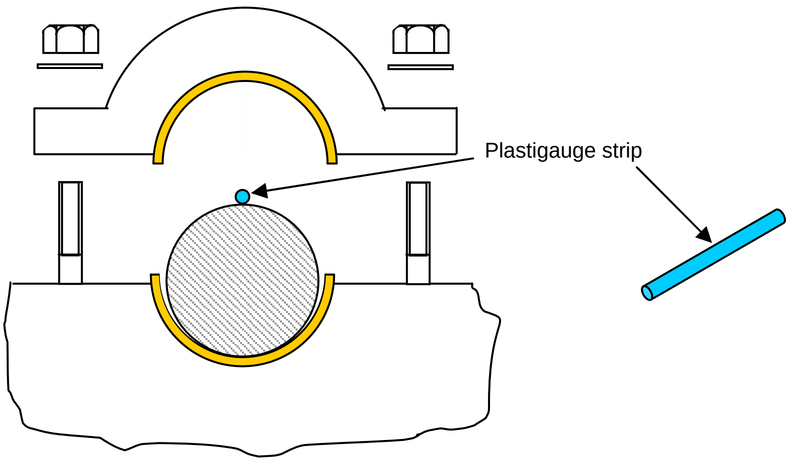
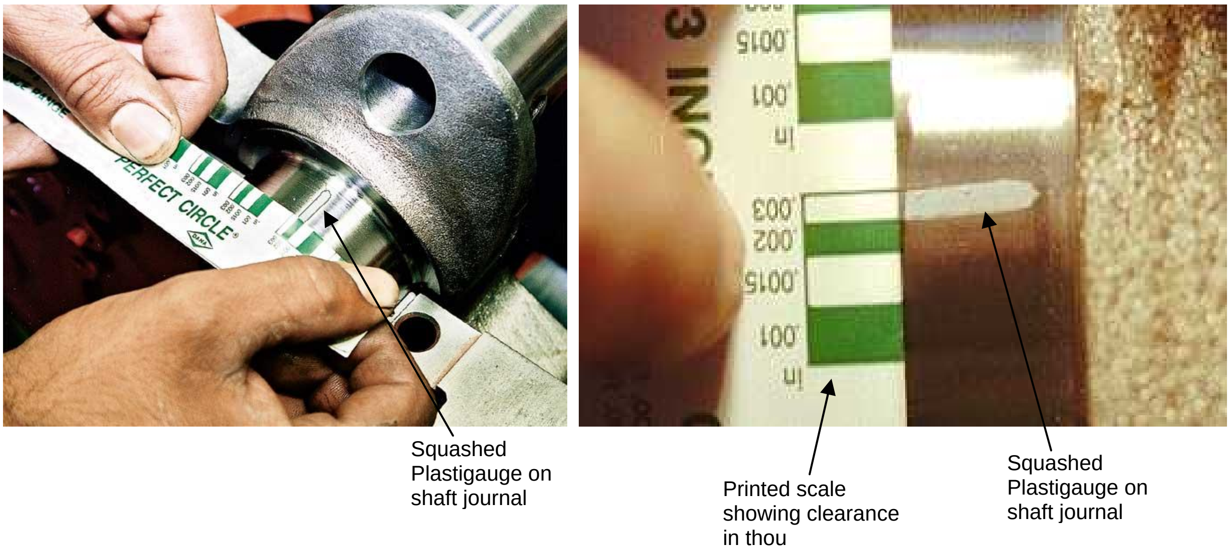


Figure 4.21: Using Plastigauge Strip

2. Replace the cap and tighten to the correct torque. This squashes the Plastigauge strip.

3. Remove the cap again—make sure that the shaft does not turn.

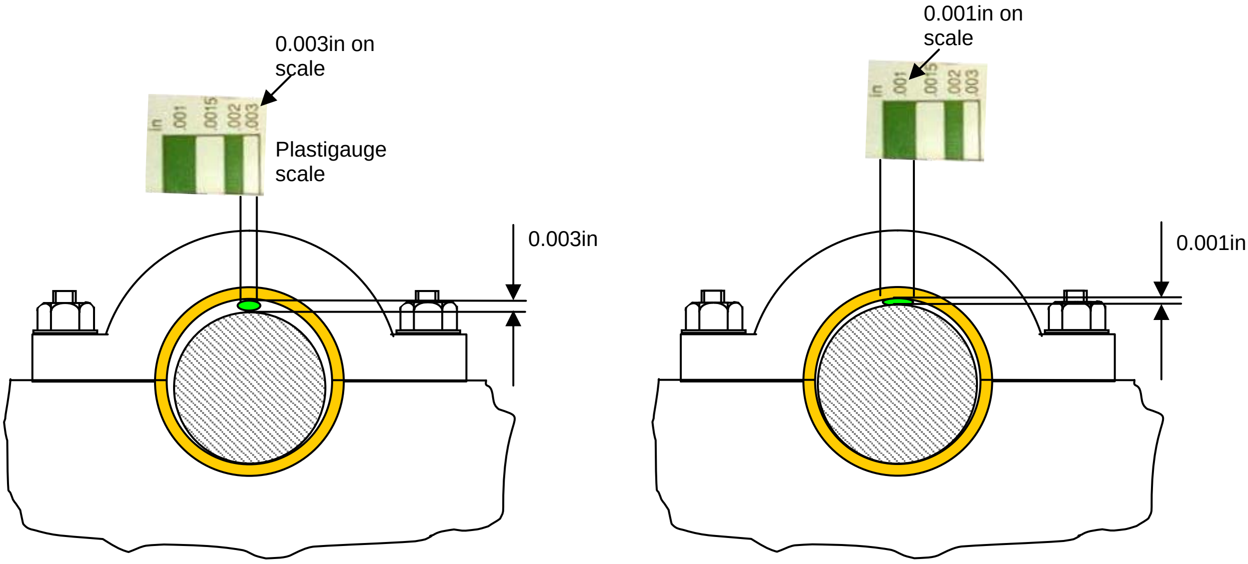
4. Compare the width of the squashed Plastigauge with the scale printed on the packet as shown in **Figure 4.22**



(a) Plastigauge after Compression by Bearing (b) Close-up of Plastigauge Reading

Figure 4.22: Using Plastigauge to Measure Clearance

The width of the Plastigauge after squashing depends on how much it is squashed and this depends on the bearing clearance, as shown in **Figure 4.23**.



(a) (b)

Figure 4.23: Reading the Plastigauge Scale

The more clearance, the less the Plastigauge is squashed, so the narrower it is. The bearing in **Figure 4.23(a)** has more clearance than the one in **Figure 4.23(b)**, so the Plastigauge strip is narrower.

The printed scale does not measure the width of the Plastigauge, it tells you the clearance that squashed it to that width.

- The narrower strip in **Figure 4.19(a)** shows that the bearing clearance is 0.003in or three thou.
- The wider strip in **Figure 4.19(b)** shows that the bearing clearance is 0.001in or one thou.

Another method of measuring split-bearing clearance uses a lead wire. Lead is a very soft metal that squashes, but not as easily as Plastigauge. The wire is used in the same way as Plastigauge, but it is measured differently. After removing the cap, carefully remove the wire from the journal. Then measure the clearance directly from the **thickness** of the wire, not from the width as for Plastigauge. Measure the wire thickness with a micrometer.

If the clearance is too small, *shims* can be used. Shims are thin spacers. They are fitted between the lower housing and the cap to increase bearing clearance. **Figure 4.24** shows a bearing cap, shell and shims.

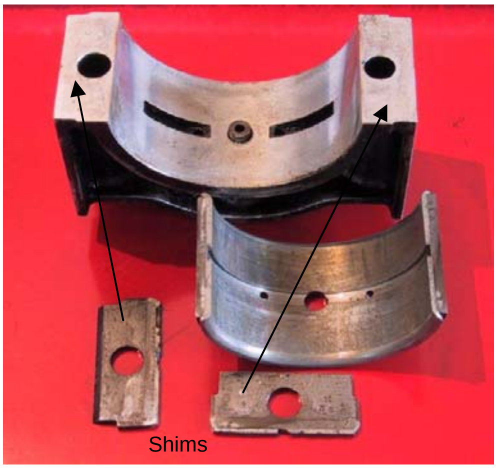
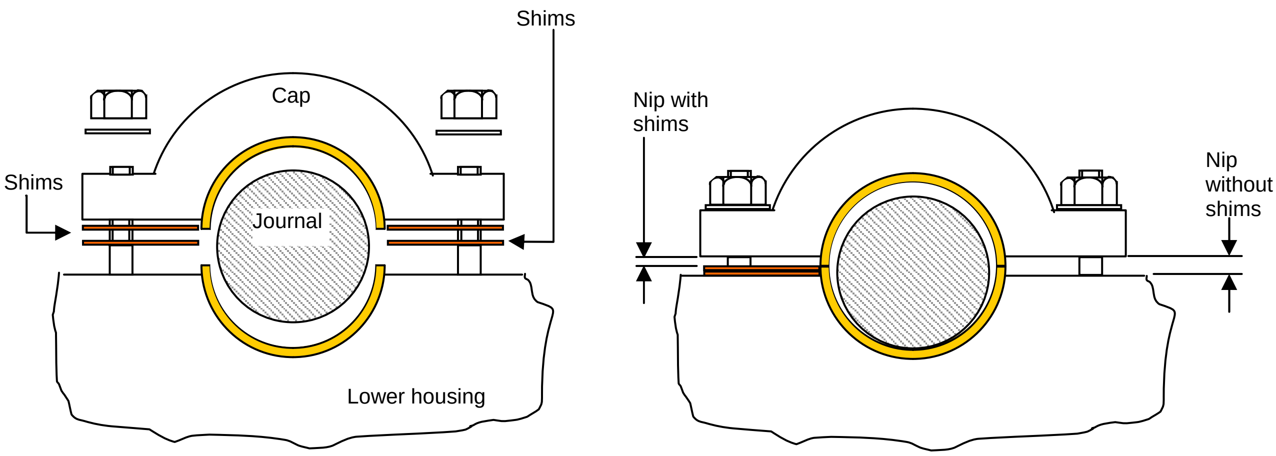


Figure 4.24: Bearing Cap, Shell and Shims

Shims reduce the nip on bearing shells as shown in **Figure 4.25**



(a) Shims Fitted to Both Sides

(b) Shims Shown on One Side Only to Show Effect of Shims on Nip

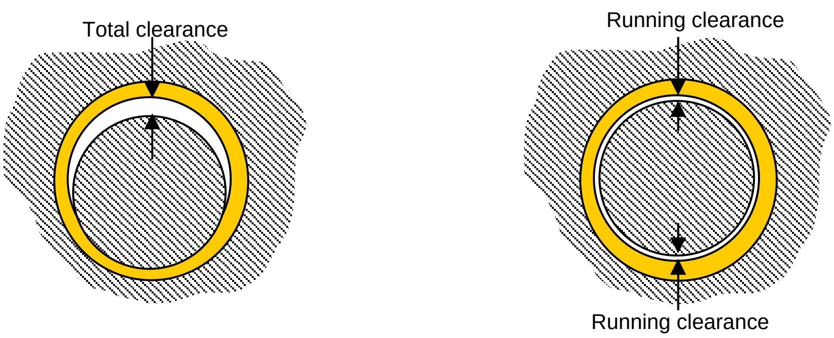
Figure 4.25: Effect of Shims on Nip

Do not use more than the recommended thickness of shims. Too many shims result in a loose fit between the bearing and the housing. They also change the shape of the hole in the housing, making it out-of-round.

Note: All clearances shown here are *total clearance*:

total clearance = bearing ID – shaft diameter

Sometimes *running clearance* is given, which is half the total clearance as shown in **Figure 4.26**.



Total clearance = bearing ID – shaft diameter

Total clearance = 2 x running clearance

Figure 4.26: Clearance Types

4.3 Plain Bearing Materials

Plain bearing materials must:

- have a low coefficient of friction when sliding on the shaft material—to reduce the power wasted to overcome friction and to reduce wear
- be softer than the shaft—so that the bearing material wears before the shaft material

Before looking at bearing materials you should know about some important material *properties*.

4.3.1 Material Properties (Plain Bearings)

Material properties tell you how a material behaves. They are the *characteristics* that belong to a material.

Characteristics, like features, are the things that help us to recognise something or someone.

Some typical properties of metals are:

- density—the mass of one unit of volume of a material
- melting point—the temperature at which a material melts
- conductivity—how easily heat or electricity passes through a material
- strength—how difficult it is to break a material
- **hardness**
- **anti-friction** (*anti*- means *against*)
- **corrosion resistance**
- **fatigue resistance**

The last four are most important for plain bearing materials and are described below.

You may think that all metals are hard, but some metals are much harder than others. The **hardness** of a material is measured by its ability to resist being scratched or dented:

- hard materials are difficult to scratch
- soft materials are easier to scratch
- a hard material can scratch a soft material, but a soft material can not normally scratch a hard material

One purpose of a bearing is to make repair and replacement of components easier during maintenance. Rotating shafts are components that are most likely to wear because of friction at their supports. Shafts are often expensive and difficult to replace; you may have to dismantle the whole machine to replace a shaft. Bearings are usually much cheaper and easier to replace than shafts.

Any wear that takes place should wear away the bearing surface before it wears the shaft. To do this, bearing surfaces are made of materials that are softer than the shaft material.

Soft materials are usually not very strong. Strong materials are more difficult to break then weak materials. To give plain bearings more strength, a stronger material may be used with a layer of soft bearing material on the surface.

Anti-friction is the ability to slide easily over most surfaces. All bearing materials need to be able to do this to reduce wear. Some polymers (plastics) have very low coefficients of friction, e.g. PTFE (poly-tetra-fluoro-ethylene).

Corrosion happens when contact with other substances chemically changes a material. The most well known type of corrosion is called *rust*. Rust forms on iron and steel when it contacts the oxygen in the air. **Figure 4.27** shows part of a ball and a race of an anti-friction bearing that has been eaten away by rust.

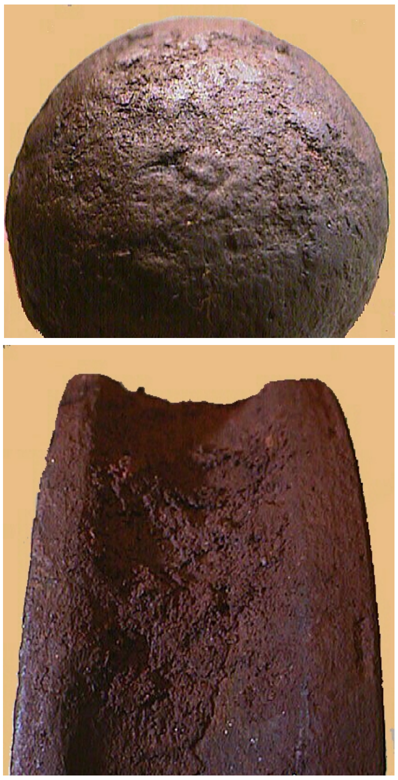


Figure 4.27: Badly Corroded Ball and Race

Bearing materials can be corroded by contact with substances they were not designed to work with, including an incorrect lubricant. A small amount of corrosion can cause a bearing to *fail*. Bearing materials should have good corrosion resistance.

Fatigue can cause materials to crack and break with a relatively small force. You might not be able to break a strip of metal by pulling it, but you can often break it by bending it back and forth a number of times. The metal starts to crack and finally breaks as you continue to bend it. This is called *fatigue failure*.

Fatigue means tiredness. It is as if the metal becomes tired when it is bent back and forth, gets weaker and then breaks. Fatigue failure can happen in machine components when the load on them keeps changing. The component does not have to be bent as much as the strip just described: small load changes are enough to cause fatigue, but then it takes a lot longer to fail. Fatigue in machines is often caused by vibrations. Cracks may start after many months or even years of operation but can cause a lot of damage when the component fails. Some materials are better at resisting failure from fatigue than others.

Bearings often have changing loads because of vibrations in the shaft. Bearing materials should have good fatigue resistance.

Two other special properties that are used only for plain-bearing materials are:

- **Embeddability**—the ability to allow small particles of dirt etc., to be embedded or sink into the material so that they do not scratch the shaft. Softer materials have better embeddability than harder materials.
- **Conformability**—the ability of the material to adjust to very slight misalignment of the shaft. Softer materials also have better conformability than harder materials.

4.3.2 Materials Types (Plain Bearings)

Most plain bearings are made of metals but some are made of polymers (plastic materials) or have parts made of these materials. It is not possible to get one material that has all the properties needed for a bearing. For this reason it is important that the material has the properties most needed for the conditions under which the bearing operates.

Two important operating conditions are:

- load—heavy or light loads
- running speed—fast or slow operating speeds

Metals can be divided into two main types:

- pure metals—*elements* in the language of chemistry
- alloys

Pure metals are usually found in the ground as *ores*. They are then processed to give the metals that we use. Some pure metals you should know are:

- iron
- copper
- zinc
- tin

The properties of pure metals can often be improved by 'mixing' them with other metals or materials that are not metals. These 'mixtures' are called *alloys*.

A very important engineering alloy is steel. Steel is an alloy made by adding small amounts of carbon to iron. This makes the alloy much stronger than pure iron. Most machine shafts are made of steel. By adding different amounts of carbon you can change the properties of steel—adding more carbon makes steel stronger and harder.

Because shafts are made of steel, most plain bearings are made of materials that are softer than steel. Some alloys used for plain bearings are:

Brass—an alloy of two metals, copper and zinc. Good corrosion resistance; quite hard so it has poor embeddability and conformability. Used for high loads operating at slow speeds

Bronze—an alloy of copper tin and sometimes other elements. Bronze containing phosphorus is known as *phosphor bronze*. Bronzes have similar properties to brass.

White metal or *Babbitt*—alloys mainly of tin and lead. These are the most common alloys used for plain bearings as they have many of the properties needed. Babbitt has good anti-friction properties and good corrosion resistance. It is soft, so has good embeddability and conformability but is not strong. Because of this and the poor fatigue resistance of thick sections of Babbitt, a shell made of steel, cast iron or bronze is given a thin layer of Babbitt. The shell gives the bearing strength and the Babbitt gives it good bearing properties. **Figure 4.28** shows a large cast-iron shell with a Babbitt lining.

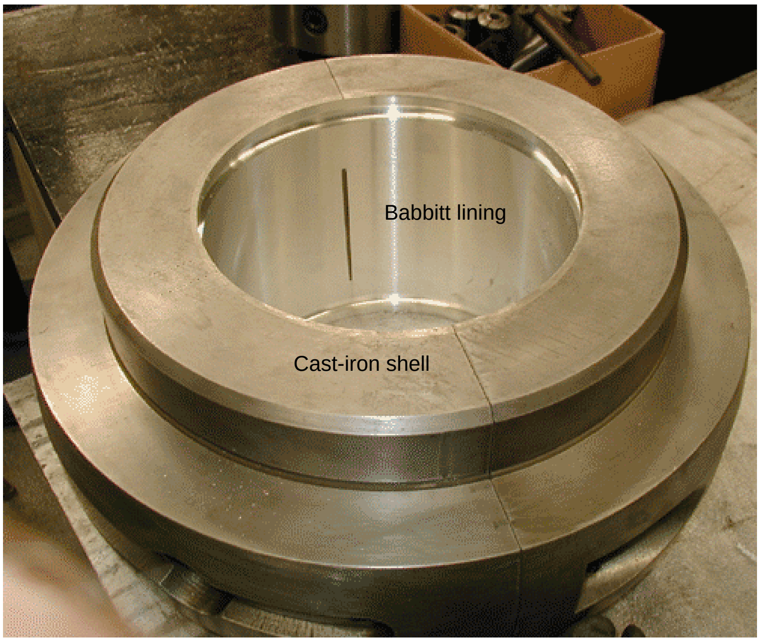


Figure 4.28: Large Babbitt or White-Metal Lined Bearing

Other metal alloys used for bearings are **aluminium-tin alloys** and **copper- or bronze-lead alloys**.

Pre-lubricated and **self-lubricating** bearings do not need additional lubrication during service.

Some bronze bushes are **pre-lubricated**. These are made from bronze powder that is pressed into a mould and heated until the powder particles stick together. This process is called *sintering*. A sintered bearing has tiny spaces between the particles that can soak up and hold oil. The bush is soaked in oil before fitting.

Self-lubricating bushes do not need lubrication: they can run dry. Examples are:

- Nylon—a polymer (plastic) used for small bushes that can take light loads.
- PTFE (**p**oly**t**etra**f**luoro**e**thylene)—a polymer with very good anti-friction properties and resistance to chemicals, etc. Bushes are sometimes made up of three layers: a steel backing or outer layer for strength, a sintered bronze insert or interlayer and a coating of lead mixed with PTFE. Others may have a glass-fibre body with a PTFE bearing surface as shown in **Figure 4.29(a)**.
- Some self-lubricating bushes have a bronze body with holes that hold solid lubricant as shown in **Figure 4.29(b)**.

(a) Glass-fibre Bearings with PTFE Bearing Surface

(b) Bronze Bearings with Solid Lubricant

Figure 4.29: Self-lubricating Bushes

4.4 Plain Bearing Lubrication

The moving surfaces of plain bearings slide over each other. Although the bearing surfaces are made of materials that have low coefficients of friction, direct contact between them still causes them to wear quickly. Lubricant between the sliding surfaces reduces friction and wear.

Water can be used as a lubricant in some large, slow-speed *applications* but oil and grease are much better lubricants.

An ***application*** is a purpose to which something is put.

Although their main purpose is to reduce friction, lubricants also:

- reduce wear—friction causes wear
- remove heat by cooling the moving parts—friction causes heat
- prevent corrosion—by protecting metal surfaces with a coating of lubricant
- remove dirt—by washing dirt or other *contaminants* from the bearing surfaces

Lubricants change sliding friction in a plain bearing to fluid friction.

