

# ●●● POWER ENGINEERING

## Fourth Class

Edition 3.5

### Lubrication and Bearings

#### Part B

#### Unit B-1



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## LUBRICATION AND BEARINGS

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## UNIT INTRODUCTION

Bearings are fundamental components of all machines with moving parts. Properly installed, maintained, and lubricated bearings is essential to keep a machine operating smoothly, safely and efficiently. This unit covers bearing types, bearing installation, principles of lubrication, lubricant types, and methods of bearing lubrication.

Failure to provide a suitable and consistent supply of lubricant to bearings can have serious consequences, including:

- a) Costly repairs,
- b) Loss of production, and
- c) Catastrophic equipment failure that could shut down the entire plant.

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## UNIT RATIONALE

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Understanding the bearing designs and lubrication principles is fundamentally important to prevent bearing failure. They include:

- a) Types of bearing lubrication.
- b) Lubricant properties.
- c) Lubrication application principles.

Improperly lubricated bearings will:

- a) Reduce the energy efficiency of the equipment.
- b) Increase the risk of catastrophic failure, with possible injury or death.

Safety and efficiency are vital to Power Engineers. Therefore, it is critical to understand lubrication principles.





## Lubrication Principles

### LEARNING OUTCOME

*When you complete this chapter you should be able to:*

*Describe the importance of lubrication and the principles concerned with lubrication.*

### LEARNING OBJECTIVES

*Here is what you should be able to do when you complete each objective:*

- 1. Discuss the concept of lubrication and list the purposes of a lubricant.*
- 2. List the various classes and types of lubricants and describe their respective properties and application.*
- 3. List the properties of lubricating oils, the additives used, and their selection criteria.*





## CHAPTER INTRODUCTION

Lubrication systems are essential for rotating and reciprocating machinery. These machines operate within strict design parameters, including temperature and pressure. Lubrication systems permit the equipment to start and operate safely and efficiently.

The Power Engineer needs to be familiar with the principles behind lubrication. This chapter will explain how to:

- a) Recognize the purpose and importance of lubrication.
- b) Identify classes of lubricants.
- c) Describe the properties of lubricants.
- d) Select the appropriate lubricants and additives using selection criteria.

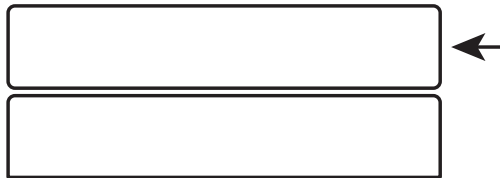
## OBJECTIVE 1

*Discuss the concept of lubrication and list the purposes of a lubricant.*

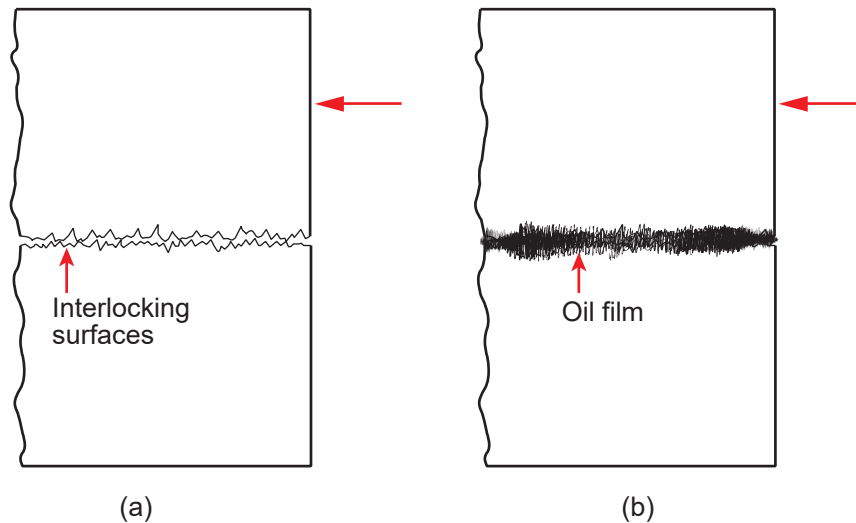
## FRICTION

Friction between two surfaces can be defined quite simply as resistance to motion (or attempted motion). For example, suppose that two smoothly ground flat pieces of metal rest upon each other, as in Figure 1. It might appear that these surfaces would offer little or no resistance to their relative movement, due to their smoothness. Microscopic analysis, though, reveals countless surface irregularities similar to the hills and valleys shown in Figure 2(a). The interlocking of these irregularities produces a definite resistance to relative motion.

**Figure 1 – Smooth Metallic Surfaces**



**Figure 2 – Magnified Surfaces**



**Lubrication** separates surfaces with interlocking surface irregularities. This allows the surfaces to move freely in relation to each other. The separation of these contacting surfaces happens by adding a **lubricant** between the two surfaces. Lubricants have other functions besides the separation of surfaces. These other purposes need further discussion.