Remember: fluid friction < sliding friction

Plain bearing materials still need good anti-friction properties because there is sliding friction when a shaft starts to turn, even with a lubricant. When the shaft is not turning, it rests on the bottom of the bearing as shown in **Figure 4.30(a)**.

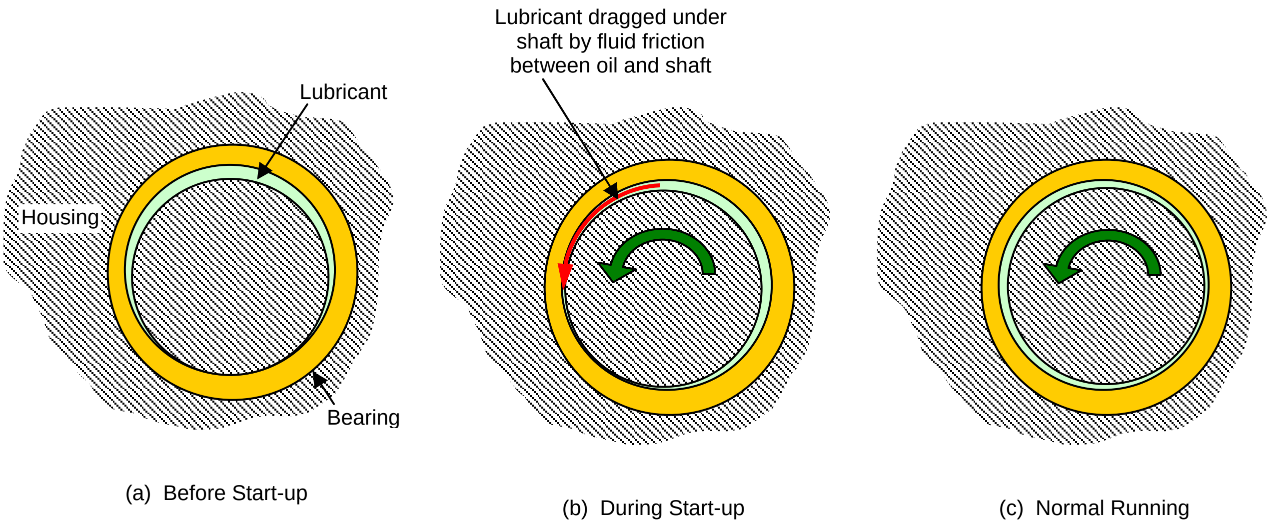


Figure 4.30: Plain Bearing Lubrication

As the shaft starts to turn, it slides on the bearing surface. Sliding friction between the bearing surface and the shaft makes the shaft climb the side of the bearing like a wheel rolling up a slope, as shown in **Figure 4.30(b)**. Fluid friction between the shaft and the lubricant drags lubricant in the direction of rotation, between the sliding surfaces.

At operating speed the shaft has a *film*, or layer, of lubricant between it and the bearing surface. The shaft centre is now located in its correct position for operation as shown in **Figure 4.30(c)**. This is not quite in the centre of the bearing as the pressure of the lubricant is greater where it is being continuously dragged under the shaft. Remember that the total clearance of the shaft in the bearing is very small, much smaller than shown in the figure.

When the machine is shut down, the shaft slides on the bearing surface again just before it stops rotating.

Lubricant is supplied to the bearing through a hole in the housing or from one end of the bearing. Many plain bearings have holes or grooves to help *distribute* the lubricant over the bearing surface.

To ***distribute*** is to spread over an area.

Figure 4.31(a) shows bearing shells with lubricant holes and grooves. **Figure 4.31(b)** shows plain bushes, bearing pads for *linear* sliding and a thrust washer, with grooves for lubricant distribution.

Linear means in a straight line.

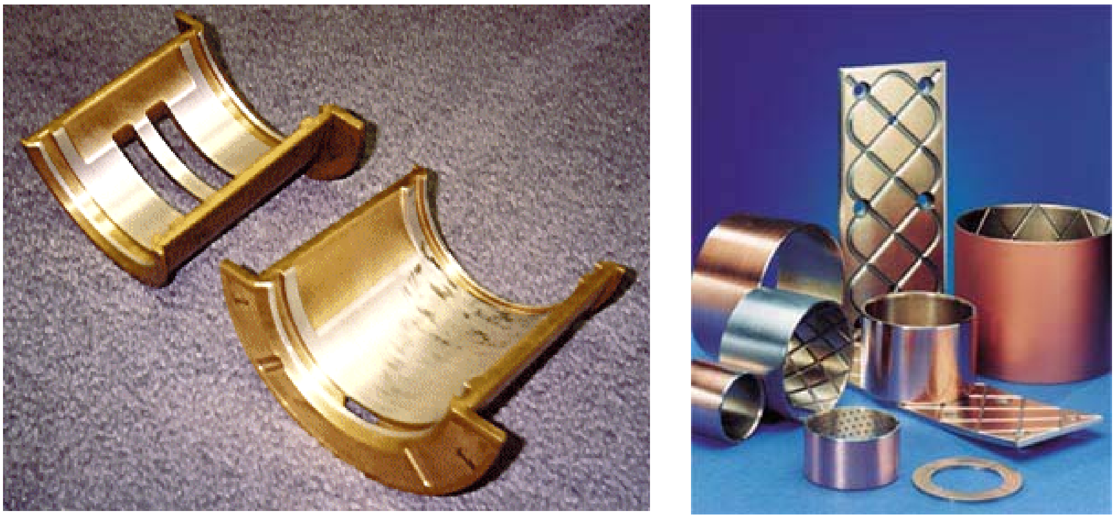


Figure 4.31: Lubrication Holes and Grooves in Plain Bearings

It is very important to use the correct lubricant. Equipment manufacturers' manuals always recommend lubricants that are suitable and lubricant manufacturers give *equivalent* lubricants. These are their own products that can replace those of other manufacturers.

Equivalent means equal—something that works just as well.

One important property of oil is *viscosity*. Viscosity is a measure of how easy it is to pour:

- Low viscosity oil is easy to pour—it is *thin*.
- High viscosity oil is hard to pour—it is *thick*.

Oil viscosity changes with temperature:

- Low temperature increases viscosity—it makes the oil thicker and harder to distribute over bearing surfaces.
- High temperature decreases viscosity—it reduces the ability of the oil to form a film over the bearing surfaces.

Some oils have *additives* that reduce the effect of temperature. This makes them able to work well over a larger temperature range.

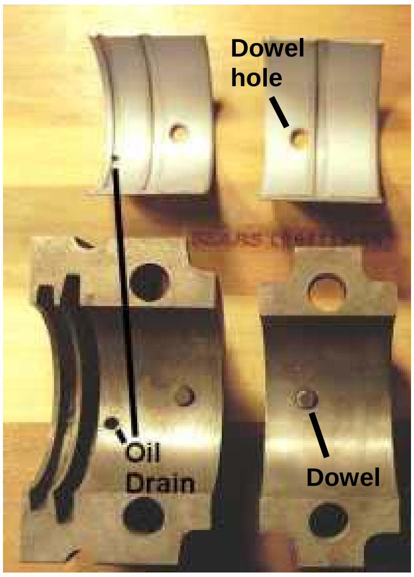
The effect of temperature on oil viscosity is very important on ADGAS plant. Equipment used in the gas liquefaction process has to operate at temperatures as low as -162^{o}C for LNG. Other equipment has to handle superheated steam at +440^{o}C. Even equipment that does not have to work at these temperatures must work in the very high summer temperatures in the Gulf.

4.5 Fitting and Removing Plain Bearings

In most cases, plain bearings have a clearance fit on the shaft and an interference fit in the housing. This means that the shaft slides easily into the bearing. The way you fit the bearing into the housing depends on the amount of interference and whether the housing is split.

4.5.1 Split Bearings

Split bearings are always fitted into split housings. When the bearing cap is tightened, the nip makes sure that the fit is tight, as described in **Section 4.2**. Dowels or *lugs* may be used to locate the shells correctly in the housing during assembly. **Figure 4.32(a)** shows bearing shells and caps that have locating dowels



(a) Dowel Location

(b) Lug Location

Figure 4.32: Shell Locating Methods

Figure 4.32(b) shows a bearing shell with a lug. This lug fits into a matching *notch* in the housing. Notice the hole and groove for oil distribution in **(a)** and **(b)** above.

Fit shells to the lower housing and cap; locate the cap on the lower housing and finger-tighten the nuts (on studs) or bolts. Then torque up the nuts or bolts to the manufacturer's recommended torque.

You can replace worn shells without removing the shaft. Remove the cap and top shell. Support the weight of the shaft and then slide the bottom shell around to the top of the shaft. If dowel locators are used, they are only in the cap so the bottom shell can slide when you remove the cap. Shells with lugs can be slid around the shaft in one direction only.

Check the clearance after assembling using Plastigauge or lead wire.

Now try **Exercise 2**

4.5.2 Bushes

Bushes or sleeve bearings are fitted into the housing by:

- press fitting—with a screw press or a hydraulic press
- shrink fitting—by cooling the bush or heating the housing
- a combination of both methods

You can press a bush into its housing if the interference is not too great and the bush is strong enough to take the force without damage.

A better way is to *shrink-fit* the bush into its housing.

When you heat anything it expands or gets bigger. If you heat the housing it expands and so does the hole that the bearing fits into. By heating and expanding the housing enough you can gently push in the bush. The fit is then a transition or very small clearance fit. When the housing cools, it tries to contract back to its original size and grips the bush. This process is shown in **Figure 4.33**.

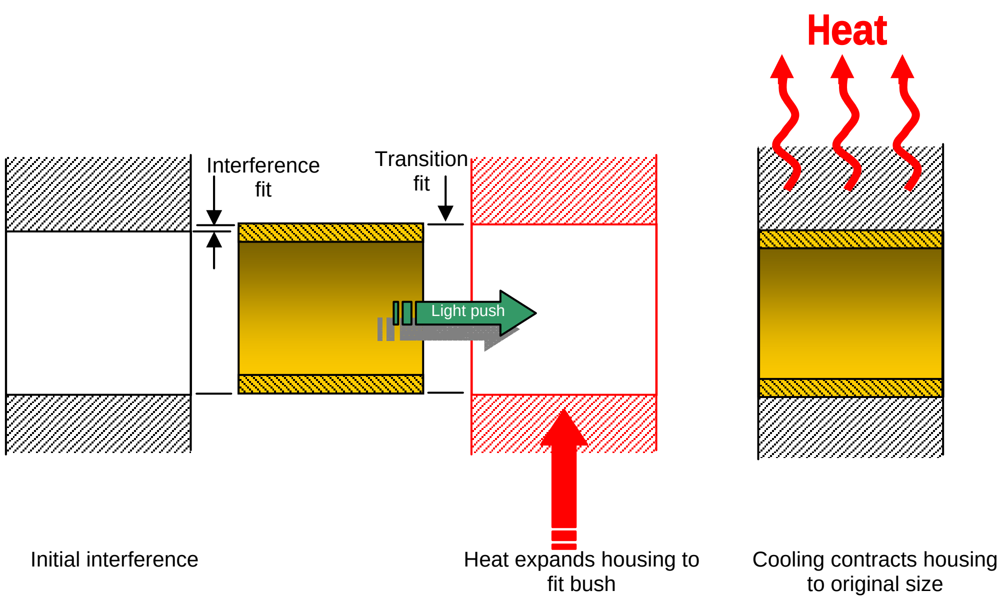


Figure 4.33: Shrink-fit by Heating Housing

You might not be able to heat the housing. Perhaps it is too big, or heating it might damage other components, like seals. In that case you can cool the bush. Cooling has the opposite effect to heating, it makes things contract or get smaller. Cooling the bush makes it contract so that you can gently push it into its housing. The fit is then a transition or a very small clearance fit. When the bush warms up again, it tries to expand back to its original size and is held securely in the housing. This process is shown in **Figure 4.34**.

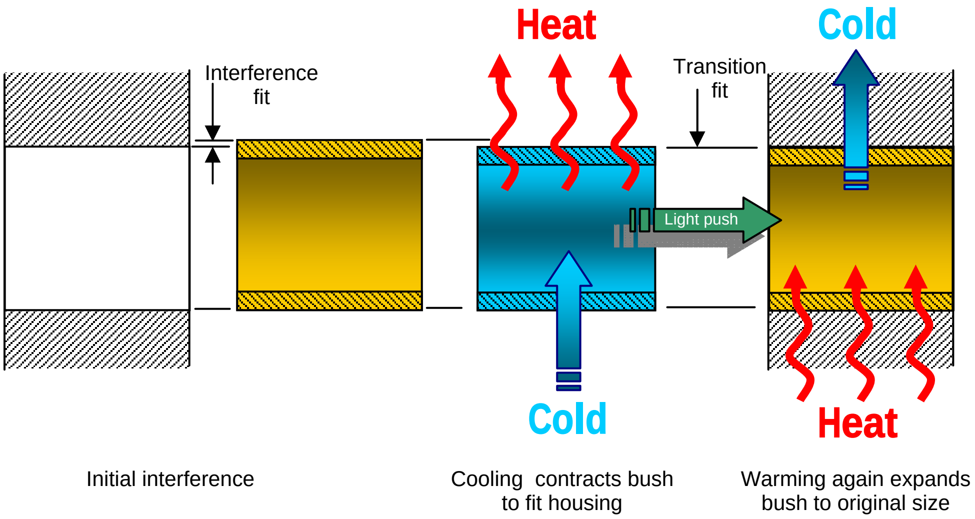


Figure 4.34: Shrink-fit by Cooling Bush

If it is not possible to supply enough heat or enough cold to allow the bush to slide into the housing easily, you can gently push it in with a press after heating or cooling.

You can heat the housing by:

- putting it in an oven
- putting it in an oil bath
- using an induction heater

Handling hot materials can be dangerous—take great care

Wear the correct PPE, especially when using an oil bath

These heating methods can be used in the workshop but are often not possible on the plant. More information is given in **Section 6.6** where fitting anti-friction bearings is described.

You can cool the bush by:

To ***submerge*** something is to lower it below the surface of a liquid.

- *submerging* it in liquid nitrogen—temperature -196°C
- packing solid carbon dioxide (CO_2) or *dry ice* around it—temperature -123°C
- packing ordinary ice around it—temperature 0°C

Handling very cold materials can be just as dangerous as handling hot materials

Wear the correct PPE, especially when using liquid nitrogen and dry ice

It is normally easier to cool the bush than to heat the whole housing. This is especially true when the housing is part of the machine casing.

Take great care if you use liquid nitrogen or dry ice. Very low temperatures can burn you just as seriously as very high temperatures. This is one reason these are not used in the plant.

If you have nothing else, you can make the bush easier to fit by packing it with ice and leaving the housing in the sun. This makes the bush contract a little and the housing expand a little. This reduces the force needed to push the bush into the housing. If you have no press to push the bush you can tap it in carefully. Always use a soft drift to do this, do not hit the bush directly. Make sure that the drift makes contact with the full *circumference* of the bush and that the bush is square to the housing as you tap it in.

Check the clearance after fitting the bush by measuring the internal diameter of the bush and the diameter of the shaft journal.

Remember that the ID of the bush is reduced by the interference fit in the housing

Now try **Exercise 3**

5 Troubleshooting—Plain Bearing Failure

When equipment is taken out of service for *overhaul* it is normal procedure to inspect all the bearings. What you look for are signs of damage. If you see damage, there are two things that you must do:

- decide if the bearing needs to be replaced
- identify the *root cause* of the damage

A good Maintenance Technician does not just find a worn or broken component and replace it; he wants to know why it is worn...why it has broken. If you replace a damaged component without finding out what has caused the damage, you will probably find the same problem again in a few weeks or months.

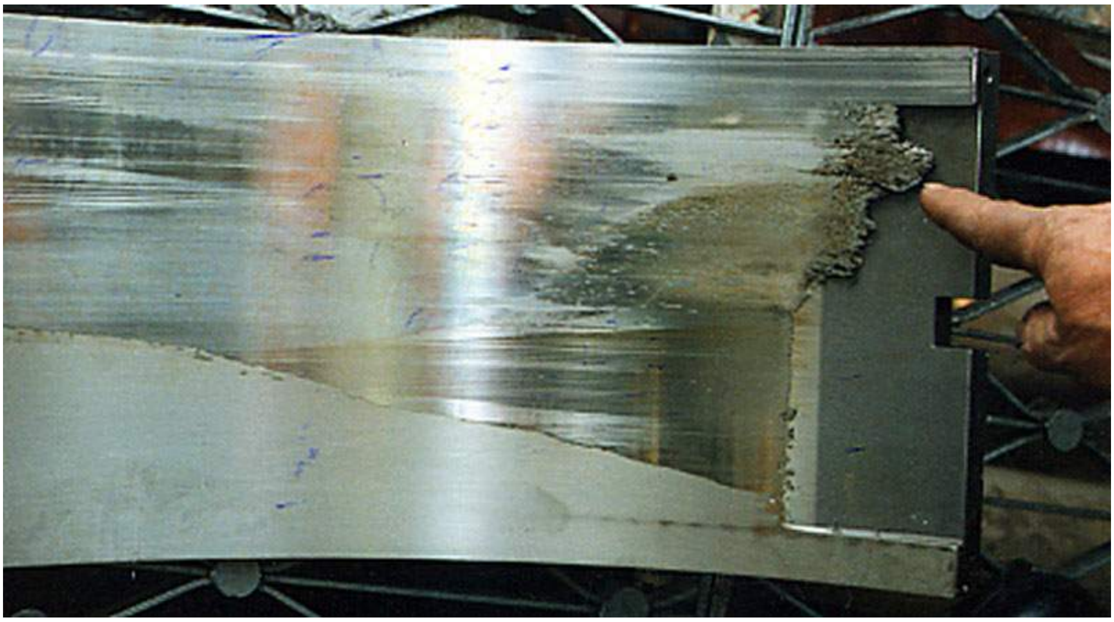
Troubleshooting is finding out **why** a machine breaks down...**why** a component is damaged. You are looking for the *root cause* of the damage—not just what has happened but **why** has it happened. You have to act like a doctor or a detective: looking for *symptoms* or *clues* to find out what has happened.

Symptoms and ***clues*** are things you find that help you to solve a problem.

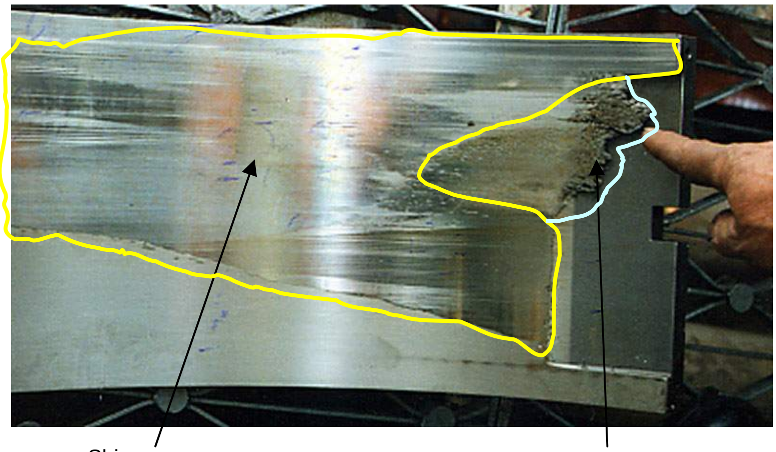
Inspecting damaged bearings can give you clues to the cause of damage. With practice you can learn a lot from looking at the bearing surfaces. This comes with experience but some examples of common types of damage and their causes are described in this section.

5.1 Wiping

Wiping happens when the surface of a plain bearing melts. It is dragged by the rotating shaft and re-solidifies at a cooler part of the bearing. It looks like the liquid metal has been wiped with a rag. **Figure 5.1** shows wiping on a large white-metal bearing shell.



(a)



(b)

Figure 5.1: Wiping on a White-metal Bearing Shell

In **Figure 5.1(b)** you can clearly see the two important areas outlined:

- the area where the metal has melted is outlined in yellow
- the area where the metal has cooled and become solid again is outlined in light blue

If the metal has melted, it must have become hot.

The most likely cause of too much heat at a bearing is too much friction.

The most likely cause of too much friction is too little lubricant.

The cause of wiping is either:

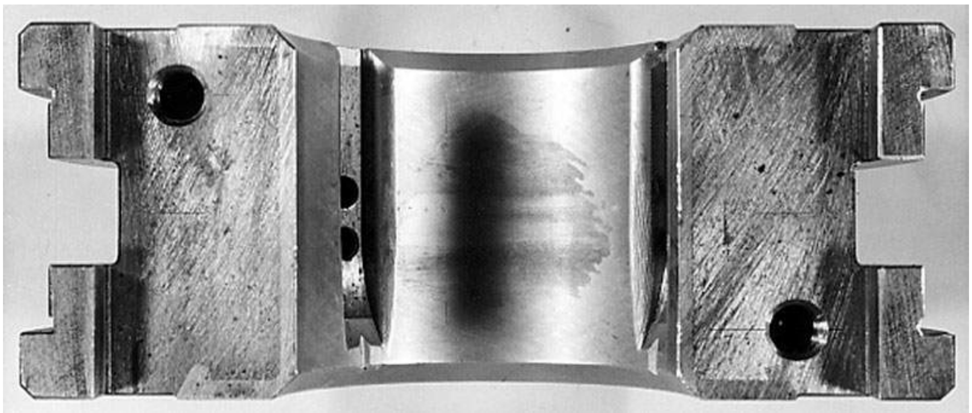
- break-down of the lubricant film between the shaft and the bearing
- the oil has become so hot that it has reached the melting temperature of the white metal—about 240°C

The first cause is the most common. The second cause can sometimes happen on high-speed rotating equipment.

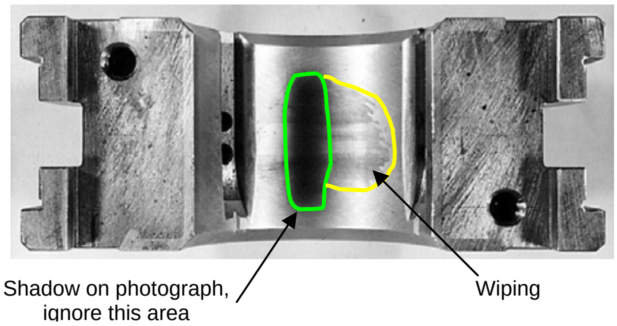
To find the root cause of the problem, you need to know why the lubricant film has broken down. The most common reasons are:

- poor lubricant supply—there could be a problem with a lubricant pump or supply lines
- incorrect lubricant—an oil with a viscosity that is too low
- lubricant supply too hot—this reduces the viscosity of the lubricant and may even be hot enough to melt the bearing material
- too much load—can make the lubricant too hot or break down the film, especially on start-up
- faults that reduce the bearing surface supporting the load—uneven wear, corrosion, etc.—this increases the load on the surface that remains

As described earlier, there is always some sliding contact between shaft and bearing on start-up. If the load on the bearing is too great, or the lubricant film is slow to form, this can cause wiping on start-up. **Figure 5.2** shows a shell that shows this type of damage.



(a)



(b)

Figure 5.2: Start-up Wiping

The area outlined in yellow shows where the shaft has started to climbe the side of the bearing on start-up (see **Figure 4.30**). This happens before the lubricant film has formed.

The lubricant film is slow to form if the lubricant viscosity is too high. A thick oil takes longer to reach the bearing surfaces than a thin oil. In very cold weather the oil viscosity increases but this is not normally a problem in the Gulf.

The damage in **Figure 5.2** was caused either by using an oil with too high viscosity or because the start-up load was too great for the bearing used.

5.2 Scoring

Scoring means scratching. Scoring happens when there are solid particles of dirt, etc., that get between the bearing and the shaft. **Figure 5.3** shows a very bad case of scoring.

Figure 5.3: Heavy Scoring of a Lead-bronze Journal Bearing

The deep scratches all go around the bearing *circumference*, in the direction of rotation of the shaft. This is caused by hard solid particles that are bigger than the minimum film thickness of the lubricant. The example shown in **Figure 5.3** was a main bearing from a reciprocating pump. The pump had been started up after maintenance without cleaning out the crankcase.

Another example of scoring is shown in **Figure 5.4**.

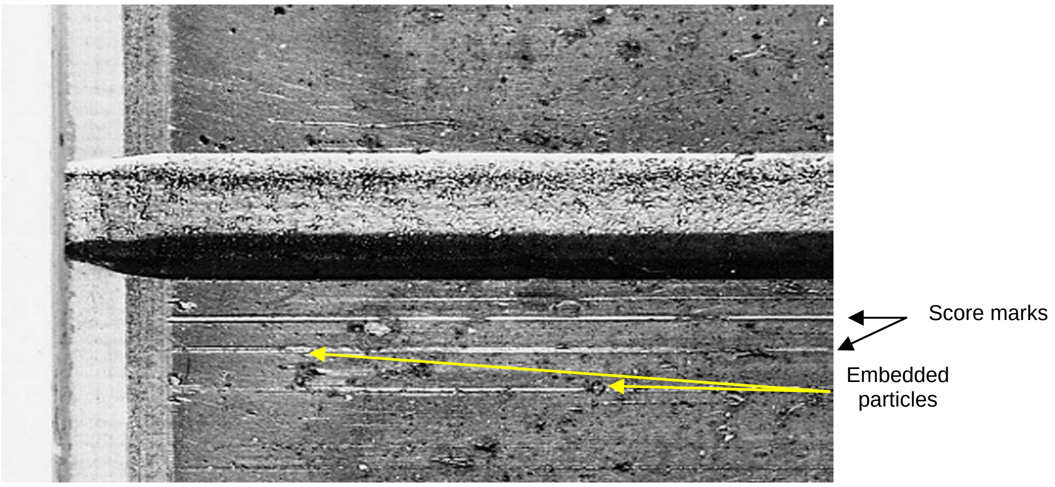


Figure 5.4: Scoring in a White-metal Bearing

There are often particles embedded at the end of score marks. White metal has good embeddabilty properties, which help to reduce the amount of scoring.

Scoring is usually caused by dirt in the oil. This is caused by poor filtering of the oil or failure to change the oil when necessary.

If there are no embedded particles, the cause of scoring could be a damaged shaft journal.

Figure 5.5 shows another example of scoring, this time on the pad of a thrust bearing.

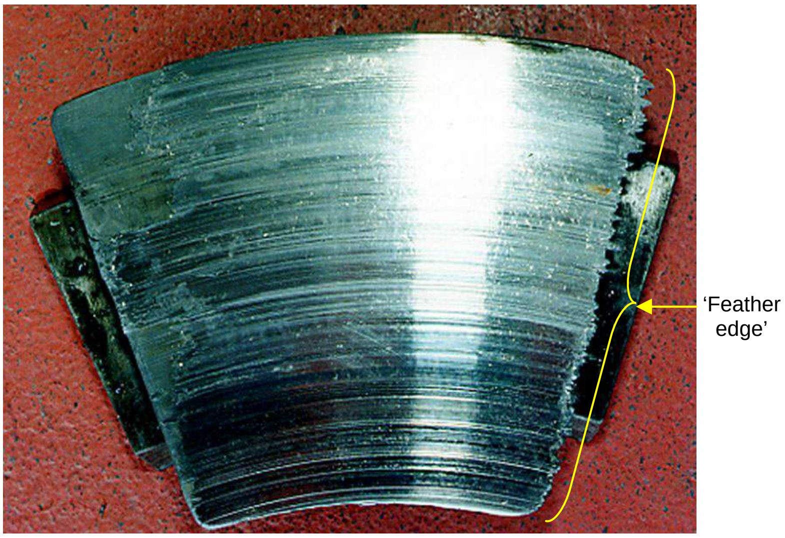


Figure 5.5: Scoring on a Thrust Pad

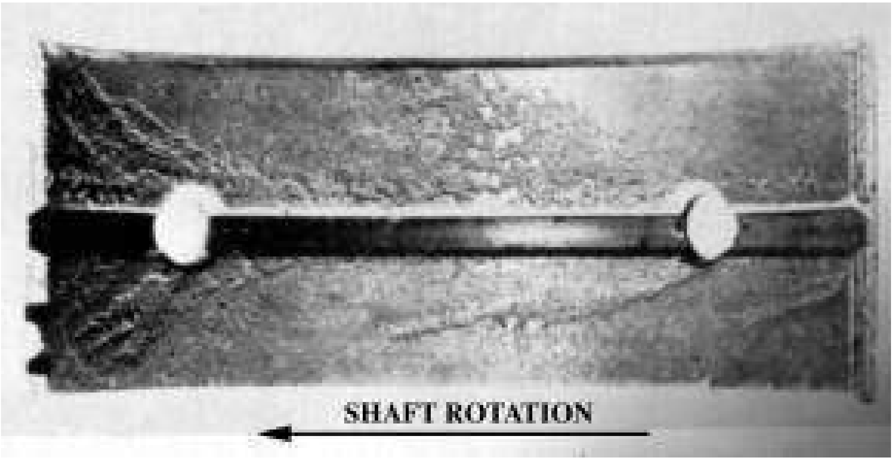
Here, you can see where some bearing material has been dragged to the edge of the pad in the direction of rotation. This is sometimes called a *feather edge*. It looks a little like wiping, but the scratches on the surface tell you that it is not.

5.3 Erosion

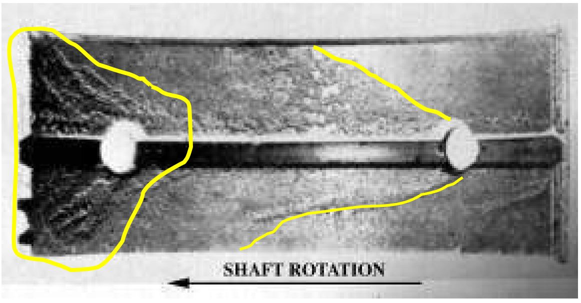
Erosion is caused by solid particles in the oil continually hitting the bearing surfaces. These particles are smaller than the minimum lubricant film thickness so they do not cause scoring. They are small enough to be carried in the oil as it *circulates* between the bearing surfaces.

To ***circulate*** is to move around.

Figure 5.6 shows erosion damage to a white-metal shell.



(a)



(b)

Figure 5.6: Erosion by Small Particles

You can see the erosion marks as if they were flowing out from the oil holes, outlined in yellow in **Figure 5.6(b)**. The flow of the oil and particles is in the same direction that the shaft rotates in. The shaft rotation drags the oil around in this direction. Erosion damage makes the white metal surface rough and dull.

5.4 Fatigue

Fatigue was described in **Section 4.3.1**. It is caused by a continuously changing load over a long period of time.

Figure 5.7 shows examples of fatigue damage at different stages.

(a) Fatigue Damage in its Early Stages

(b) More Advanced Fatigue Damage

(c) Severe Fatigue Damage

Figure 5.7: Fatigue Failure in White Metal

The first signs of fatigue damage in soft materials are small cracks on the surface (**Fig. 5.7(a)**). These cracks can be in any direction are often described as surface *crazing*. As the cracks grow, they join up to form a loose piece that falls off (**Fig. 5.7(b)**).

This *flaking* or *spalling* of the surface continues until you can see the material under the white metal (**Fig. 5.7(c)**).

5.5 Fretting

Fretting is caused by very small back-and-forth rubbing movements often due to vibration. This can happen on journal bearings when the shaft is stationary. If there is equipment operating nearby, vibrations can pass to the stationary equipment causing fretting.

Fretting on white metal makes a black stain on the surface. **Figure 5.8** shows fretting damage on a journal bearing.

Figure 5.8: Fretting

The damage is at the bottom of the bearing, where the stationary shaft was sitting.

The outside of a bearing shell can fret in the housing when there is not enough nip before fitting the cap. This allows small movements between the shell and its housing. Fretting between two steel surfaces, e.g. the shell backing and the housing, can leave a reddish-brown stain on the surfaces, as shown in **Figure 5.9**.

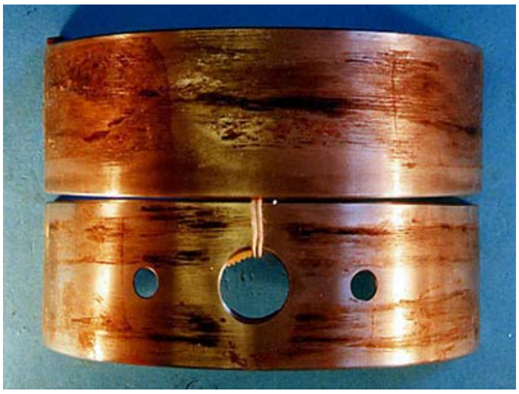


Figure 5.9: Fretting Due to too Little Interference between Shells and Housing

5.6 Misalignment

Misalignment is the opposite of alignment.

If the shaft axis does not align accurately with the bearing axis, the load is only carried by part of the bearing. The shaft pushes on one side at one end of the bearing and on the opposite side at the other end, as shown in **Figure 5.10**.

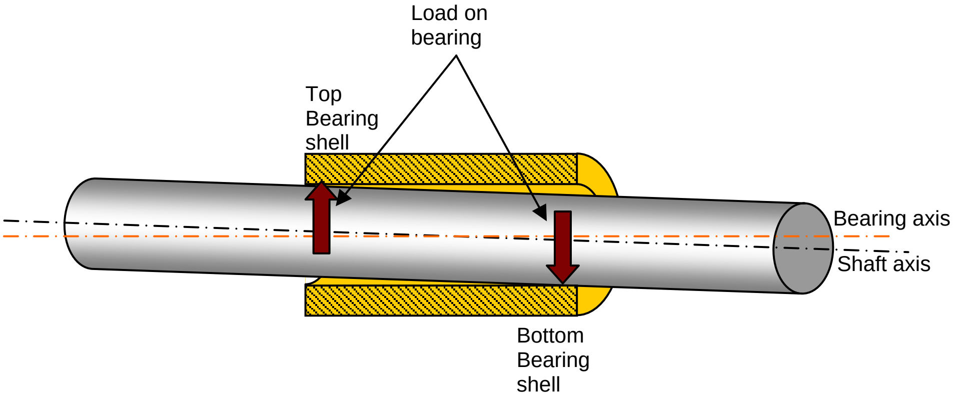


Figure 5.10: Misalignment

The lubricant film can break down where the load is high. This causes wear in those areas and may also cause wiping. **Figure 5.11** shows a pair of bearing shells that have worn unevenly because of shaft misalignment.

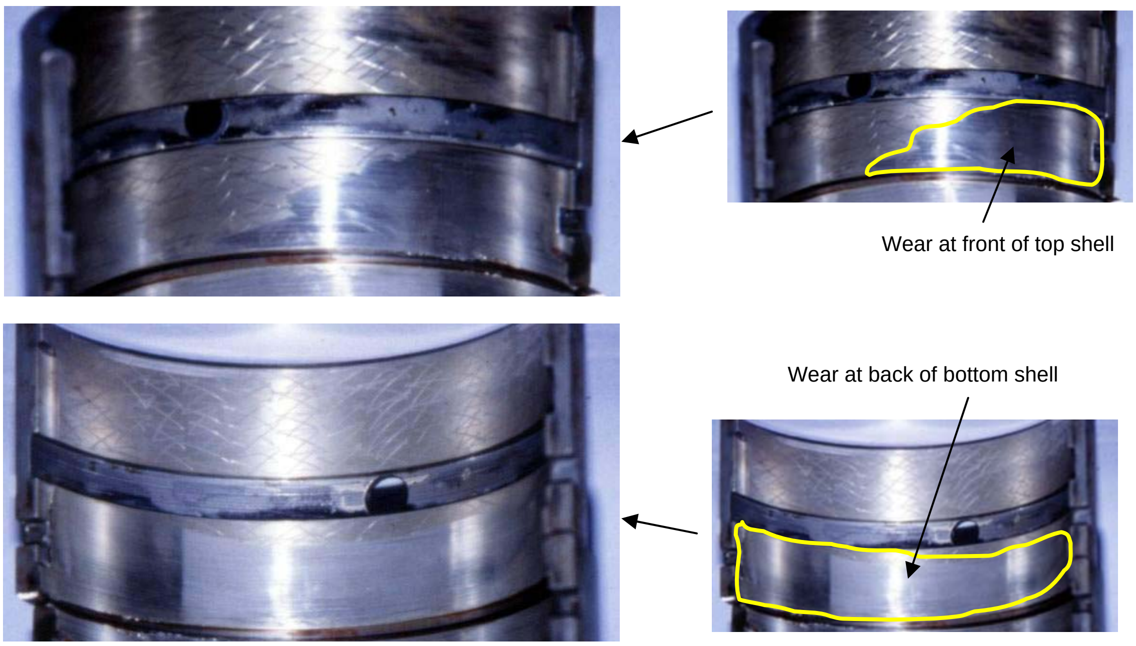


Figure 5.11: Misalignment Wear

5.7 Corrosion and Deposits

Corrosion and deposits form as a result of chemical reactions in the lubricant. Corrosion was described in **Section 4.3.1** of this module. Deposits are solids that form in the lubricant and are left on the surface of the bearing.

Chemical reactions may result from using the wrong lubricant or from *contamination* of the lubricant, often by the product being processed in the equipment. High lubricant temperatures increase the problem.

> ***Contamination*** is caused when unwanted substances are added to something.

Corrosion and deposits can cause high spots on the bearing surface. High spots will carry more load than low spots and the lubricant film can break down where the load is greatest.

Figures 5.12 and **5.13** show examples of deposits on bearing materials.

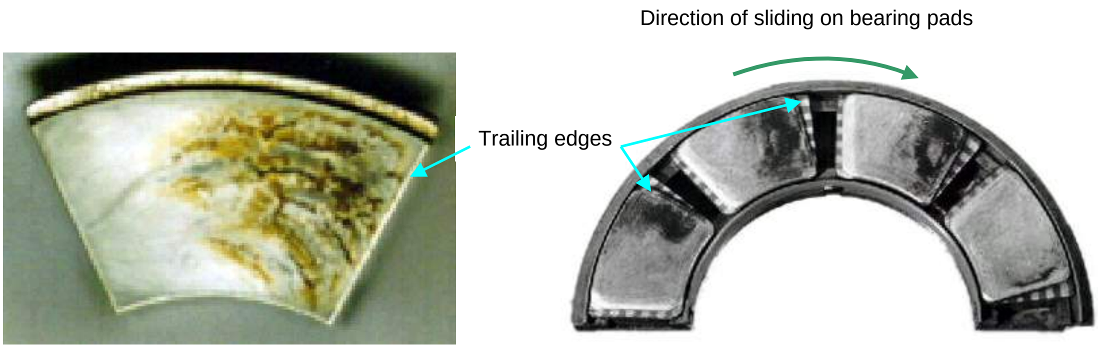


Figure 5.12: Lubricant Oxidation

If the oil temperature gets too high, it can react with oxygen in the air. A chemical reaction with oxygen is called *oxidation* and the product formed is an *oxide*.

Deposits form on the part of the bearing that has the greatest load, where the temperature is highest. This is the trailing edge of the pad in a thrust bearing, as shown in **Figure 5.12**. The colour varies from reddish-brown to almost black depending on the temperature reached and is patchy as shown in the figure.

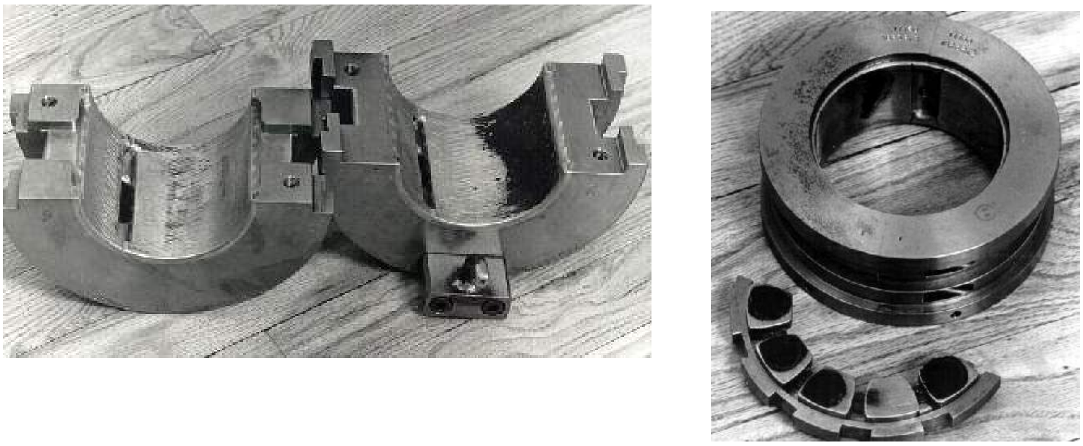


Figure 5.13: Sulphur Deposits

Figure 5.13 shows another type of deposit that also forms in the areas of greatest load. This black deposit is caused by sulphur in process gas reacting with the copper that is often part of a white-metal alloy. The reaction between copper and sulphur forms a *copper sulphide*. This contaminates the lubricant and forms deposits on the bearing surface.

There are many types of chemical deposits that can form but they usually form where the load is greatest: on the trailing edges of thrust pads and where the lubricant film is thinnest on journal bearings (see **Figure 4.30(b)**).

Now try **Exercise 4**

6 Anti-friction Bearings

The bearing surfaces of anti-friction bearings do not slide over each other. Anti-friction bearings use balls or rollers to replace sliding friction with rolling friction.

Remember: rolling friction < sliding friction

Because rolling friction is so much lower than sliding friction, these bearings are called anti-friction, or ‘against’-friction bearings.

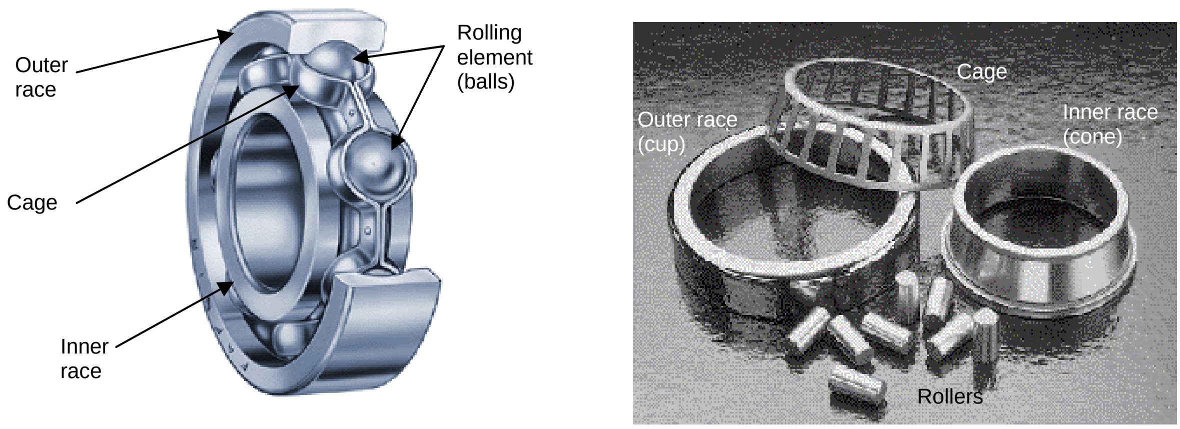
Because there is no sliding contact, these bearings give better protection to the shaft than plain bearings. Like plain bearings, they are cheaper and easier to replace than the shaft and the housing.