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## LUBRICANT PURPOSES

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Lubricants serve several purposes, including:

- Friction reduction
- Wear reduction
- Corrosion control
- Shock absorption
- Sealing
- Temperature control

Of these, friction reduction and wear reduction are considered to be the most important.

### Friction Reduction

Refer back to the surface irregularities shown in Figure 2(a). When surfaces rub together, these irregular surfaces (hills and valleys) interlock. This causes the surfaces to cling or weld together. Additional force, then, will be required to move the surfaces.

The extra force required is known as the “force of friction.” By using a lubricant to separate the two moving surfaces, the friction can be considerably reduced (Figure 2(b)).

### Wear Reduction

When two surfaces rub together, the high spots (or hills), will wear down or break off due to hitting against other high spots. Under some circumstances, this results in the surfaces becoming smoother. In these cases, the wear is beneficial. Frequently, however, a continuous wearing process causes large pieces of material to be torn away. This will result in even rougher surfaces, increased friction, and increased rate of wear.

If a lubricant separates the surfaces, their high spots do not come into contact. Therefore, the lubricant reduces or eliminates the wear.

### Corrosion Reduction

As well as separating the bearing surfaces, a lubricant forms a corrosion barrier film. Metal surfaces are susceptible to acid attack, resulting in corrosion. Oils that are exposed to air oxidize and form acids. Chemical compounds (additives) are added to the lubricant to prevent the formation of acids due to oxidation of the oil.

### Temperature Control

The force used to overcome friction is converted into heat. If not controlled, the heat will cause high **bearing** temperatures. At high temperatures, bearing materials lose their strength, hardness and ability to support load. Lubricants reduce the production of heat by reducing friction. As well, lubricants may be used to carry heat away from bearing surfaces. In this situation, large quantities of lubricant are circulated to the bearings to absorb and carry away heat. The lubricant is then cooled in a heat exchanger before returning to the bearings.

### Shock Absorption

In cases where surfaces impact each other, as with gear teeth intermeshing, the lubricant serves as a cushion to absorb shock.

### Sealing

Lubricants are frequently used to provide sealing between pistons and cylinder walls, or in rotating shaft seals.

## OBJECTIVE 2

*List the various classes and types of lubricants and describe their respective properties and application.*

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### CLASSES OF LUBRICANTS

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Lubricants are manufactured to meet the requirements of the service for which they are intended. The particular properties desired will depend on the:

- a) Nature of the surfaces to be lubricated
- b) Load carried
- c) Speed of rubbing
- d) Operating temperature

In general, lubricants must provide the following services. Emphasis is placed upon one or more of these depending to the needs of the particular application.

- a) Minimum coefficient of friction
- b) Maximum adhesion to the surfaces to be lubricated
- c) Physical stability under variations of temperature and pressure
- d) Resistance to oxidation
- e) Resistance to emulsion (an emulsion is a liquid dispersed in a different liquid)
- f) Fluidity at low temperatures

The great majority of lubricants are mineral oils, manufactured from crude petroleum oil. Lubricants may also be:

- **greases**
- “**fixed**” **oils**, of animal or vegetable origin
- **synthetic oils**, and
- solids.

The above lubricants are divided into three general classes.

- Solids
- Semi-solids
- Liquids

### Solid Lubricants

Solid lubricants are suitable for use with heavy loads, extreme temperatures, or both. In addition, they are frequently used where bearings contact materials, such as certain chemicals, which could have a deteriorating effect on other classes of lubricants.

Solid lubricants may be used to lubricate idle equipment in storage and bearings difficult to service because of their locations. They are also used to lubricate electrical equipment and instruments, where other classes of lubricants would collect dirt and become gummy.



Materials usually used as solid lubricants are:

- Graphite
- **Soapstone**
- **Molybdenum disulfide**
- Mica and polymer films

Solid lubricants are applied to bearing surfaces in various ways. They may be applied directly by rubbing and polishing. Often, they are dispersed in a liquid and distributed in this way. Another method is to mix the solid lubricant with a bonding agent in a solvent. The surface is sprayed with the mixture and then it is baked on.

## Semi-Solid Lubricants

Semi-solid lubricants or greases are made by combining a liquid lubricant, usually petroleum oil, with a thickening agent.

The fact that grease has a thick, stiff consistency means that it can be used under conditions where oil could leak or drain away, leaving the bearing dry. Also, grease is less likely to drip or splash from bearings. Therefore, it has a wide application in the textile and food industries.

Grease is suitable for **ball bearings** and **roller bearings**. A single application to the bearing housing is sufficient for an extended period of time. As well as providing lubrication, grease serves to seal out dirt and water from bearings. It gives the working surfaces a more permanent protective coating which will not drain away. This prevents rusting during idle periods.

The equipment necessary for grease lubrication is generally less expensive and less complicated than for liquid lubrication. Grease is more convenient to handle and replenish. It can also produce cost savings since grease-lubricated bearings require less attention.