6.1 Parts of an Anti-friction Bearing

Most anti-friction bearings have four main parts

- inner race—fits onto the shaft
- outer race—fits into the housing
- rolling elements—either balls or rollers (or small rollers called needles)
- cage—holds the rolling elements in place

Figure 6.1(a) shows a cutaway or part-section of a typical radial ball bearing with its parts labelled. **Figure 6.1(b)** shows a dismantled taper roller bearing.



(a) Ball Bearing (b) Taper Roller Bearing

Figure 6.1: Parts of an Anti-friction Bearing

6.2 Types of Anti-friction Bearings

Anti-friction bearings can be divided into two main groups:

- ball bearings
- roller bearings

All ball bearings have *spherical* rolling elements, as shown in **Figure 6.1** and the exploded drawing in **Figure 6.2** below.

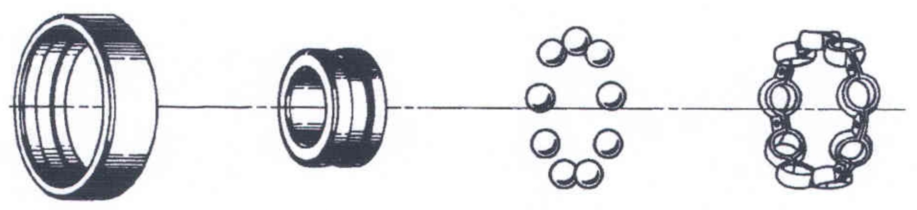
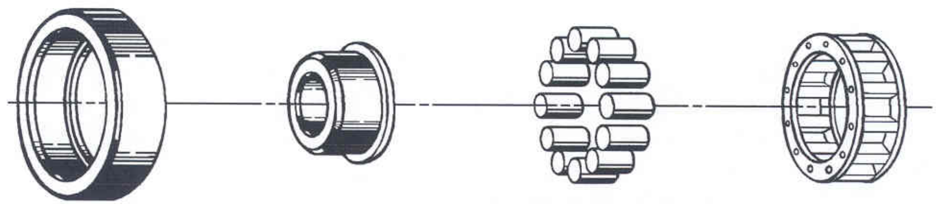


Figure 6.2: Ball Bearing—Exploded Drawing

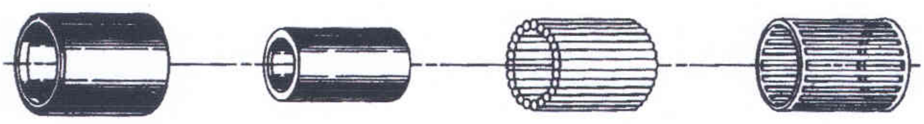
Roller bearings can have four different types of rolling elements, as shown in **Figure 6.3**:

- cylindrical rollers (**Fig. 6.3(a)**)
- needle rollers (**Fig. 6.3(b)**)
- tapered rollers (**Fig. 6.3(c)**)
- spherical rollers (**Fig. 6.3(d)**)



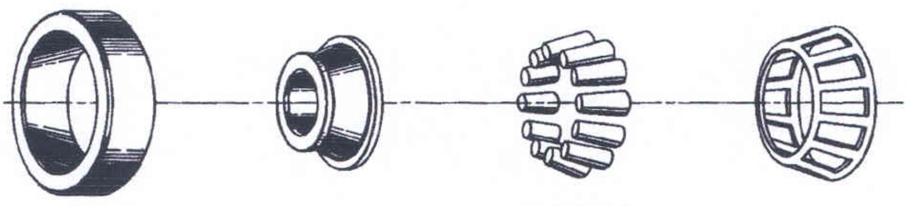
Outer race Inner race Cylindrical rollers Cage

(a) Cylindrical Roller Bearing



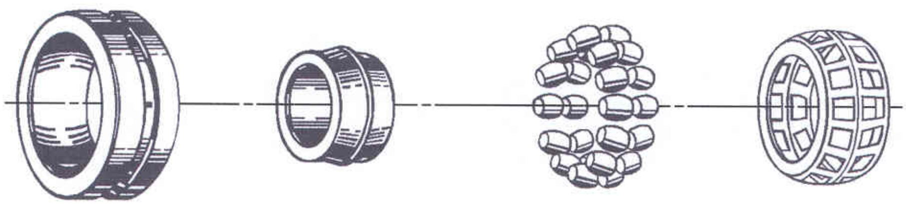
Outer race Inner race Needle rollers Cage

(b) Needle Roller Bearing



Outer race (cup) Inner race (cone) Tapered rollers Cage

(c) Taper Roller Bearing



Outer race Inner race ‘Spherical’ rollers Cage

(d) Spherical Roller Bearing

Figure 6.3: Roller Bearings—Exploded Drawings

Roller bearings can take higher loads than ball bearings of the same size. This is because a ball and a roller spread the load differently. Heavy load can damage a material. But it is not just the load that does the damage, it also depends on the area the load pushes on:

- the bigger the load, the more damage it can do
- the smaller the area it pushes on, the more damage it can do

It is the *pressure* pushing on the surface that does the damage.

You have learnt about pressure in liquids and gases. It was defined as:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

The same pressure can act on a solid.

If you compare the ball and the roller in **Figure 6.4** you can see the different areas the force pushes on. It is the *contact area* under the rolling element.

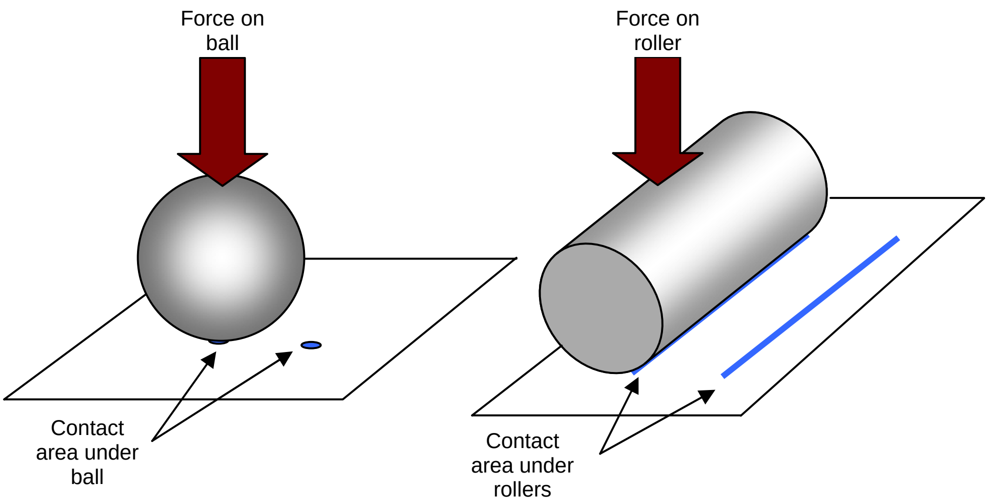


Figure 6.4: Contact Areas under Balls and Rollers

The same force is spread over a bigger area by the roller than by the ball.

This means that:

- For the **same force**, the pressure under the roller is less than under the ball.
- For the **same pressure**, the roller can take a bigger force than the ball.

Anti-friction bearings can also be described according to the type of load they are designed to take:

- radial or journal bearings
- thrust bearings
- combination radial/thrust bearings

A fourth type of bearing is designed to allow for changes of alignment of the shaft in its bearings.

- self-aligning bearings

6.2.1 Radial Bearings

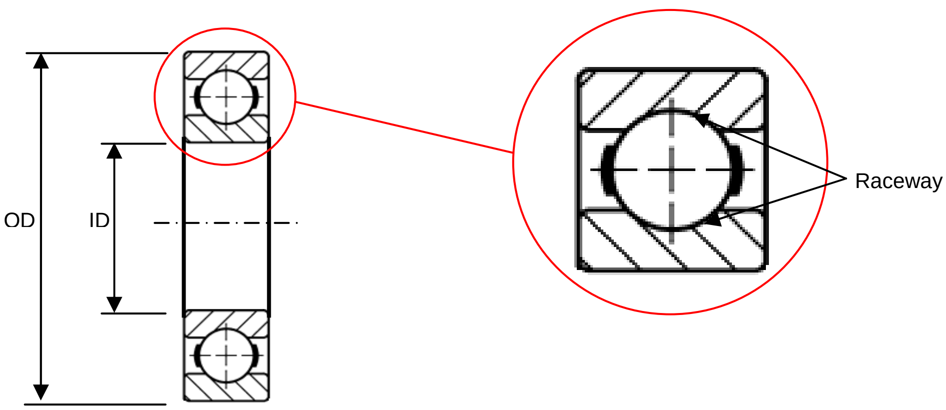
Radial-load, or journal, bearings are designed to take radial loads.

They may be:

- ball bearings
- cylindrical roller bearings
- needle roller bearings

Radial Ball Bearings

The inner and outer races of radial ball bearing have groove-shaped *raceways* to take the rolling elements, as shown in **Figure 6.5**.



(a) Section through Bearing (b) Detail of Races and Rolling Element

Figure 6.5: Ball Bearing Section Drawing

If you look in bearing catalogues you will see drawings like those in **Figure 6.5**. Bearing dimensions are shown on drawings like **Figure 6.5(a)** and details of the bearing design are shown on drawings like **Figure 6.5(b)**.

Radial ball bearings may be:

- shallow groove—to take only radial loads
- deep groove—can take some thrust as well as radial loads

The most common radial ball bearing is the deep-groove ball bearing. As you can tell by its name, it has deeper grooves than the shallow-groove bearing. The deeper grooves allow the bearing to support some axial thrust, but it is designed mainly for radial loads.

Cylindrical Roller Bearings

Figure 6.6 shows a typical cylindrical roller bearing.

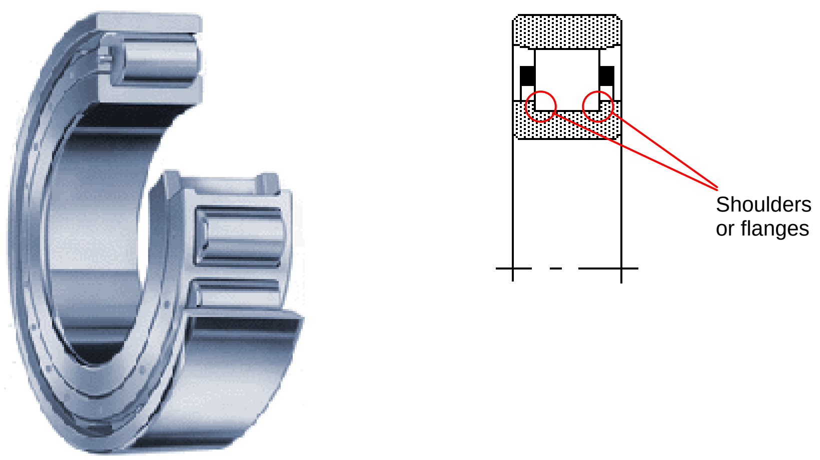


Figure 6.6: Cylindrical Roller Bearing

There are many different designs of roller bearing races for different applications. The bearing shown in **Figure 6.6** has *shoulders* or *flanges* on the inner race but none in the outer race. This is called a *non-locating* or *floating bearing* because the outer race is free to move axially relative to the inner race and rollers. This stops the bearing being axially loaded. If a shaft is mounted between two bearings, expansion of the shaft when it gets hot would push axially on the bearings. This type of bearing allows some axial expansion of the shaft. This is just one type of cylindrical roller bearing.

Roller bearings have letter codes to identify the types of races. **Table 6.1** shows some designs and their identification letters.

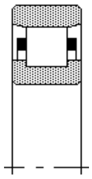
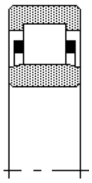
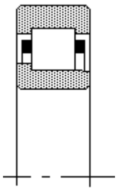
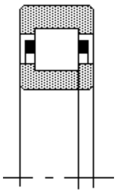
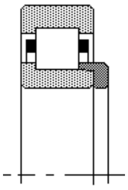
Bearing Type Code	Description	Diagram
N	Two shoulders on inner race. Non-locating (floating outer race). (As shown in **Figure 6.5**)	
NU	Two shoulders on outer race. Non-locating (floating inner race).	
NJ	One shoulder on inner race, two shoulders on outer race. Locates shaft axially in one direction.	
NUP	Two shoulders on both races. Locates shaft axially in both directions.	
NJ+HJ	Two shoulders on outer race, one shoulder on inner race + one removable shoulder on inner race. Locates shaft axially in both directions.	

Table 6.1: Cylindrical Roller Bearing Types

You can remove a race that does not have two shoulders. Bearings with races that can be removed are called *separable* bearings because you can separate their parts.

Needle Roller Bearings

These have many, small-diameter rollers. This has two advantages:

- the load is spread over more needles so the pressure under each is less—they can support greater loads
- they take up less radial space so the housing can be smaller

Figure 6.7 shows the the difference between the space taken up and the load on the rollers of cylindrical roller and needle roller bearings. Both bearings shown have the same shaft diameter and carry the same load.

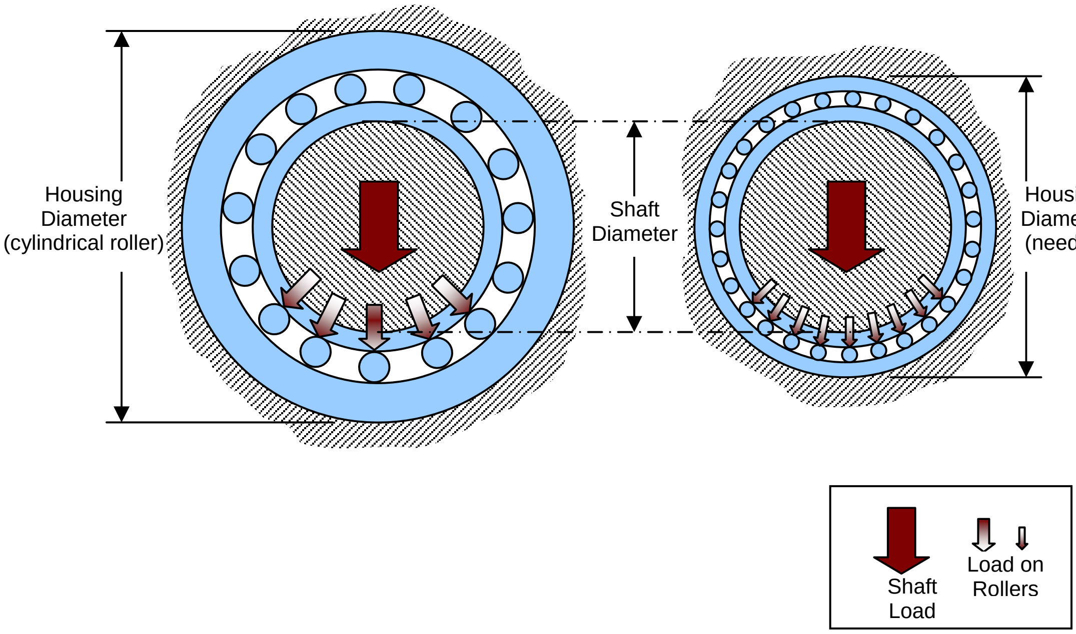


Figure 6.7: Comparison of Housing Diameter and Load Distribution in Roller and Needle Bearings

If there is very little space between the shaft and the housing you can get needle roller bearings that have no inner race. The rollers make direct contact with the shaft so the shaft must be made of hardened steel. You can also get needle roller bearings that have no races. These must run in a hardened steel housing as well as on a hardened steel shaft. These three types of needle roller bearings are compared in **Figure 6.8**.

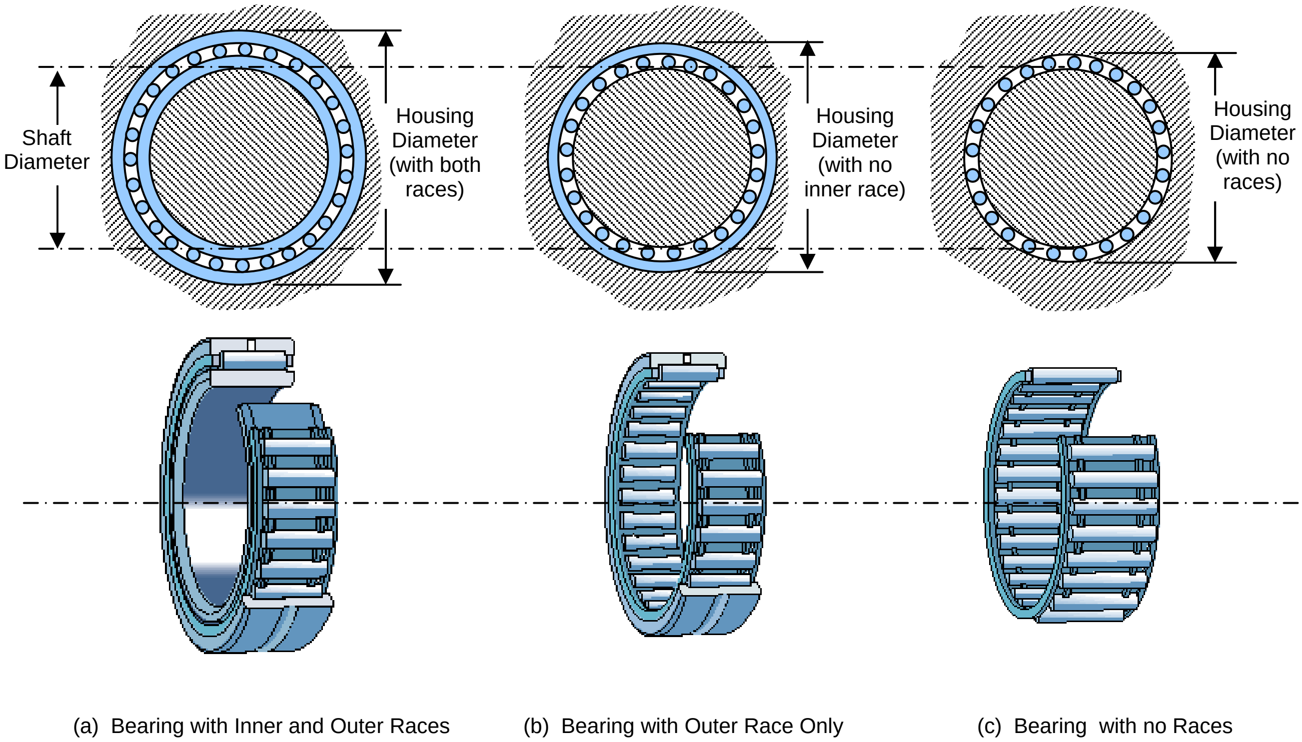


Figure 6.8: Comparison of Housing Diameters for Different Types of Radial Needle Roller Bearings

6.2.2 Thrust Bearings

Thrust bearings are designed to take only axial loads. **Figure 6.9** shows examples of ball, roller and needle thrust bearings.

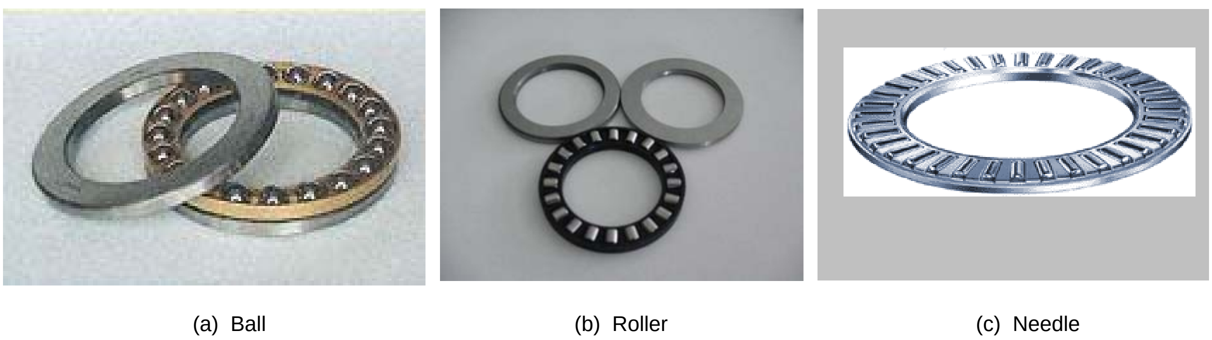


Figure 6.9: Anti-friction Thrust Bearings

6.2.3 Combination Radial/Thrust Bearings

These bearings can take both radial and axial loads. Some can take more thrust than radial load, others more radial than thrust load.

Angular Contact Ball Bearings

These bearings can take thrust loads in one direction. The direction of the load must push the balls against the races as shown in **Figure 6.10**.

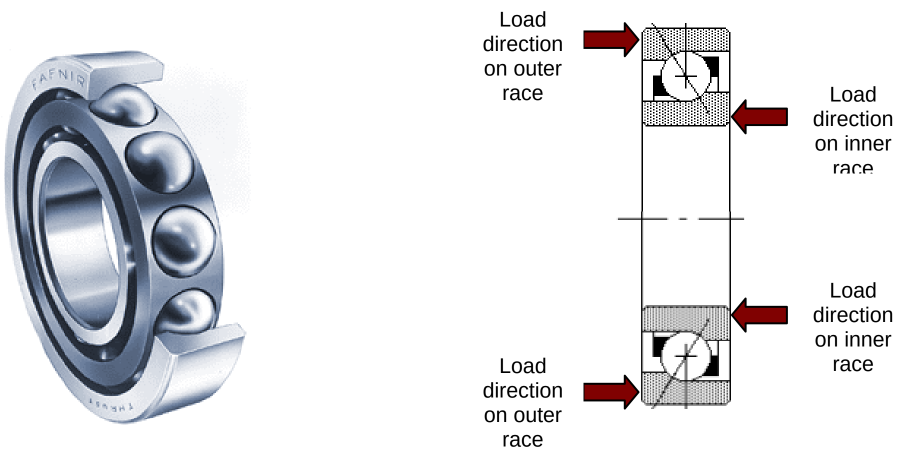
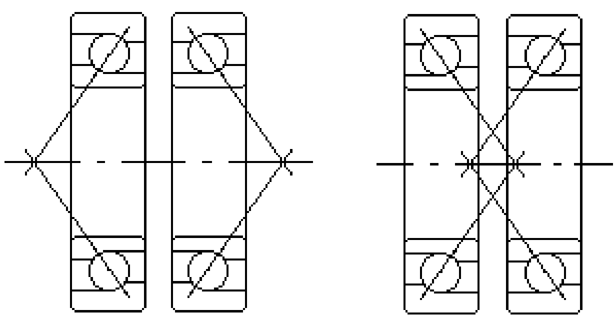


Figure 6.10: Angular Contact Ball Bearing

Make sure that you fit these bearings facing the correct way. They are often fitted in pairs, one in each direction, to take axial loads on both directions. You can do this in the two ways shown in **Figure 6.11**.