However, grease is not suitable in cases where large amounts of heat must be continually carried away from the bearing. Under these conditions, a liquid lubricant would be used.

The characteristics required in good grease are:

- Purity
- Consistency
- Chemical stability
- Thermal stability
- Tenacity

These are determined by the thickening agent, or “soap” used in its manufacture.

## Calcium (Lime) Base Greases

Calcium or lime greases have the cheapest cost and are the most commonly used. They are insoluble in water. Therefore, they can be used under damp conditions. They are often used for:

- Grease cups
- Pressure gun grease
- Axle grease
- Water pump grease

However, they are not suitable for use where temperatures exceed 70°C. Above this temperature, the grease will lose its moisture, and the soap and oil will separate.

## Sodium (Soda) Base Greases

The sodium base greases are more adhesive and cohesive than the calcium types. They are suitable for temperatures as high as 120°C. However, they are soluble in water and therefore are not suitable for wet conditions. They are frequently used for high speed ball and roller bearings.



### **Mixed Base Greases**

These have a base mixture of sodium and calcium. They are water resistant to some degree and can withstand higher temperatures than the calcium base types.

### **Barium and Lithium Base Greases**

These are greases which use either barium or lithium as a base. They are water resistant and are suitable for high temperature service. They find use in antifriction bearings (roller and ball bearings). Some types of lithium based greases are suitable for extreme low temperatures ( $-55^{\circ}\text{C}$ ).

### **Aluminum Base Greases**

These types of greases have good water resistance and may be used for temperatures up to  $80^{\circ}\text{C}$ . They are very adhesive and stick well to metal surfaces, thus providing rust protection. However, this adhesiveness or stickiness makes them unsuitable for high speed applications as they have excessive internal friction (viscosity).

### **Specialty Greases**

Specialty greases are made of mineral oils thickened with solid lubricants such as graphite, mica, and talc. They are used for heavily loaded machinery that operate at slow speeds, such as tractor rollers, cement mixers, and excavating equipment.

## **Liquid Lubricants**

Liquid lubricants are divided into three general classes:

1. Mineral oils
2. Fixed oils
3. Synthetic oils

### **Mineral Oils**

Mineral oils are produced from crude petroleum. They are the most commonly used class of all lubricants. The crude petroleum, from which gasoline, kerosene, and light fuel oil have already been extracted, is processed in a fractionating tower. Here, the various grades of lubricating oil are drawn off at different levels from the tower, as they condense. The heavy oils are drawn off near the bottom of the tower, while the lighter grades of oil are removed from the higher levels.

### **Fixed Oils**

Fixed oils, also called fatty oils, are of animal or vegetable origin. They include:

- Lard
- Whale oil
- Castor oil
- Cottonseed oil
- Canola oil

They are called “fixed” because they are non-volatile. These are rarely used by themselves as lubricants, but are incorporated into greases or mixed with mineral oils for special applications.

### **Synthetic Oils**

This class includes polyglycols and silicones suitable for high temperature service. Some types are used as fire resistant turbine lubricants. Synthetic oils demonstrate resistance to sludge formation and oxidation.



## OBJECTIVE 3

*List the properties of lubricating oils, the additives used, and their selection criteria.*

## LUBRICATING OIL PROPERTIES

### Viscosity

**Viscosity** is a measure of the resistance of a liquid to internal deformation or shear. It indicates the liquid's ability to flow. The viscosity also indicates the:

- a) Ability of an oil to support a load.
- b) Power required to overcome internal friction.
- c) Amount of heat produced due to internal friction.

Oil viscosity is greatly affected by its temperature. As the temperature increases, oil will become thinner and less viscous (viscosity will be reduced). Conversely, at low temperatures, oil will be thicker and more viscous (viscosity will be increased).

A commonly used method of measuring the viscosity of oil is by means of a **Saybolt viscometer**. This instrument measures the time taken, in seconds, for a given quantity of oil at a given temperature to flow through a small diameter orifice. This viscosity is expressed in units called **Saybolt Seconds Universal (SSU)**.

### Viscosity Index

The **viscosity index** is a measurement of how much the viscosity of a certain oil changes with a temperature change. Oil with a high viscosity index (V.I.) indicates that its viscosity changes little when its temperature changes.

Oils with a very high V.I. are favoured for use in automatic transmissions in automobiles as well as in other applications. This oil will have a suitable viscosity at operating temperatures and still will not be too thick or viscous at lower temperatures (during a cold start-up).

### Pour Point

The **pour point** of oil is the lowest temperature at which a certain oil will flow. Oils to be used in cold climates and refrigeration compressor oils must have low pour points; otherwise, the oil may congeal in service. Lubrication will fail as a result.

### Flash and Fire Points

The **flash point** of an oil is the temperature at which it will give off sufficient vapour to ignite momentarily when mixed with air and exposed to a source of ignition.

The **fire point** of an oil is the temperature at which it gives off enough vapour to burn continuously.

Flash and fire points are important because they indicate the temperature at which a fire or explosion may occur when the temperature rises during operating conditions.

### Neutralization Number

The neutralization number indicates the acidity of oil. When lubricating oils are in service, they tend to oxidize and form acids. By testing oil periodically, it can be determined if its neutralization number has changed. This will give an indication of when the oil should be replaced.



## Carbon Residue Test

The carbon residue test is used to determine the amount of carbon an oil will form when subjected to high temperatures. The carbon residue factor is important in choosing suitable oil. Carbon formed from the oil will interfere with the functioning of engine and compressor piston rings and valves.

## Floc Point

**Floc point** is the temperature at which wax or other suspended particles in the oil will separate out from the oil.

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## LUBRICATING OIL ADDITIVES

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Frequently it is possible to improve the desirable characteristics of lubricating oil with the use of additives. These are materials that are added to the oil. They can improve certain characteristics of the oil without adversely affecting other characteristics. A large variety of additives are in general use. Some of these include:

- a) **Anti-oxidants** will decrease the amount of oxygen that combines with the oil. This prevents corrosion of bearings, varnish and sludge deposits.
- b) **Detergent-dispersants** will act to keep deposit-forming substances in suspension in the oil.
- c) **Viscosity index improvers** will reduce the amount the viscosity of an oil changes with temperature.
- d) **Antifoam additives** will cause the collapse of air or vapour bubbles within the oil to stop oil from foaming.
- e) **Pour point depressants** will lower the pour point of the oil, thus allowing the oil to remain fluid at low temperatures.
- f) **Corrosion inhibitors** will form a protective film on metal surfaces and so reduce corrosion.

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## SELECTION OF LUBRICATING OILS

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The following sections deal with various applications that require lubricating oils, and the desired properties that the oil must possess for the application.

### Turbine Oils

The oil used in a turbine circulating system functions as both a lubricant and a cooling medium for the bearings. In many cases, the oil also serves as a sealing medium, and as a hydraulic fluid to operate turbine governor control systems.

Such an oil should be readily separable from water (to prevent potential of contamination of the oil). It should incorporate corrosion inhibitors, antifoam, and anti-oxidant additives.

Most oil used in steam turbines is refined mineral oil. However, synthetic fire resistant turbine oils are sometimes used to reduce the risk of ignition with nearby high temperature steam lines and turbine components.



## Air Compressor Cylinder Oils

The viscosity must be within a suitable range at the operating temperatures of the compressor. If the viscosity is too high, the oil will not spread rapidly over the cylinder walls and will cause a drag on the piston. Conversely, if the viscosity is too low, the oil will not maintain the proper lubricating film or the proper sealing of piston rings to the cylinder walls.

In addition to having the proper viscosity, the oil should have a low carbon residue. In cases where the compressor cylinder is lubricated by the splash method from the crankcase, the oil used will have to be suitable for both bearing and cylinder lubrication.

## Internal Combustion Engine Oils

For internal combustion engine service, the oil must withstand the high temperature of the cylinder walls. When exposed to high temperature, oils tend to evaporate, thicken, and form varnish and carbon deposits. This reduces the lubricating ability of the oil.

In addition, the oil must lubricate the crankshaft and other bearings, which are at a lower temperature particularly at start-up. Therefore, internal combustion engine oil should have a high viscosity index. Its viscosity will then be suitable at both high operating temperatures and low starting temperatures.

Usually anti-oxidant additives are used, as well as, detergent dispersants to deal with deposits that may be formed. To prevent corrosion, rust preventers and corrosion inhibitors are also added.

## Refrigeration Compressor Oil

The pour point of a refrigeration compressor oil must be low enough so that it will not congeal at evaporator temperatures as some refrigerants will carry over oil to the system. Also, the oil must not react chemically with the refrigerant used. Some refrigerants, are miscible with oil; this results in a reduction in the oil viscosity. Therefore, viscosity selection will vary between refrigerants. The floc point is another important variable in selection of a refrigeration oil. If the floc point is too high, paraffin wax will settle out in refrigeration control valves and impede refrigerant flow and operation.

Additives for refrigeration oils could include the following:

- Detergent dispersants
- Viscosity Index improvers
- Pour point depressants
- Corrosion Inhibitors

Some refrigerants, are only partially miscible with oil. Due to chemical reactivity and miscibility issues, systems charged with some refrigerants require compatible synthetic **polyol ester oils**.

Always consult the manufacturer's information for correct lubricant selection, use and maintenance requirements.

## Gear Lubricating Oils

In the case of enclosed gears, such as turbine reduction gears, low viscosity oil is preferred. This reduces power losses due to oil drag and prevents excessive oil heating due to fluid friction. Frequently, extreme pressure additives are incorporated into the oil to improve the load carrying ability.

For heavy industrial open gears, high viscosity oil is used. It will cling to the surfaces and resist washing off.