(a) Back-to-back (b) Face-to-face

Figure 6.11: Fitting Angular Contact Bearings in Pairs

Taper Roller Bearings

Taper roller bearings can take both radial and thrust loads. They can only take thrust in one direction but can be used in pairs, back-to-back or face-to-face. **Figure 6.12** shows a typical taper roller bearing.

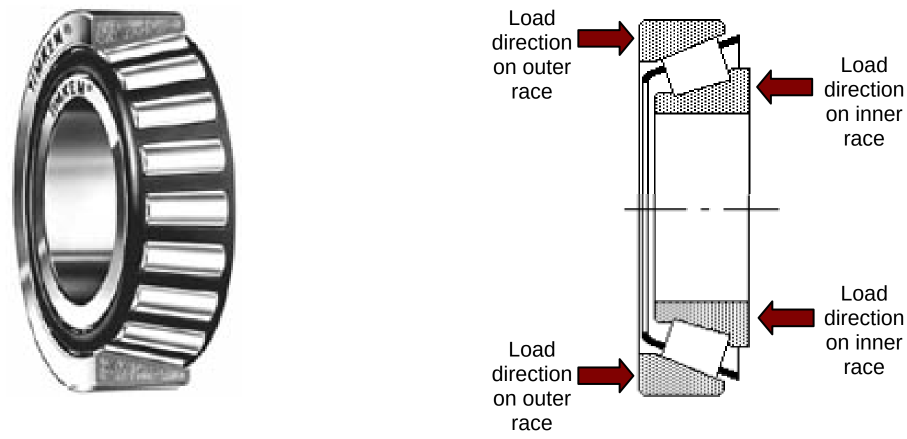
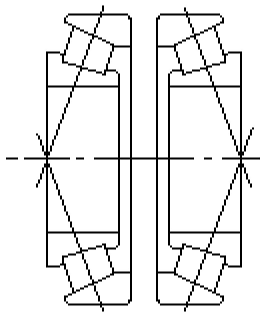
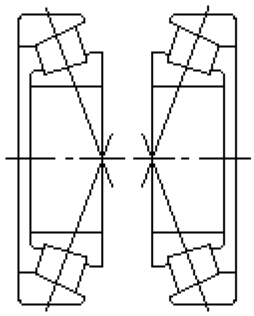


Figure 6.12: Taper Roller Bearing

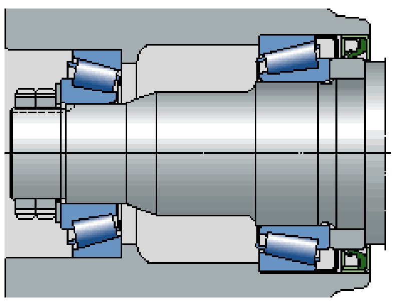
Figure 6.13 shows taper roller bearings mounted in pairs.



(a) Back-to-back



(b) Face-to-face



(c) Back-to-back in Assembled Hub Unit

Figure 6.13: Fitting Taper Bearings in Pairs

Double-row taper bearings come in back-to-back and face-to-face pairs, as shown in **Figure 6.14**.

(a) Back-to-back (b) Face-to-face

Figure 6.14: Double-row Taper Bearings

The amount of thrust load that a taper bearing can take depends on the angle of the taper: the bigger the angle α in **Figure 6.15**, the more thrust load the bearing can take.

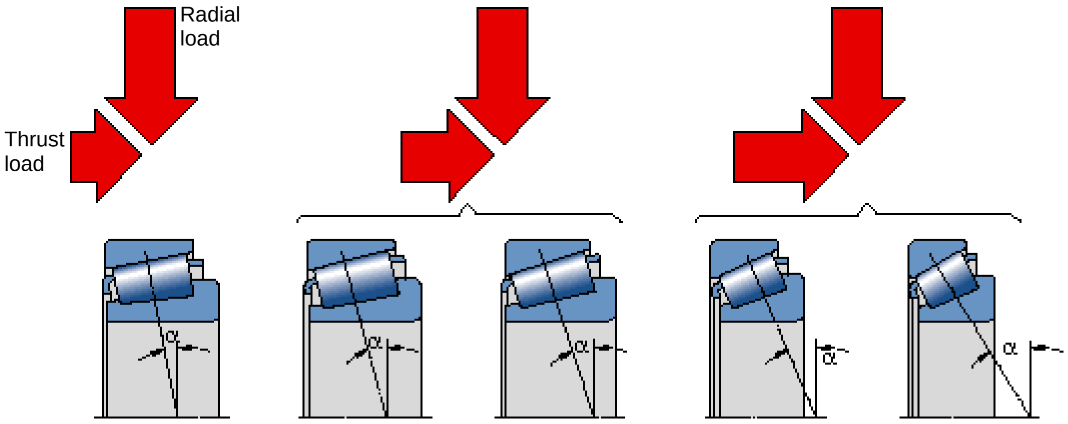


Figure 6.15: Effect of Taper Angle on Ability to Take Thrust

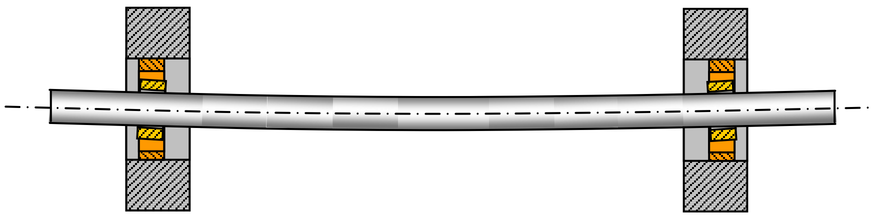
The bearing shown in **Figure 6.16** is designed to take mainly thrust loads but can also take some radial load.

Figure 6.16: Taper Thrust Bearing

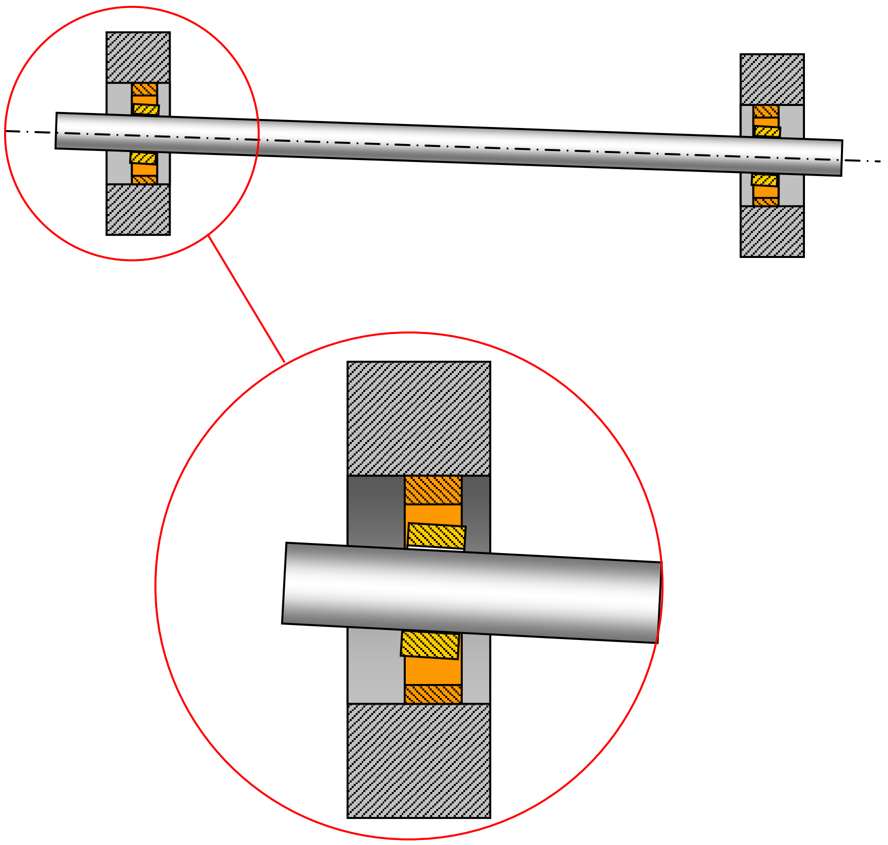
6.2.4 Self-aligning (Spherical) Anti-friction Bearings

Self-aligning plain bearings were described in **Section 4.1.5** of this module.

Self-aligning anti-friction bearings allow some angular change between the axis of the inner race and that of the outer race. This allows some bending of the shaft or misalignment between bearing housings on the same shaft as shown in **Figure 6.17**.



(a) Misalignment due to Bending of Shaft

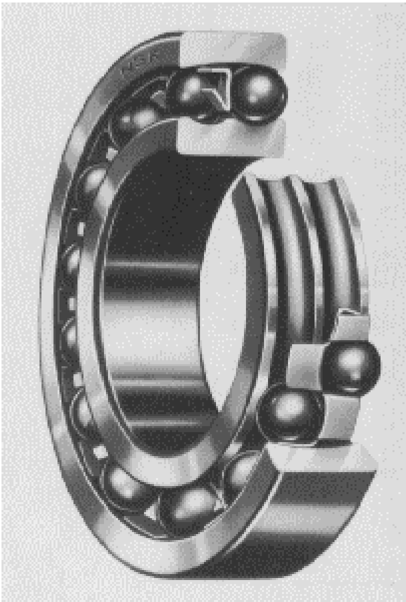


(b) Housing Misalignment

Figure 6.17: Misalignment

Self-aligning Ball Bearings

These bearings have a double row of balls running in two grooves around the inner race. The outer race has no grooves; it is curved to allow the outer race to move out-of-alignment with the balls and inner race. The shape of this curve forms part of a sphere and they are often called *spherical* ball bearings. **Figure 6.18** shows two views of a typical self-aligning ball bearing



(a) Cut-away Showing Grooves on Inner Race and Spherical Outer Race

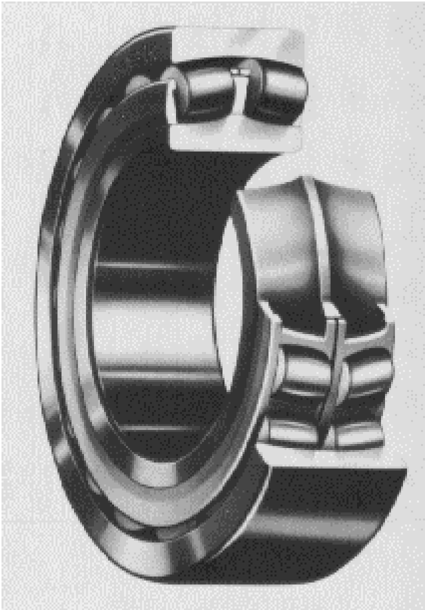
(b) Inner Race Rotated Out-of-line

Figure 6.18: Self-aligning or Spherical Ball Bearing

In service the inner race can only rotate out-of-line by a small amount. The balls must not lose full contact with the outer race. They can not take very great radial loads and only very small thrust loads as there are no grooves in the outer race to locate the balls.

Self-aligning Spherical Roller Bearings

These can take greater radial and thrust loads than self-aligning ball bearings. They have specially shaped rollers to run in the spherical outer race. **Figure 6.19** shows typical spherical roller bearings.



(a) Cut-away Showing Shaped Rollers and Spherical Outer Race

(b) Inner Race Rotated Out-of-line

Figure 6.19: Spherical Roller Bearing

Now try **Exercise 5**

6.3 Anti-friction Bearing Fits

It is a general rule to have an interference fit on one race and a fit that has a very small clearance, sometimes called a *sliding* fit, on the other. The race that has the sliding fit can either float to allow for expansion of the shaft length, etc., or it is secured by a *retaining nut* or a plate.

If the housing is stationary and the shaft is rotating, e.g. a centrifugal pump shaft:

- the outer race is a sliding fit in the housing
- the inner race is an interference fit on the shaft

If the shaft is stationary and the housing is rotating, e.g. a wheel on an axle:

- the outer race is an interference fit in the housing (hub)
- the inner race is a sliding fit on the shaft (axle)

The general rule is:

- the rotating race has an interference fit
- the stationary race has a sliding fit

There is clearance between the rolling elements and the races to allow the bearing to rotate. The clearance before fitting is fixed by the manufacturer (**Fig. 6.20(a)**). After fitting the clearance is reduced by the interference fit on the shaft or in the housing. (**Fig. 6.20(b)**).

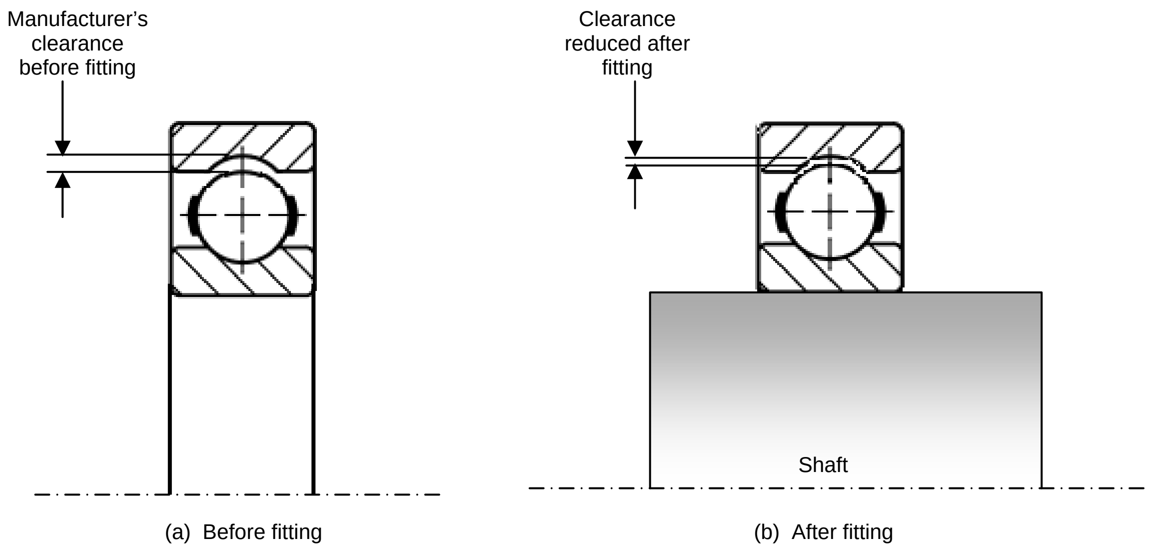


Figure 6.20: Radial Bearing Internal Clearance

To make sure that the internal clearance is correct, you must use the correct amount of interference when fitting the bearing. The correct fits are given in the bearing manufacturer's information.

Now try **Exercise 6**

6.4 Anti-friction Bearing Materials

Because there is no sliding friction in anti-friction bearings, the material does not need to have a low coefficient of friction. It also does not have to be softer than the shaft material as there is no wear between the bearing and the shaft. The only exception to this is when a needle roller is used without a race. If there is no inner race the shaft must be at least as hard as the needle rollers. If there is no outer race, the housing must be hard.

To reduce rolling friction to a minimum, the surfaces of the rolling elements and the races must be smooth. They must not become scratched, dented or badly worn during operation. To reduce scratching, denting and wear in the bearing, the surfaces need to be as hard as possible.

In **Section 4.3.1** of this module, hardness was defined as the ability to resist being scratched. One disadvantage of a hard material is that it is also *brittle*. A brittle material cracks and breaks easily if it is hit. Glass is a brittle material.

A bearing made from a very hard material has low rolling friction and good wear resistance but it would break easily if it received a sudden *impact* or *shock load*.

An ***impact*** is a sudden hit.

Toughness is another material property; it is the ability to resist breakage from shock loads.

The ideal material for an anti-friction bearing is hard on the surface but tough in the middle.

Steel is an alloy of iron and carbon. The amount of carbon in steel is very small: from 0.1% to 1.4%. In **Section 4.3.2** of this module you learnt that the hardness of steel depends on how much carbon it contains.

Another effect of adding carbon to steel is that you can *heat treat* it. Heat treatment changes the properties of a metal by heating and cooling it in a controlled way.

Steels that contain more than 0.15% carbon can be made harder by heat treatment:

- high-carbon steel can be hardened, but then it is brittle
- low-carbon steel is tougher, but it can not be hardened

Steel is hardened by heating, and then cooling it quickly by submerging it in oil or water.

There is a way of increasing the amount of carbon near the surface of a component. This component can then be heat treated and only the high-carbon part close to the surface is hardened. The low-carbon steel closer to the centre remains tough as shown in **Figure 6.21**. This process is called *case hardening*.

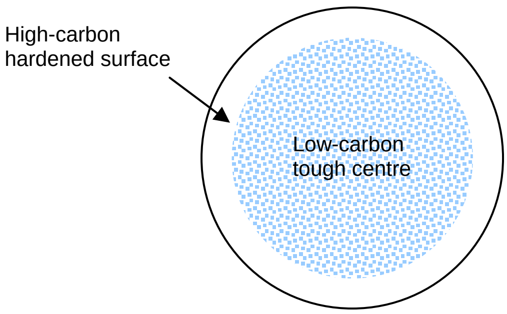


Figure 6.21: Case Hardening

Anti-friction bearings are made of case-hardened steel.

The cage keeps the rolling elements in place and does not carry any load. Cages may be made of a low-carbons steel, brass or sometimes a polymer.

6.5 Anti-friction Bearing Lubrication

Rolling friction in anti-friction bearings is much less than the sliding friction in plain bearings. This reduces friction and wear during start-up and shut-down of equipment but lubricant is till needed during normal operation. The lubricant forms a film over the races and rolling elements, reducing friction and cooling the bearings.

Anti-friction bearings are either packed with grease or supplied with oil.

If grease is the recommended lubricant, make sure that the rolling elements are well packed with grease before fitting. After fitting, pack the housing about $^1/_2$ full for low running speeds and about $^1/_3$ full for high running speeds ($^1/_3 < {}^1/_2$). Higher running speeds produce more heat and the grease expands more. Greased bearing housings have a cap to keep the grease in and to keep dirt out as shown in **Figure 6.22**.

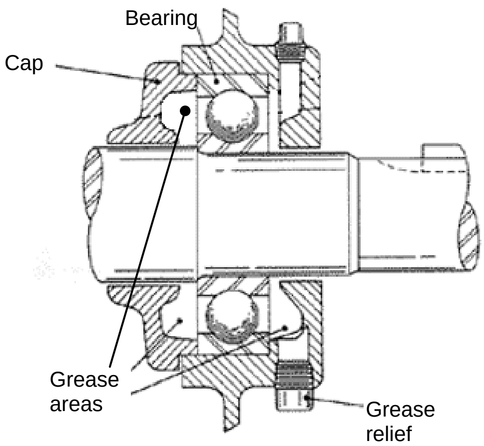


Figure 6.22: Greased Bearing

Sealed bearings are packed with grease by the manufacturer. A seal, shown in **Figure 6.23**, between the inner and outer races keeps the grease in place.

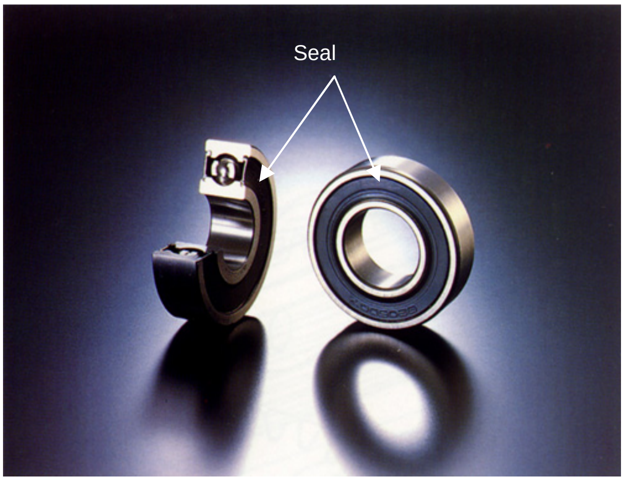


Figure 6.23: Sealed Bearing

These bearings do not need any further lubrication.

Grease has the advantage that it stays in the bearing and does not drain away like oil. It also acts as a barrier to dirt, keeping it out of the bearing. Its disadvantage is that it is not as good a lubricant as oil. Also, because it does not flow through the bearing, it does not remove heat from the bearing. It is used for relatively slow running speeds.

Oil may be supplied to a bearing in different ways:

- oil bath—part of the housing acts as a *reservoir* for oil. The lower part of the bearing is under the surface of the oil and carries oil with it as it turns. (**Fig. 6.24**)

A ***reservoir*** is a container for liquids.