## CHAPTER SUMMARY

The importance and application of lubrication were discussed in this chapter. This information will aid in understanding the types of bearing lubrication in the next chapter.

This chapter showed how to:

- a) Relate the importance of the lubrication system to other topics such as prime movers, compressors, and rotating machinery.
- b) Discuss lubrication concepts and list the purposes of a lubricant.
- c) Identify the various types and classes of lubricants, and describe their application and properties.
- d) List the lubricating oil properties and additives.
- e) Make use of lubricant selection guidelines and criteria.



## Types of Bearings and Lubrication

### LEARNING OUTCOME

*When you complete this chapter you should be able to:*

*Describe bearing types, methods for care and maintenance of bearings, and bearing lubrication systems.*

### LEARNING OBJECTIVES

*Here is what you should be able to do when you complete each objective:*

- 1. Define boundary and full fluid film lubrication.*
- 2. Describe shell (sleeve) bearings.*
- 3. Describe the construction and operation of antifriction and thrust bearings.*
- 4. Describe how to clean and replace roller and ball type bearings.*
- 5. Explain the causes of bearing failure.*





## CHAPTER INTRODUCTION

This chapter will deal with the application of the principles of lubrication discussed previously. Bearings are one of the most important parts of any piece of rotating equipment. For Power Engineers to properly operate and maintain process equipment, they must be familiar with bearing lubrication.

This chapter will discuss how to:

- a) Describe the types of bearing lubrication.
- b) Be familiar with the basic construction and description of sleeve, thrust, ball, and roller bearings.
- c) Clean or replace a ball or roller bearing.

It is costly to replace or repair bearings. Identifying the root cause of bearing failure is essential, and will help to avoid unexpected breakdown or plant shutdown.

## OBJECTIVE 1

*Define boundary and full fluid film lubrication.*

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### TYPES OF BEARING LUBRICATION

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Lubrication can generally be divided into two categories:

1. Boundary lubrication
2. Fluid film lubrication

#### Boundary Lubrication

With boundary lubrication, only a microscopic film of lubricant separates the surfaces. This occurs when the supply of lubricant is restricted or intermittent. A certain amount of metal-to-metal contact will exist between the surfaces. However, the friction will be reduced because the lubricant film wets the surfaces.

For slow speeds and heavy loads the “oiliness,” or film strength, of the lubricant is a critical factor. For these operating conditions, grease or solid lubricant should be used. The greases provide greater wetting ability than conventional oil. Solid lubricants should only be used under special conditions.

#### Fluid Film Lubrication

Fluid film lubrication, also called flood lubrication, occurs when the lubricating film is thick enough to completely separate moving surfaces.

This condition will only exist if:

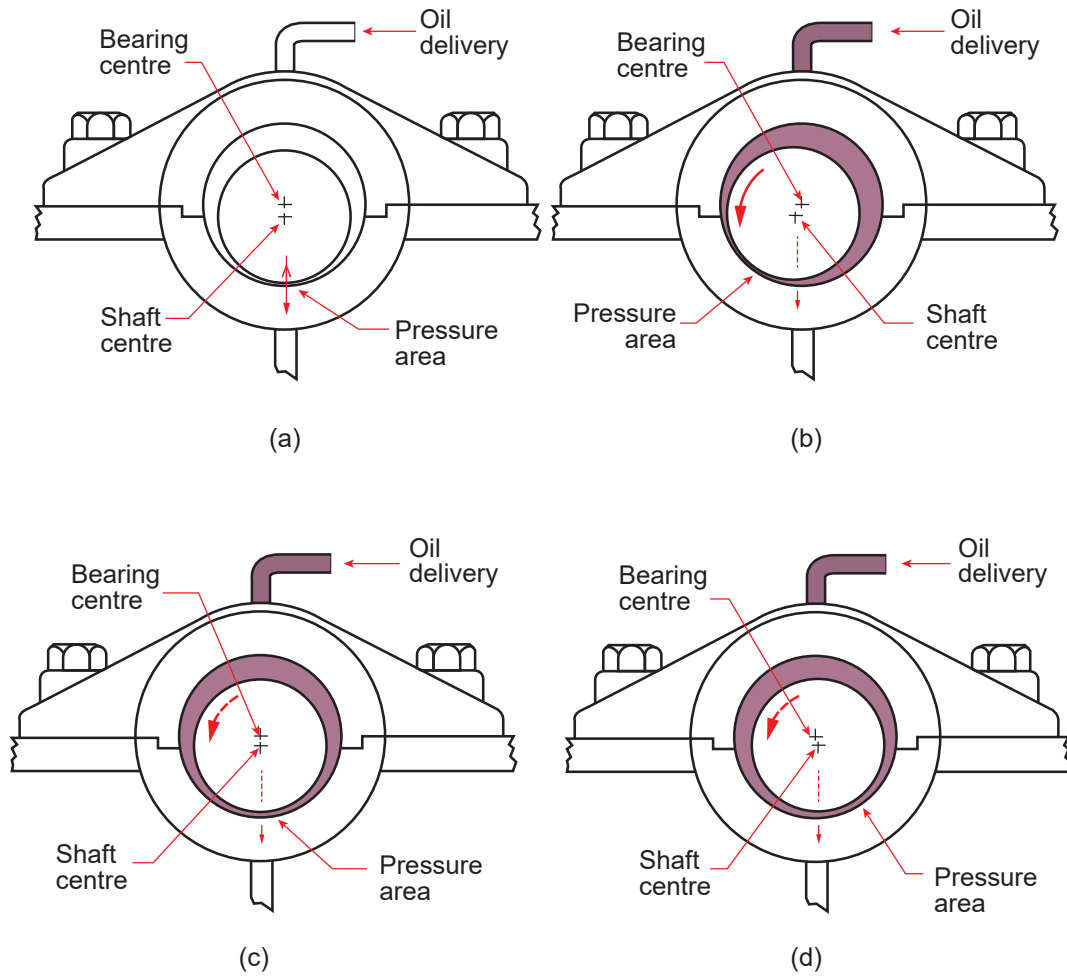
- a) The bearing clearance space is completely filled with oil, and
- b) The moving surface in the bearing is in continual motion.

In the case of a turbine or engine main bearing, the rapidly revolving shaft forces oil between it and the bearing; as a result, the shaft floats on a film of oil. The shaft must be rotating above a certain minimum speed in order to force the oil beneath it. For this reason, most of the wear in a bearing will occur during stopping and starting periods when the shaft is rotating below the minimum speed, and only boundary lubrication is in effect.

Figure 1 illustrates how fluid film lubrication is established in a shaft bearing. For the sake of clarity, the bearing clearance space shown is greatly exaggerated.

In Figure 1(a), the shaft is not turning and is in contact with the bottom of the bearing. When the shaft begins to rotate, Figure 1(b), the shaft tends to roll up the side of the bearing. Oil flows in behind and below the shaft. As its speed increases (Figure 1(c)), the shaft forces the oil into the wedge shaped space in front of and below the shaft. Enough pressure is produced to separate the shaft from the bearing surface. At high speed, Figure 1(d), the shaft is forced slightly over to the right due to the oil pressure.

At high speeds, the oil film that separates the shaft from the bearing becomes thicker due to the increased pumping action of the shaft. As the speed decreases, the film becomes thinner until, at slow speeds, it breaks down to a microscopic film, which results in only boundary lubrication.

**Figure 1 – Fluid Film Lubrication**

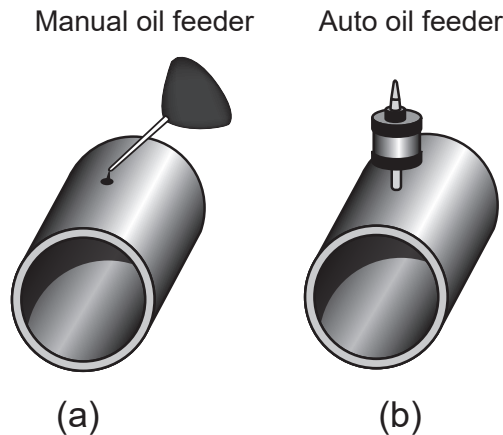
**OBJECTIVE 2***Describe shell (sleeve) bearings.***SHELL OR SLEEVE BEARINGS**

The shell or sleeve bearing is usually constructed with a white-metal alloy (“**babbitt**”) lining carried on a cast iron or steel housing. The relatively soft white-metal alloy is suitable for the lining because it will yield or deform slightly to conform to load conditions. Also, the bearing material is soft enough to allow foreign particles to become imbedded in it rather than scoring the shaft. Its comparative softness allows it to “wear in” to a smooth condition. Finally, the bearing material is fairly corrosion resistant.

In order to achieve full fluid lubrication, the bearing must provide sufficient clearance around the shaft. As well, the oil must be supplied in the low pressure area of the bearing.

Some of the usual methods of oil supply to the sleeve bearing are illustrated in Figure 2.