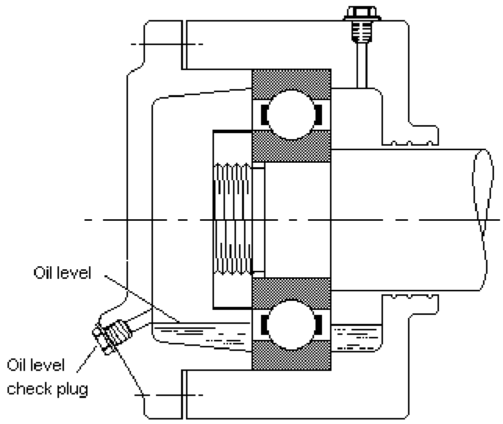


Figure 6.24: Oil-bath Lubrication

- splash lubrication—oil is splashed onto the bearings by a ring that hangs from the shaft or by gears. These dip into the oil. (**Fig. 6.25**). The oil then drains back to the bottom of the housing. Too much oil causes drag on the oil ring or gears affecting lubrication and possibly the operation of the equipment.

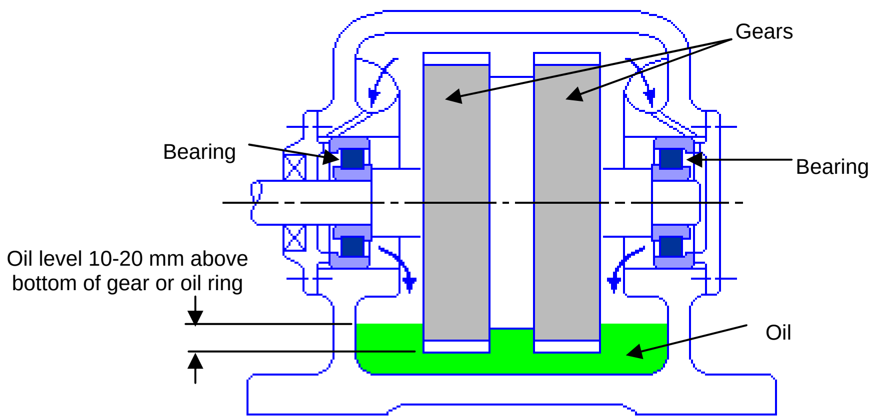


Figure 6.25: Splash Lubrication

- pressurised lubrication—oil is pumped from a reservoir to the bearings. It then returns to the reservoir to be re-circulated. Oil continually *flushes* through the bearings. This cools the bearings and washes out any particles of dirt. Larger dirt particles settle to the bottom of the reservoir. Strainers and filters in the system remove dirt that is carried in the oil as shown in **Figure 6.26**.

To ***flush*** something is to clean it by passing a lot of liquid through it.

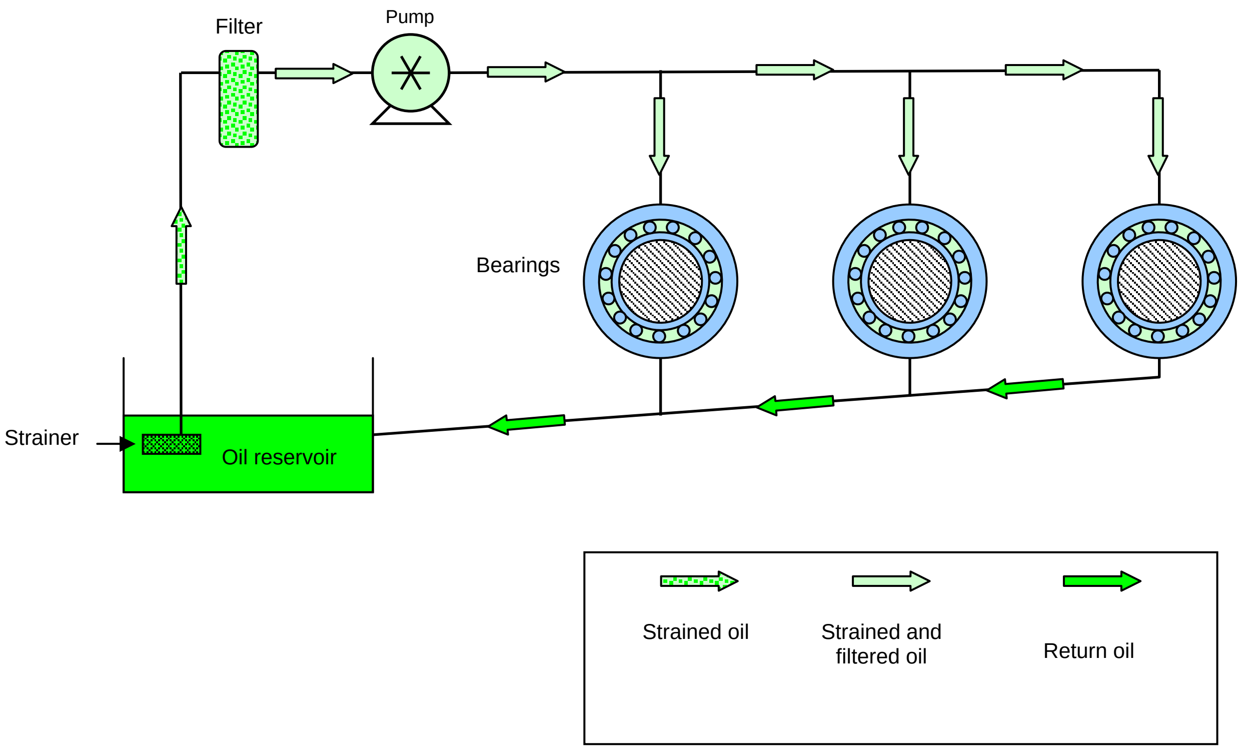


Figure 6.26: Pressure Lubrication System

6.6 Fitting and Removing Anti-friction Bearings

Anti-friction bearings have either a sliding fit or an interference fit, as described in **Section 6.3** of this module.

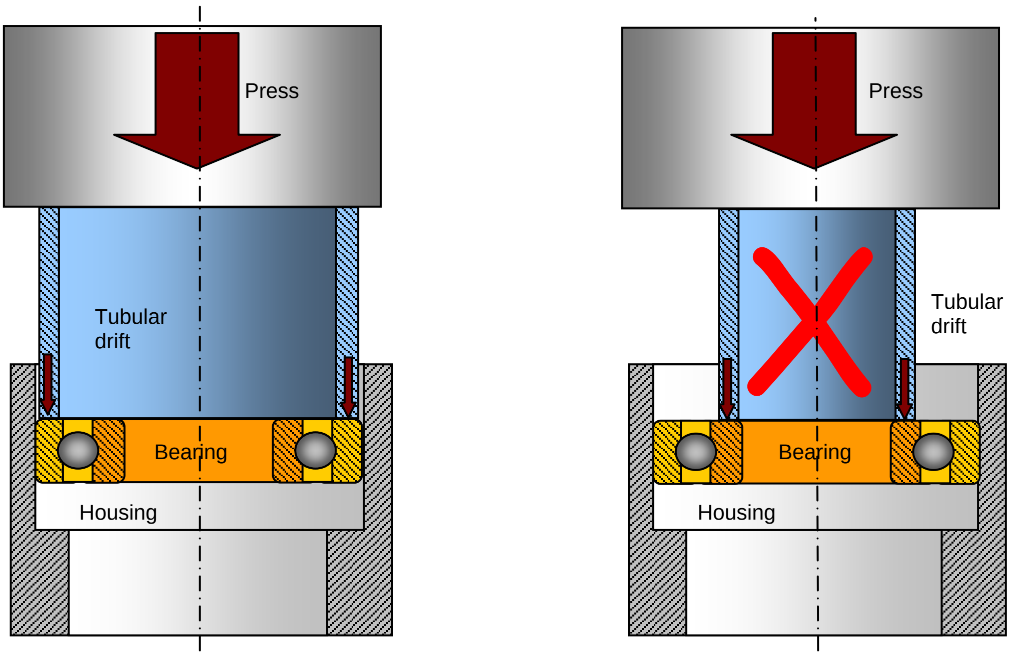
A stationary race has a sliding fit on the shaft or in the housing. A sliding fit is a transition fit with very little clearance or interference. The bearing race with this fit can be easily pushed into place.

A rotating race has an interference fit on the shaft or in the housing. For smaller bearings, the rotating race is pressed into place with a press. Use a drift between the press and the race. Many bearings are not separable and you must fit them with the races and rolling elements assembled. For these bearings, the drift should be a tube (a *tubular* drift) with the correct inside and outside diameters to match the race you are fitting.

The most important rule to follow when press-fitting an anti-friction bearing is:

only push on the race you are fitting

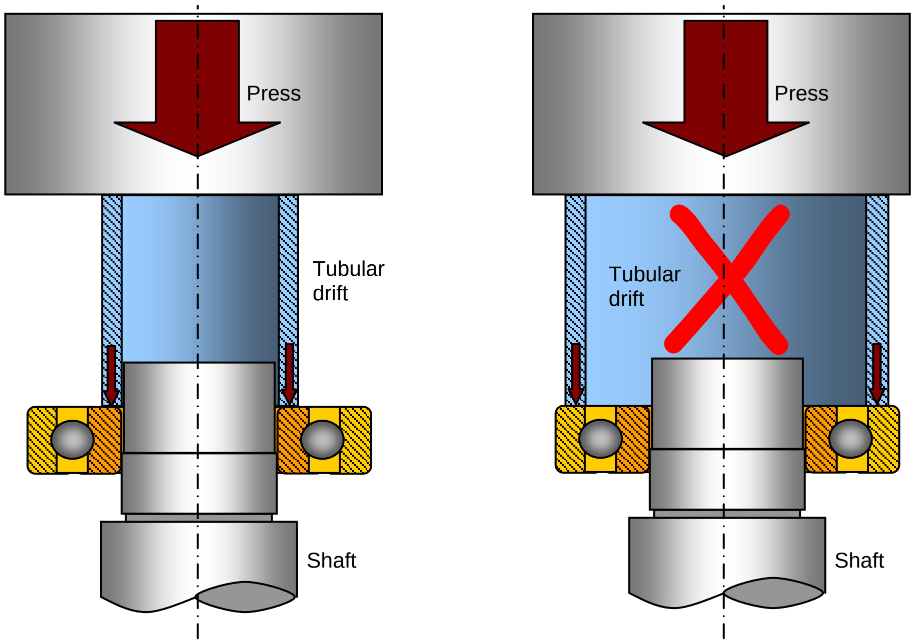
The correct and incorrect use of a drift to press-fit an anti-friction bearing into its housing is shown in **Figure 6.27**.



(a) **Correct**—Drift Pressing on Outer Race (b) **Not Correct**—Drift Pressing on Inner Race

Figure 6.27: Bearing with Outer Race an Interference Fit in the Housing

The correct and incorrect use of a drift to press-fit an anti-friction bearing onto its shaft is shown in **Figure 6.28**.



(a) **Correct**—Drift Pressing on Inner Race (b) **Not Correct**—Drift Pressing on Outer Race

Figure 6.28: Bearing with Inner Race an Interference Fit on the Shaft

- Never push on the outer race to press the inner race onto the shaft.
- Never push on the inner race to press the outer race into the housing.

If you do not have a press, you can knock the drift carefully with a hammer.

⚠ Look on your Permit-to-Work to see if you must use a non-spark hammer

If you do not have the correct tubular drift to fit a bearing it is possible to use a simple drift. This should be made of a material that it softer than the bearing. If you use this method you must be careful to fit the bearing square to the shaft or housing or misalignment damage will result. Do this by moving the drift around the race as you tap lightly to keep the race square.

Figure 6.27 shows some important features of a shaft designed to take an anti-friction bearing. These are labelled in **Figure 6.29** and described below.

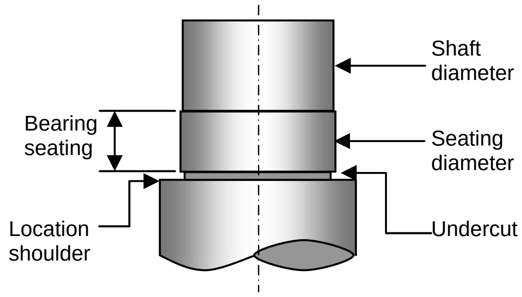


Figure 6.29: Shaft Features

- Bearing seating—the part of the shaft on which the bearing is located. Make sure that it is clean before fitting the bearing.
- Seating diameter—the seating is accurately machined to give the correct fit for the inner race.
- Shaft diameter—this need not be as accurate as the seating diameter. It is slightly smaller than the seating diameter to allow clearance for the bearing to slide along the shaft to its seating when fitting and removing. The difference between the seating diameter and the shaft diameter is called the *relief*.
- Undercut—reduced diameter between the seating and shoulder to make sure the bearing inner race locates on the shoulder. The undercut must be clear of particles of dirt, etc., before fitting the bearing.
- Location shoulder—an axial location for the bearing. This can be on the shaft as shown in **Figures 6.29** and **6.28** or in the housing, as shown in **Figure 6.27**.

You can separate the races of taper roller bearings for fitting, as shown in **Figure 6.30**.

Figure 6.30: Taper Bearings Separated before Fitting

Larger bearings have more interference. If the interference is too great, press-fitting can damaging the shaft or housing. To reduce the interference during fitting, you can shrink-fit the bearing. Shrink-fitting plain bearings was described in **Section 4.5.2** of this module.

To shrink-fit the outer race into the housing, either:

- cool the bearing—so that it contracts

or

- heat the housing—so that it expands

To shrink-fit the inner race onto the shaft, either:

- heat the bearing—so that it expands

or

- cool the shaft—so that it contracts

It is usually easier to heat or cool the bearing than the shaft or the housing.

You can cool the bearing by:

- submerging it in liquid nitrogen—temperature -196°C
- packing solid carbon dioxide (CO_2) or *dry ice* around it—temperature -123°C
- packing ordinary ice around it—temperature 0°C

Handling very cold materials can be just as dangerous as handling hot materials

Wear the correct PPE, especially when using liquid nitrogen and dry ice

You can heat the bearing by:

- putting it in an oven
- submerging it in an oil bath
- using an induction heater

Handling hot materials can be dangerous—take great care

Wear the correct PPE, especially when using an oil bath

You can heat smaller bearings in an oven or an oil bath. An oil bath is a container filled with oil heated to a maximum temperature of 120°C. The bearing is carefully lowered into the oil and left for about 30 minutes to reach the same temperature as the oil.

Induction heaters are quicker and can heat bearings of any size. An induction heater uses electric current and a magnetic field to heat the bearing. **Figure 6.31** shows typical induction heaters for small and large bearings.

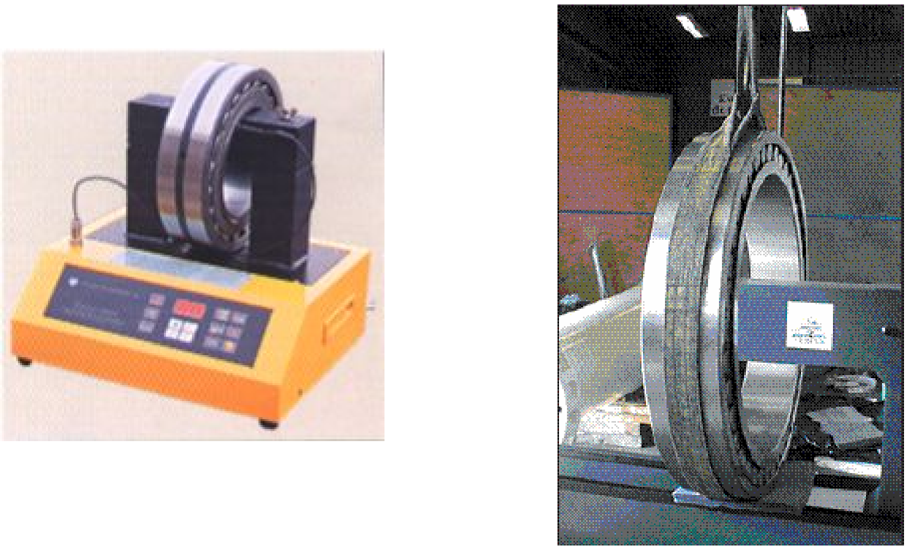


Figure 6.31: Induction Heaters

Because an induction heater heats the bearing quickly, you must take care not to let it get too hot.

As a general rule, the inner race should be about 80°C hotter than the shaft to fit easily. Fit the inner race on the shaft before it starts to cool.

Take the correct precautions when handling a hot bearing

Fit any retaining nuts after the bearing has cooled and contracted to the correct size.

Retaining nuts on taper bearings push the inner race into the outer race. This can *pre-load* the bearing: the tighter the retaining nut, the greater the pre-load on the bearing. **Figure 6.32(a)** shows one arrangement for a bearing that is pre-loaded when the retaining nut is tightened. Remember that taper bearings are fitted in pairs, back-to-back or face-to-face. Only one is shown in the figure.

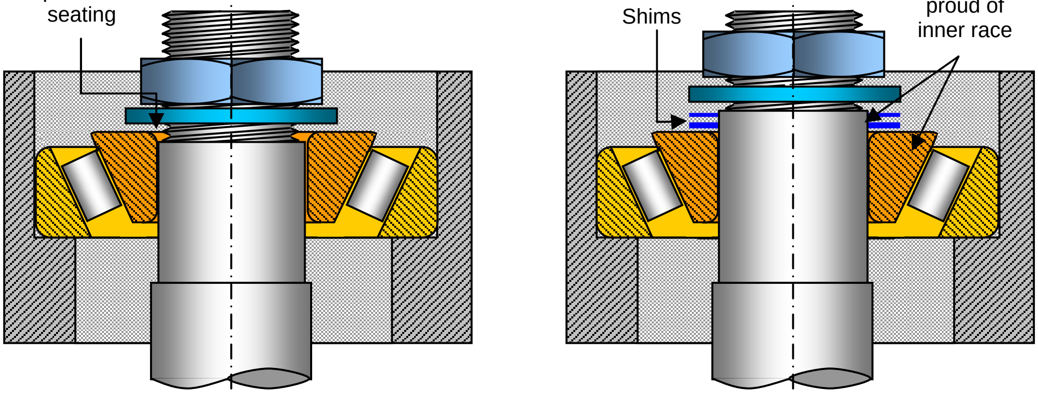


Figure 6.32: Fitting Taper Bearings

In **Figure 6.32(a)** the outer race locates on a shoulder in the housing. The washer rests against the inner race, not against the end of the seating. When the retaining nut is tightened, the washer pushes on the inner race, pre-loading the bearing. The equipment manufacturer may give the required pre-load as a torque value for tightening the retaining nut.

If no pre-load is needed, the manufacturer may give an end-float value. Shims can be used to give the correct end-float as shown in **Figure 6.32(b)**. The washer rests on a shoulder at the end of the seating. When the retaining nut is tightened, the washer pushes on this shoulder. Shims fit over the seating to adjust the gap between the inner race and the washer. This gap leaves clearance between the rollers and the races and allows some end-float between the races.

By adding more shims you can reduce the end float to zero. If you keep adding more shims you will *eventually* pre-load the bearing.

Something that happens ***eventually*** will happen sometime in the future.

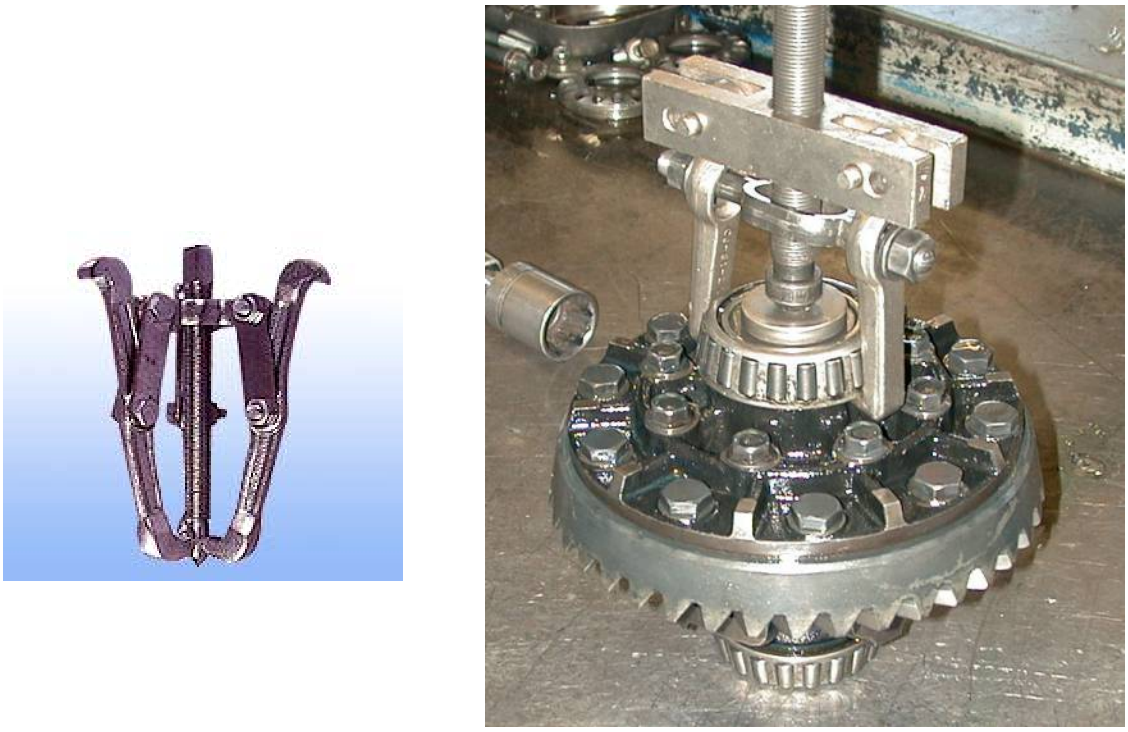
For many applications there should be no pre-load and no end float—zero clearance.

The method of removing bearings depends on how tight the fit is and whether the bearing is to be used again. Always take care not to damage the shaft or housing.

Use a drift and press or hammer on the race you are removing or a special bearing extractor or puller.