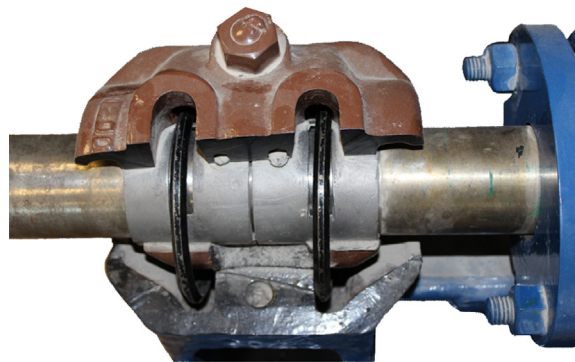
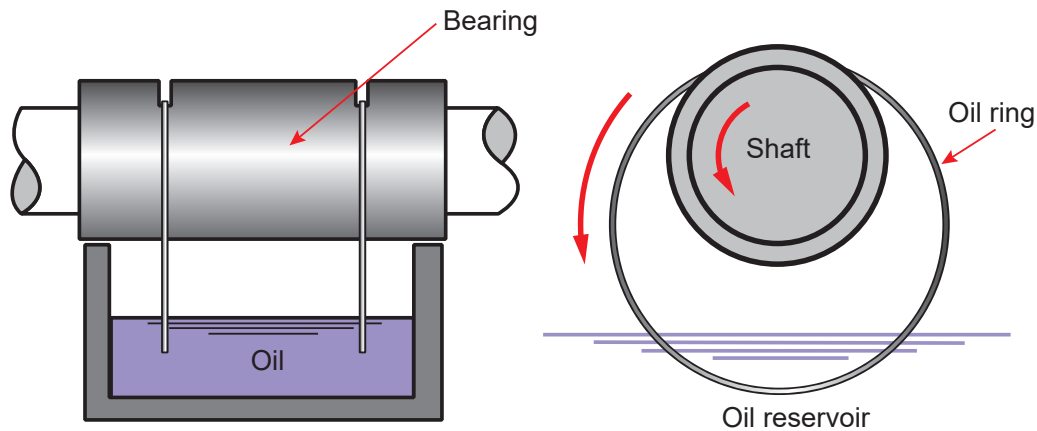
**Figure 2 – Shell or Sleeve Bearing Lubrication**



The hand-operated oil can is the simplest and oldest method of lubricating the bearing (Figure 2(a)). It is a form of intermittent lubricant supply. This method is only suitable for small bearings that require only a few drops of oil every few weeks or months.

Bearings on larger equipment need a continuous supply of oil. A feeding device, such as the automatic oiler (wick-feed or gravity feed) can be used (Figure 2(b)). The feeder must be refilled at regular intervals; otherwise, the bearing may still run short of oil.

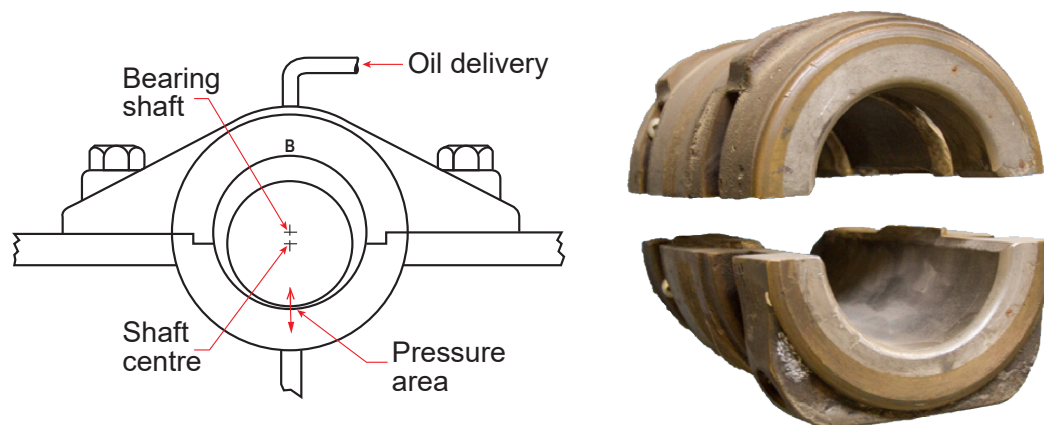
The ring-oiled bearing shown in Figure 3 is a more suitable solution, and is quite common on pump and motor bearings. The lower part of the bearing housing is filled with oil. An **oil ring** rides on the shaft through a slot in the centre of the upper part of the bearing. When the shaft rotates, it moves the oil ring slowly. The oil ring picks up oil from the reservoir beneath the bearing and drags it up through the bearing slot. The oil is then distributed between the shaft and the bearing. Once through the bearing, the oil drops back into the reservoir.


**Figure 3 – Ring-Oiled Sleeve Bearing**


### Oil Grooves in Bearings

Grooves are frequently used in the top half of the bearing, or non-pressure area, to distribute the lubricant evenly ahead of the pressure area. Grooves in the pressure area are considered harmful because they tend to disrupt the oil film and reduce the size of this area.

Figure 4 shows a sleeve bearing with the point of oil supply and the point of greatest pressure.

**Figure 4 – Sleeve Bearing**


The ability of an oil film to lift and support a heavy load is dependent upon the hydraulic pressure, which is produced by the pumping action of the rotating journal or shaft. Any grooves in the pressure area that permit oil to escape will tend to encourage metal-to-metal contact.