> Only use an extractor on the outer race to remove the inner race from a shaft if you are going to scrap the bearing

Figure 6.33 shows two typical bearing pullers. In **Figure 6.33(b)** the puller is removing the inner race and rollers of a taper roller bearing from a shaft.



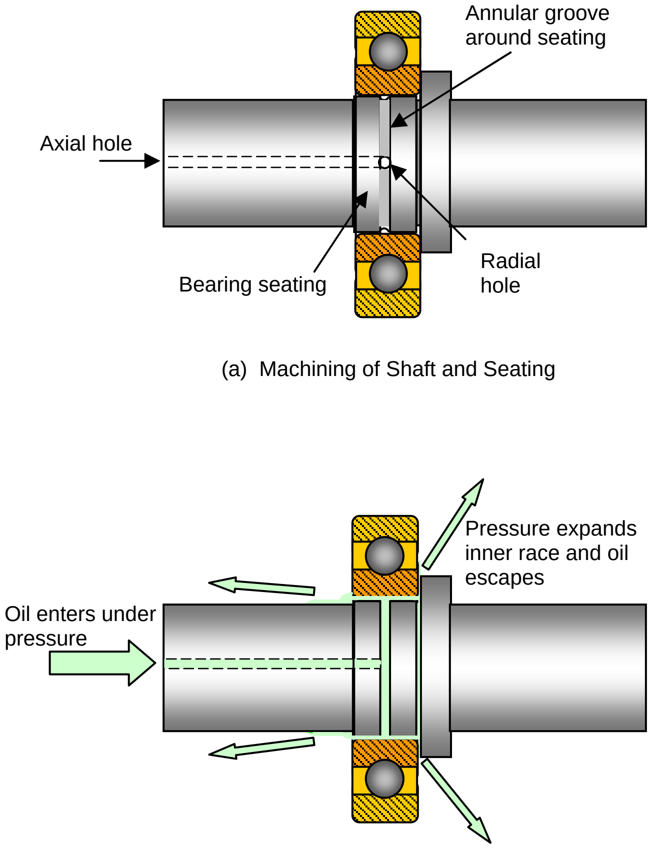
(a) Three-legged Puller (only two legs visible)

(b) Two-legged Puller being used

Figure 6.33: Bearing Pullers

Large bearings with tight-fitting inner rings may need to be heated to help remove them. Only bearings that are not to be re-used can be heated with an oxy-acetylene flame and then care must be taken not to heat the shaft. Heating the shaft too much can destroy its heat treatment and soften it.

Some large bearing inner races are removed by *hydraulic* pressure. To do this the shaft must have an annular groove machined on the bearing seating. This is connected to an axial hole in the shaft by a radial hole as shown in **Figure 6.34 (a)**.



(a) Machining of Shaft and Seating

(b) Bearing Removal from Shaft

Figure 6.34: Hydraulic Bearing Removal

Pumping oil into the axial hole fills the annular groove under the bearing with oil as shown in **Figure 6.34(b)**. As the pressure increases the oil forces the inner race to expand. When this happens the bearing can be removed from its seating.

Now try **Exercise 7**

7 Troubleshooting—Anti-friction Bearing Failure

The idea of troubleshooting to find the root cause of a failure was described in **Section 5** of this module.

The most common cause of failure of anti-friction bearings is fatigue. Fatigue is caused by constantly changing loads, the type of load caused by vibrations. Fatigue cracks usually start at a weak point in the material.

Modern bearing materials are very pure but they are not perfect. Fatigue may start at the small imperfections in the bearing material and this eventually causes failure.

In some cases incorrect fitting or incorrect use speeds up the fatigue process.

You can often find clues to help identify the root cause of a failure by inspecting the marks made on the races and rolling elements of a bearing.

7.1 Wear Marks

If you inspect the races of a bearing after it has been in service you can see wear marks made by the rolling elements on the raceways. These marks can give you information about the operation of the bearing. It is not only important to be able to recognise damage. It is just as important to know what a bearing should look like if it is in good condition. **Figure 7.1** shows the wear marks you would see on ball bearings as a result of normal radial loads. The outer races are sectioned so that you can see the wear marks on the raceways.

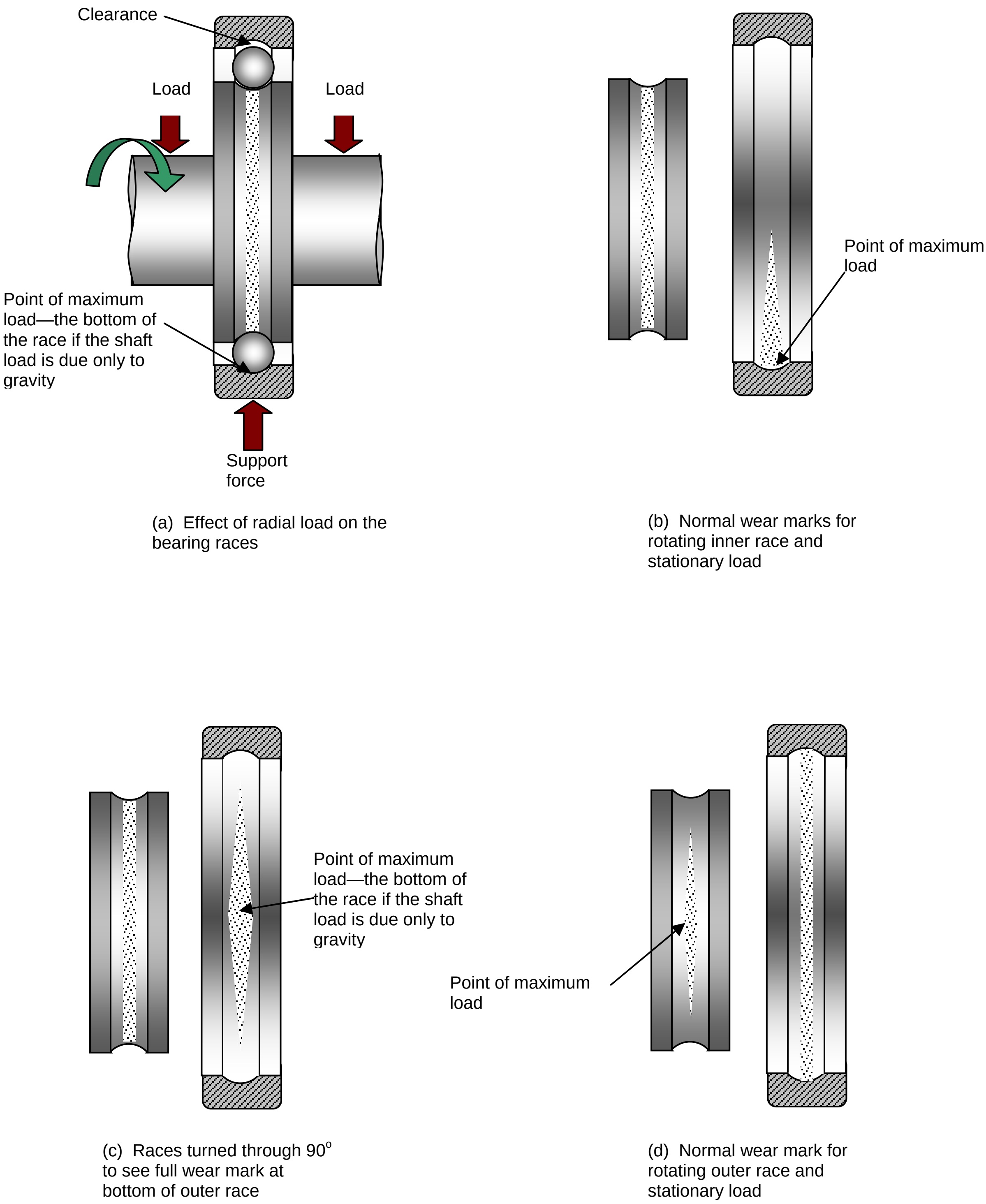
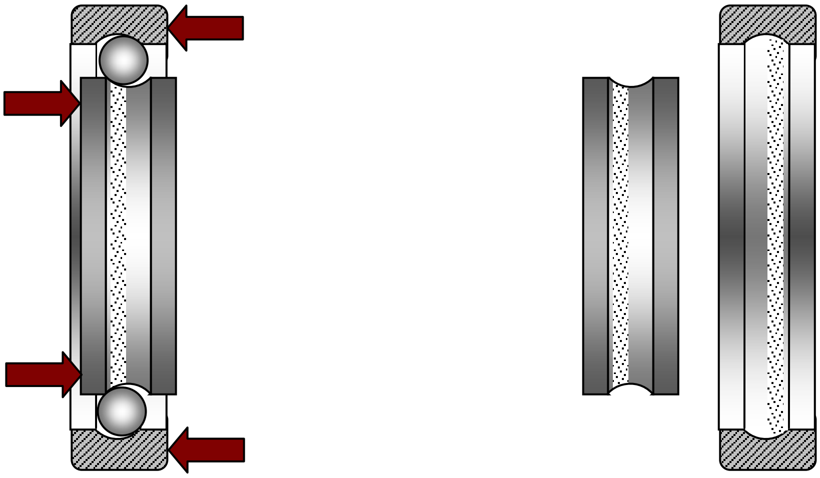


Figure 7.1: Normal Wear Marks on Ball Bearings—Radial Loads

The wear mark on a rotating race is a continuous band running around the race, parallel to the raceway. The mark on the stationary race depends on the direction and type of load.

Figure 7.2 shows the wear marks you would see on deep-groove ball bearings as a result of thrust loads.

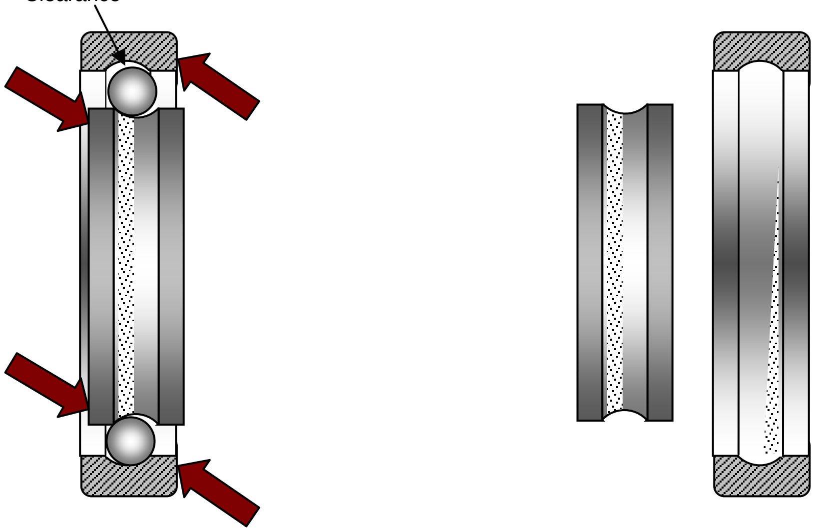


(a) Effect of thrust on the bearing races

(b) Wear marks for pure thrust load—on one side of inner race and on opposite side of outer race

Figure 7.2: Normal Wear Marks on Deep-groove Ball Bearings—Thrust Load

Figure 7.3 shows the wear marks you would see on deep-groove ball bearings as a result of combined loads.



(a) Effect of combined thrust and radial load on the bearing races

(b) Wear marks for combined thrust and radial loads—rotating inner race

Figure 7.3: Normal Wear Marks on Deep-groove Ball Bearings—Combined Load

7.2 Fatigue

Fatigue in plain bearings was described in **Section 5.4**. The first visible sign of fatigue damage in hard materials is *pitting* on the surface of the material. **Figure 7.4** shows early pitting on a race and a ball.

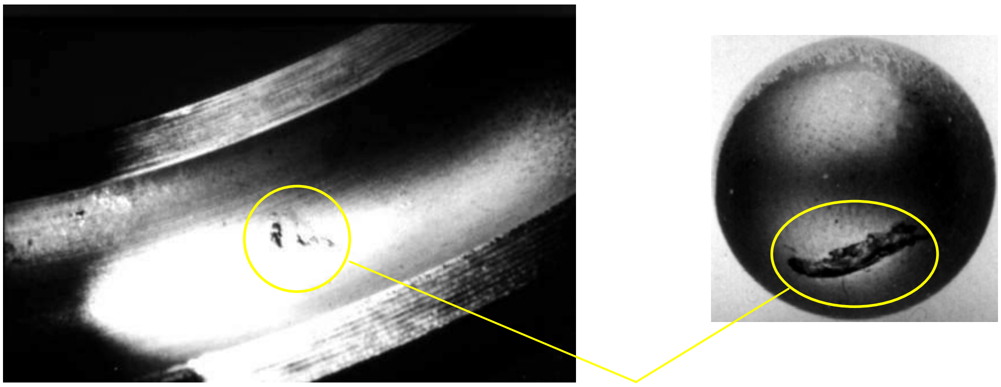
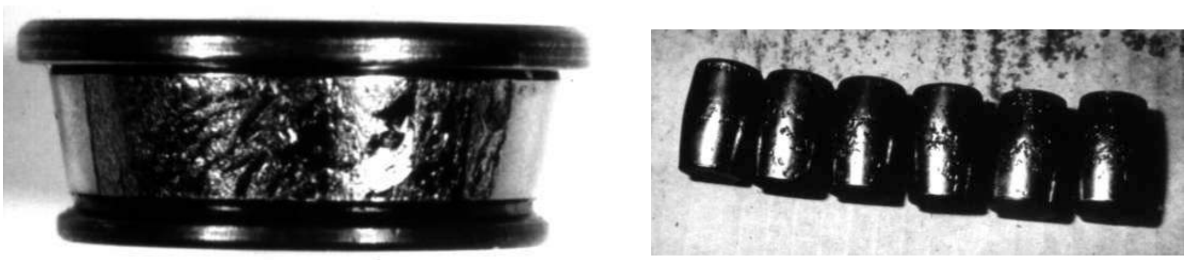


Figure 7.4: Early Fatigue Pitting in Race and Ball

A bearing can continue in service for some time after this type of pitting has started. Pitting on a race causes vibration and makes the bearing noisy in operation.

> A noisy bearing is often an early warning of trouble

Once pitting starts, vibration increases and this causes the fatigue damage to increase and spread around the bearing surface. **Figure 7.5** shows fatigue flaking (or *spalling*) damage after many more hours of operation.



(a) Fatigue Damage on Taper Inner race

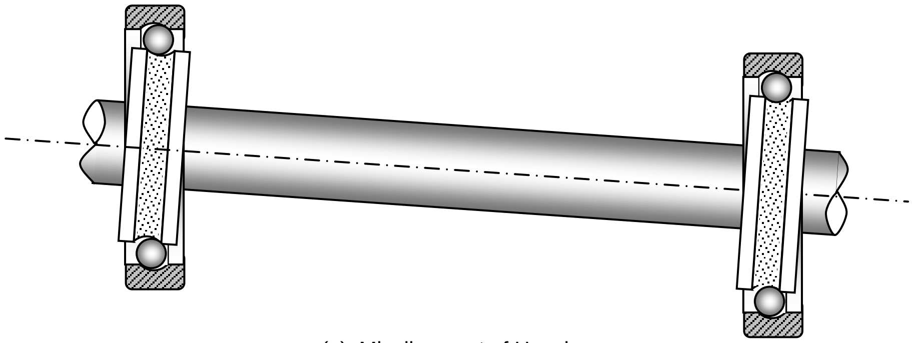
(b) Fatigue Damage on Spherical Rollers

Figure 7.5: Advanced Fatigue Damage

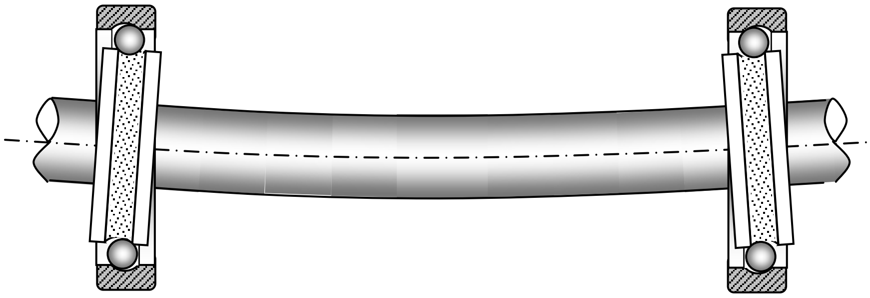
Most early bearing failures are caused by some fault in the assembly or incorrect use that leads to fatigue damage happening more quickly.

7.3 Misalignment

When the axis of the shaft is not in line with the axis of the bearing outer race, the assembly will be *misaligned*. This can happen when two housings are not aligned, as shown in **Figure 7.6(a)** or when the shaft is bent, either permanently or because of vibration, as shown in **Figure 7.6(b)**.



(a) Misalignment of Housings

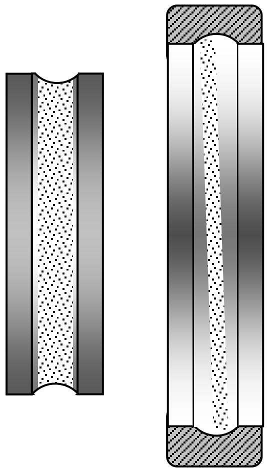


(b) Misalignment due to Bending

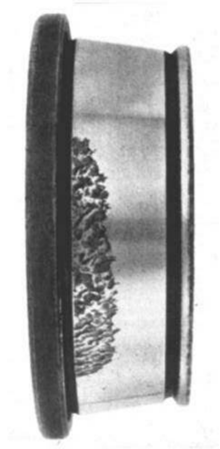
Figure 7.6: Bearing Misalignment

Self-aligning (spherical) bearings are designed to operate with some misalignment. In ordinary ball and roller bearings, misalignment causes larger than normal forces. These forces speed up the process of fatigue and cause early failure.

Wear marks on the races can give early warning of misalignment. **Figure 7.7(a)** shows the marks on a rotating inner race and a stationary outer race of a misaligned ball bearing.



(a) Wear Marks due to misalignment forces only—rotating inner race



(b) Fatigue pitting due to misalignment and radial load—stationary inner race

Figure 7.7: Misalignment Damage

The stationary outer race in **Figure 7.7(a)** has a wear mark that crosses diagonally from one side of the raceway to the other. The inner race has a wide wear mark right across the raceway. This is because the balls move from one side of the raceway to the other as the race rotates.

If the inner race is stationary and the outer race rotates, the wear marks would be reversed: the diagonal wear mark is on the inner (stationary) race and the wide wear mark on the outer (rotating) race.

If there is also a radial load on the bearing, the wear is greater on the load side. **Figure 7.7 (b)** shows fatigue damage on the load side of the stationary inner race of a misaligned taper bearing.

7.4 Damage Caused by Incorrect Fitting

Fitting a bearing by pressing on the wrong race was described in **Section 6.6** of this module. The press force is *transferred* from one race to the other through the rolling elements. Because the area of contact between the rolling elements and the races is small, the pressure can be very high. The fitting force damages the races where they contact the rolling elements as shown in **Figure 7.8**.

Something is ***transferred*** when it is moved from one place to another.

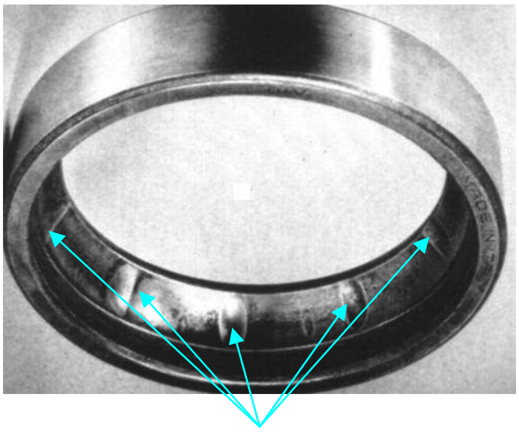


Figure 7.8: Fitting Damage—Pressing on Wrong Race

The damage caused is seen as shallow *indentations* on one side of the raceway. The spaces between them are the same as the spaces between the rolling elements.

Indentations are dents.

Some cylindrical roller bearings can be separated for fitting. If, after fitting the races, they are misaligned when assembling the bearing, the edges of the rollers can score the races as shown in **Figure 7.9**.

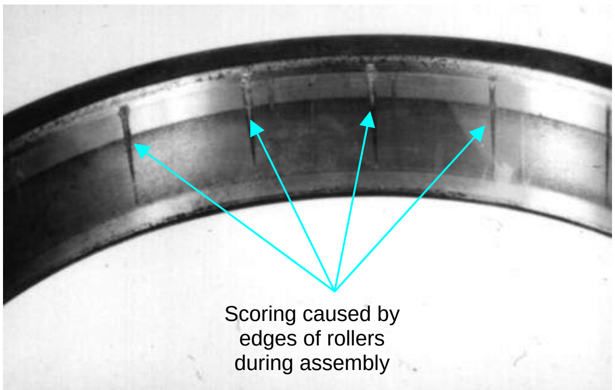


Figure 7.9: Fitting Damage—Misalignment during Assembly of a Separable Bearing

The spacing of the scores is similar to that of the indentations shown in **Figure 7.8** but their shape is not the same. The scores are scratches that run across the bottom of the raceway instead of being smooth indentations on one side. This kind of damage can happen to large, heavy roller bearings during assembly.

If a simple drift is used to fit a bearing and the races are hit carelessly, the edges can be damaged, as shown in **Figure 7.10**.

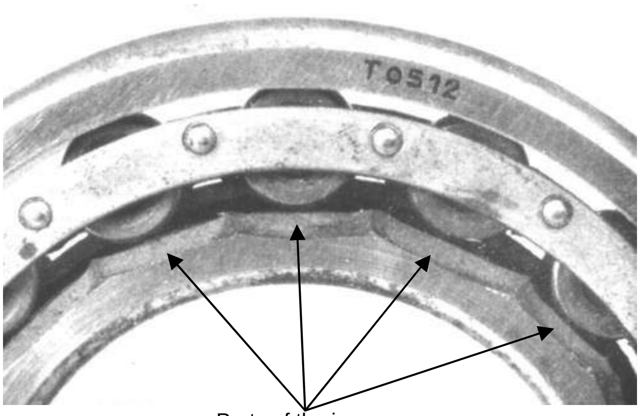
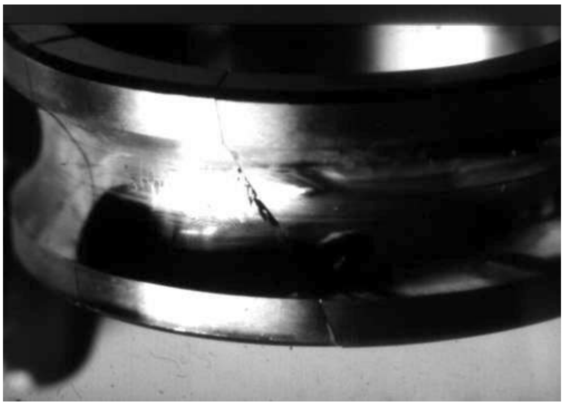


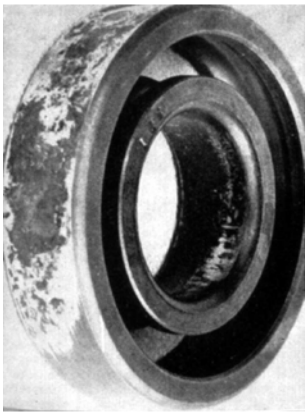
Figure 7.10: Edge Damage from Careless use of a Drift

Using incorrect fits for a bearing can also cause damage.

- too much interference reduces the clearance between the rolling elements and the races causing overheating (see **Section 7.6**of this module)
- too much interference between shaft and inner race can cause the race to crack (**Fig. 7.11 (a)**)
- too loose a fit between outer race and housing can cause fretting between housing and race (**Fig.7.11(b)**)
- too little interference between rotating shaft and inner race can cause fretting between shaft and race (**Fig. 7.11(c** and **d)**)

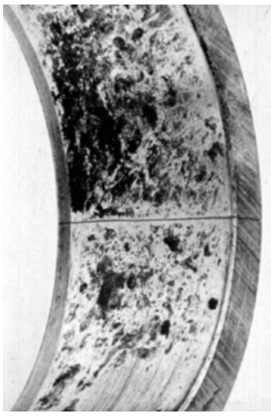


(a) Cracked Race due to too much Interference



(b) Fretting due to Loose Fit between Housing and Bearing

(c) Fretting on Shaft due to Loose Fit between Shaft and Bearing



(d) Fretting on Race due to Loose Fit between Shaft and Bearing

Figure 7.11: Damage due to Incorrect Fits

7.5 Brinnelling and False Brinnelling

If a shaft supported by bearings receives a shock load, the high pressure under the balls or rollers make indentations in the races. *Brinnelling* is the denting of the bearing race caused by a sudden impact.

A more common type of damage is *false brinnelling*. False brinnelling is a type of fretting, as described in **Section 5.5** of this module. It happens when the rolling elements of a bearing stay in the same position for a long time, with the weight of the shaft etc., resting on them.

Bearings in stand-by equipment and equipment held in stores for a long time can show signs of false brinnelling. If the shaft is vibrated by equipment that is operating nearby, the rolling elements eventually make indentations in the races. Heavy shafts on equipment that is not in use should be turned from time to time to change the positions of the rolling elements in their races.

When the equipment is put into operation, false brinnelling indentations in the races cause vibration. This results in early fatigue damage. **Figure 7.12** shows two examples of false brinnelling damage.

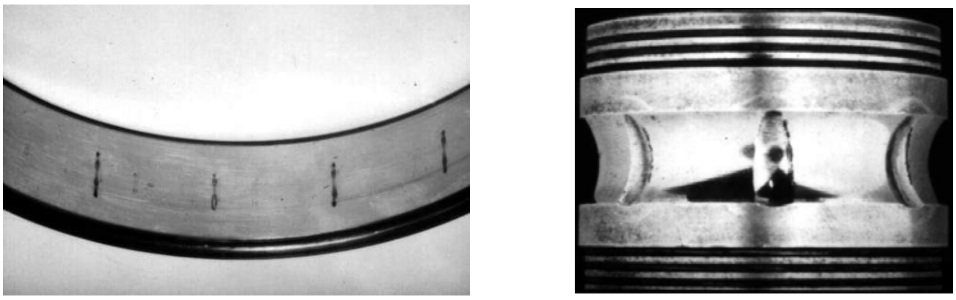


Figure 7.12: False Brinnelling

Figure 7.13 shows typical examples of fatigue damage. The patches of damage have the same spacing as the rolling elements. This type of damage is caused by indentations made by the rolling elements when they are stationary.

(a) Damage to side of raceway indicates false brinnelling under thrust load or fitting damage

(b) Damage in small patches at centre of raceway indicates false brinnelling

Figure 7.13: Fatigue Damage at Indentations Made by Stationary Rolling Elements

7.6 Lubrication Failure

Break-down of the lubricant film between rolling elements and races increases friction. This increase the running temperature of the bearing. If no oil flows through the bearing to cool it, this increases the temperature even more. If you can feel that a bearing is running hotter than usual, check that the lubrication system is working correctly.

> A hot bearing, shaft or housing is often an early warning of trouble

The first damage to appear after loss of lubricant is called *surface distress*. It produces a smooth but uneven surface as shown in **Figure 7.14**.

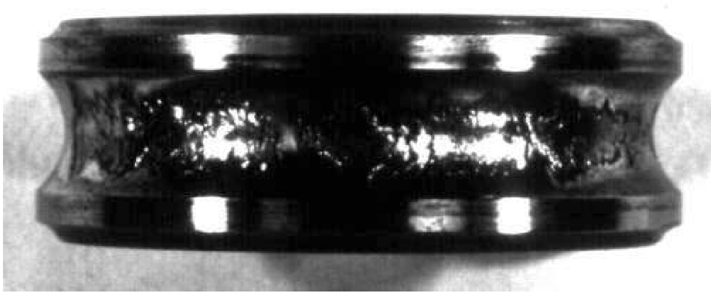


Figure 7.14: Surface Distress

If the bearing continues to run without enough lubricant the temperature keeps increasing. A rise in temperature causes metal to expand. If the inner race gets hotter than the outer race, the space between the races gets less. This reduces the bearing clearance. If the inner race expands enough, the clearance disappears. When this happens the rolling elements can not roll, they start to slide. This increases friction even more and makes the temperature rise more quickly. As the inner race continues to expand, the bearing can *seize*. If the problem is allowed to reach this point, the equipment can be seriously damaged or even destroyed.

> Report any early warning signs of bearing damage immediately

Figure 7.15 shows badly damaged bearings that have seized because of lubrication failure.

Figure 7.15: Bearing Seizure Damage

Loss of bearing clearance can be the result of other root causes:

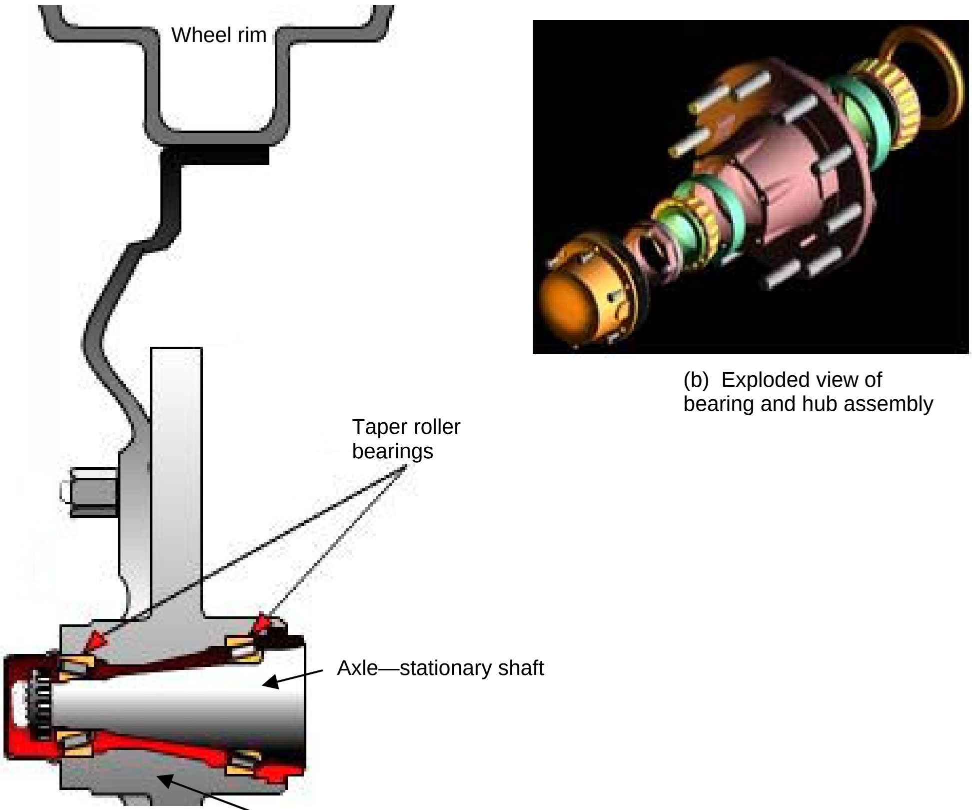
- too much interference when fitting races—reduces clearance
- using the wrong bearing for the application—manufacturer's clearance too small
- using the wrong lubricant for the application—lubrication breakdown
- too loose a fit between inner race and shaft—causes:

  slip→friction→heating→expansion
- overloading the bearing— breakdown of lubricant film

Now try **Exercise 8**

8 Bearing Housings

Bearing housings have been mentioned many times in earlier sections of this module. A bearing housing holds the bearing—the bearing fits into it. It is usually stationary, but in some applications it rotates and the shaft is stationary. The hub of a wheel is an example of a rotating housing. The bearing or bearings are fitted onto a stationary axle and into a rotating hub. **Figure 8.1(a)** shows a part-section through a vehicle hub and wheel assembly. **Figure 8.1(b)** shows an exploded view without the axle and wheel.



(a) Hub, axle and wheel assembly

(b) Exploded view of bearing and hub assembly

Figure 8.1: Vehicle Wheel, Hub and Axle Assembly

Bearing housings may be:

- one-piece or split
- part of the machine casing or separate components

Pillow blocks or plummer blocks are bearing housings that are not part of the machine. They are separate items that are secured to a machine or some other solid base. **Figure 8.2**. shows two types of pillow block.

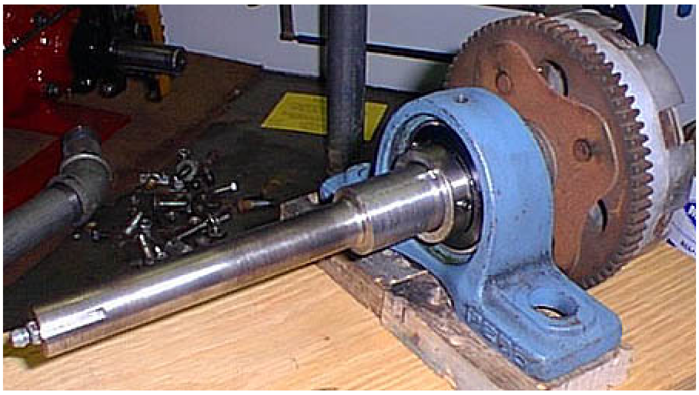
(a) One-piece Pillow Block

(b) Split Pillow Block

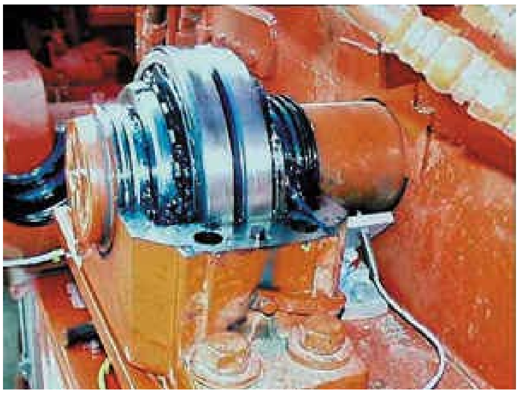
Figure 8.2: Pillow or Plummer Blocks Fitted with Plain Bearings

The housings shown in **Figure 8.2** are fitted with plain bearings. Plain bearings are pressed into one-piece housings with an interference fit. Split plain-bearing shells are held in split housings.

Anti-friction bearings are held in on-piece or split housings with the fit recommended by the manufacturer. **Figure 8.3(a)** shows an anti-friction bearing fitted in a one-piece pillow block. **Figure 8.3(b)** shows one fitted in a split housing with the top part removed.



(a) One-piece Pillow Block



(b) Split Pillow Block with Top Removed

Figure 8.3: Pillow or Plummer Blocks Fitted with Anti-friction Bearings

Notice the dowel on the bottom part of the split housing in **Figure 8.3(b)**. Dowels locate the two housing halves for assembly.

Bearings that are part of a machine casing may also be one-piece or split. The main crankshaft bearing housings on reciprocating pumps and engines are split. **Figure 8.4** shows a crankcase with a row of split main-bearing housings.

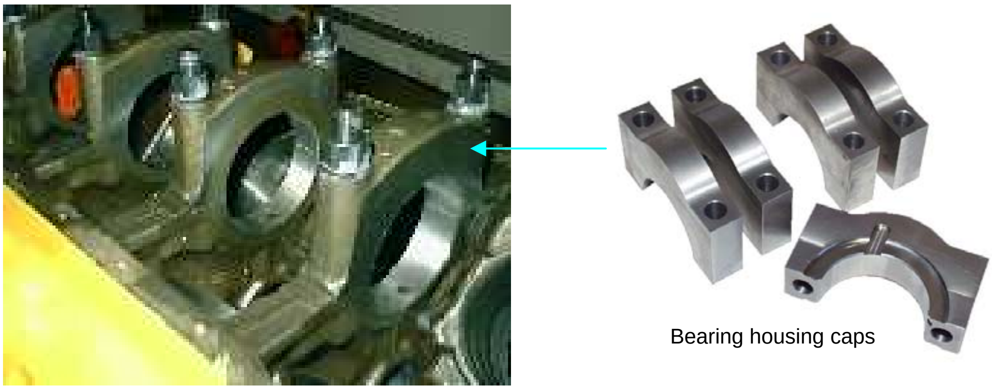


Figure 8.4: Main Bearing Housings in a Reciprocating Engine

Some housings have seatings for seals as well as for the bearing, as shown in **Figure 8.5**.

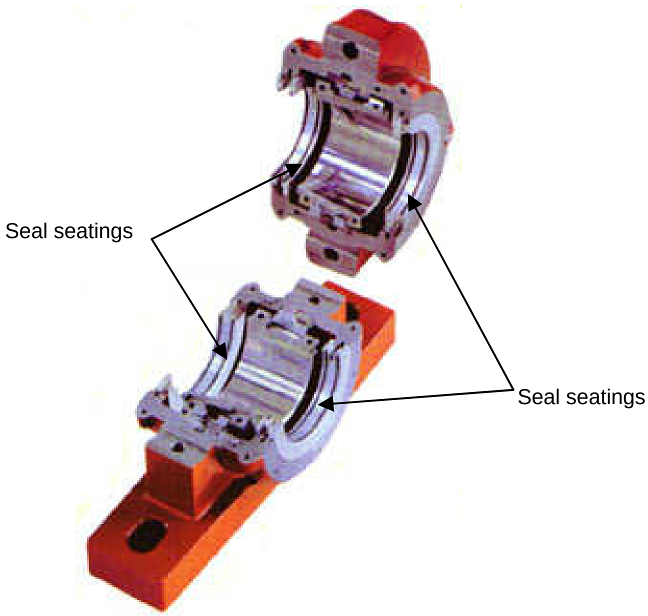


Figure 8.5: Split Pillow Block with Seal Seatings

9 Handling and Storage

Keeping all surfaces clean is very important when handling and fitting bearings. Most bearings are supplied and stored in a protective paper wrapping. This keeps the bearing clean and dry. Do not remove this wrapping until just before fitting.

There may also be a protective coating applied directly to the bearing to stop any corrosion during storage. You can fit and use the bearing without removing this coating.

Because anti-friction bearings are case hardened, they should not be hit with a hard object. Impact from a hard object can chip the hard, brittle bearing surface. If you use a drift and hammer to fit a bearing, always use a drift made of a softer material, like mild steel. It is always good practice to use a drift that is softer than the bearing, even for press-fitting.

Wear safety goggles or a visor when fitting or removing bearings

Plain bearings are sometimes made of soft materials and you must take care when press-fitting them. Only use a soft drift with great care if you can be sure of not damaging the bearing. Shrink-fit where you can, to reduce the press force needed.

If you are re-fitting a bearing after removing it you should clean it before re-fitting. Cleaning *solvents* may be *toxic* or flammable.

A ***toxic*** substance is poisonous.

Wear the correct PPE when using cleaning solvents—avoid splashes

Never spin a bearing with compressed air—this can be very dangerous

10 Summary

You should now be able to recognise the different types of bearings that are used in the plant and identify their applications. You have fitted and removed different kinds of plain and anti-friction bearings using different methods. You have also had a first look at some typical bearing failures and should be able to suggest some possible root causes of failure by inspection of the bearing.

Before finishing this module, look at the tables below, which review the advantages and disadvantages of plain and anti-friction bearings.

Plain Bearing Advantages	Anti-friction Bearing Advantages
Cheaper	Usually easier to replace
Less radial space needed	Less axial space needed
Better resistance to overloading and impact loads	Lower friction during start-up
Quieter running	Use less power because of lower friction
Not so easily damaged by particles of dirt because of the embeddability of the material	Not so quickly damaged by loss of lubrication
	Sealed bearings do not need an additional lubrication system

Anti-friction Bearings	
Type	**Advantages**
Ball bearings	Cheaper for smaller diameters
Deep-groove ball bearings	Can take some thrust as well as radial load High running speed
Cylindrical roller bearings	Can take higher loads Better resistance to impact loads Cheaper for larger diameters
Needle bearings	Less radial space needed Can take higher loads than cylindrical rollers Better resistance to impact than cylindrical rollers
Taper roller bearings	Can take radial and axial loads
Self-aligning (spherical) bearings	Can operate with some misalignment

Because different bearings are designed to work under different operating conditions, always replace a bearing with one of the same type.

11 Glossary

Here are some words used in this module that might be new to you. You will find these words in *coloured italics* in the notes. There is a short definition in a box near the word in the notes.

Word	First Used on Page:	Part of Speech	Meaning	Example of Use
Application	41	noun	A particular use of something.	Sending e-mail is just one application of the internet.
Characteristics	35	noun	Behaviour (or appearance) that makes an item or person recognisable.	He has the same characteristics as his father.
Circulate	56	verb	To move around.	I had to circulate around the guests to greet everyone.
Clue	50	noun	Something that helps you solve a puzzle.	The police inspected the car to look for a clue as to what had caused the accident.
Distribute	43	verb	To send to different places; to spread around.	One job of ADNOC Distribution Company is to distribute petrol and oil products around the U.A.E.
Eliminate	9	noun	To remove completely.	It is the aim of the company to eliminate all unsafe procedures.
Equivalent	43	adjective	Equal. Something that can be used to replace something else.	If you do not have the original tyres in stock, please fit an equivalent.
Eventually	89	adjective	Happening at the end of a period of time.	All flights from the island were delayed, but we managed to get off eventually.

Word	First Used on Page:	Part of Speech	Meaning	Example of Use
Feature	19	noun	Appearance that make an item or person recognisable.	Our features are so similar, anyone can see that we are brothers.
Flush	82	verb	To clean something by passing a large flow of liquid through it.	If you get any chemical in your eye you, flush your eye with water.
Impact	78	noun	The result of one object hitting another.	A lot of damage can result from the impact of a road accident, even at relatively low speeds.
Indentation	98	noun	A dent.	The collar is secured to the shaft by a grub screw that locates in an indentation in the shaft.
Inspection	9	noun	The process of looking very carefully at something.	After an accident an inspection must be made of the area where the accident happened.
Linear	43	adjective	Describes something that moves in a straight line.	A feather key allows some linear motion of a gear mounted on a shaft.
Mould	18	noun	A container that gives shape to something.	You can make different shaped ice cubes by freezing water in rubber moulds.
Relative	8	adjective	Compared with something else.	The traffic in the city was at a relative standstill.
Relatively		adverb		I was driving relatively slowly when my car hit the barrier.
Reservoir	81	noun	A storage place for a liquid—a container.	There is a small reservoir in your car that holds water for the windscreen wash/wipe.

Word	First Used on Page:	Part of Speech	Meaning	Example of Use
Stationary	8	adjective	Not moving.	My car was stationary at a red light when someone drove into the back of me.
Submerge	48	verb	Put under the surface of a liquid.	The flood water was deep enough to completely submerge a car.
Support	8	verb	To carry the weight of something.	Some of the trees on Das Island have metal bars to support them.
		noun	An item that carries the weight of something.	Some of the trees on Das Island have metal supports.
Symptom	50	noun	Some sign of a problem, usually a health problem.	Before the doctor could tell me what was wrong, I had to tell him my symptoms.
Tilt	24	verb	To change the angle of something—tip.	Because the glasses were so full of tea, the waiter had to take care not to tilt his tray.
Toxic	107	adjective	Poisonous.	All toxic waste must be disposed of correctly.
Transferred	97	verb	Moved from one place to another.	He lost his remote allowance when he was transferred from Das to Abu Dhabi.

Exercises