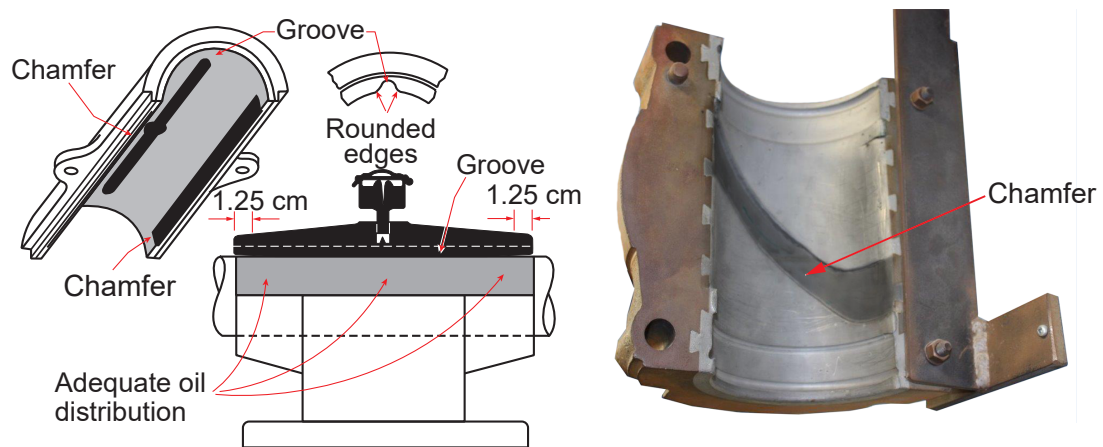
Also, when bearings are composed of two or more parts fitted together, any sharp corners at the joints will tend to scrape the oil from the shaft. All corners and edges should be chamfered or rounded to prevent scraping.

The principles of correct design and grooving of bearings may be briefly summarized as follows:

- Use grooves only where necessary for longitudinal distribution of the lubricant along the shaft (journal).
- Do not cut grooves in the pressure area.
- Chamfer or round off all sharp edges of bearing segments or grooves to prevent scraping the lubricant from the shaft.
- To minimize end leakage, grooves and chamfers should extend only to within 1.25 cm of either bearing end.
- Locate the lubricant application point in a portion of the bearing that is not under pressure.
- Heavily loaded slow-speed bearings should have the lubricant application point closer to the pressure area than is required in higher-speed and more lightly loaded bearings. Where this positioning is not possible, an auxiliary groove placed slightly ahead of the pressure area may be required to improve distribution.

Figure 5 shows the location of the oil groove and chamfer in a sleeve bearing.

**Figure 5 – Oil Groove and Chamfer**





## Sleeve Bearing Failure

One of the first signs that a bearing is failing is a rise in its operating temperature. Other signs are “knocking” or other unusual noises that might indicate excessive wear. Usually the cause of the bearing trouble is one or more of the following:

- a) Improper viscosity of oil
- b) Improper bearing design (oil groove, chamfer, clearance)
- c) Misalignment of shaft and bearing
- d) Loss of bearing metal due to corrosion or metal fatigue
- e) Loss of oil supply
- f) Temperature of oil is too high

Excessive amounts of heat can develop in heavily loaded bearings. The same is true for bearings that support shafts which are exposed to hot water or steam, since these also conduct heat to the bearing.

Extreme bearing temperatures could lead to trouble. To prevent this from happening, these bearings are usually water cooled, which takes place in one of three ways.

- a) A special cooling water channel is cast in the bearing housing through which the water flows. This method is used for oil as well as grease lubricated bearings.
- b) A special water coil is immersed in the oil basin of the bearing. The oil picks up the heat when it passes through the bearing and transfers it to the water passing through the coil.
- c) Oil may be allowed to flow from the bearing reservoir to circulate through an oil cooler, away from the bearing assembly. The oil is then recycled through the bearing for further lubrication and heat removal.

## Emergency Cooling of a Hot Sleeve Bearing

In the case of a small bearing, it is usually sufficient to increase the supply of oil. This increases the rate of heat removal from the bearing.

Large bearings are more difficult to cool. The heat produced may expand the shaft and reduces the clearance in the bearing. Large bearings in critical pieces of machinery may have their temperatures monitored continually. The control room operators receive high bearing temperature alarms. Steps are then taken to cool the bearing, at a controlled rate.

In the case of water-cooled bearing lubrication systems:

- a) Water flow to the lube oil cooler can be increased.
- b) If the lube oil cooler is experiencing water or oil flow restriction, the operator can change over to a standby lube oil cooler.
- c) Additional lube oil coolers can be put in service.

A non-water-cooled bearing may be cooled by directing a flow of cooling air to the bearing, via electric fan or air **eductor horn**.

Water should never be applied directly to a hot bearing because it may cause sudden shrinkage or distortion of the bearing cap. If this occurs, the running clearance between the bearing and the shaft would decrease further, and cause greater heat production and possible shaft seizure. In all cases, it is usually helpful to reduce the load on the equipment.

**OBJECTIVE 3**

*Describe the construction and operation of antifriction and thrust bearings.*

**FORCES ON BEARINGS**

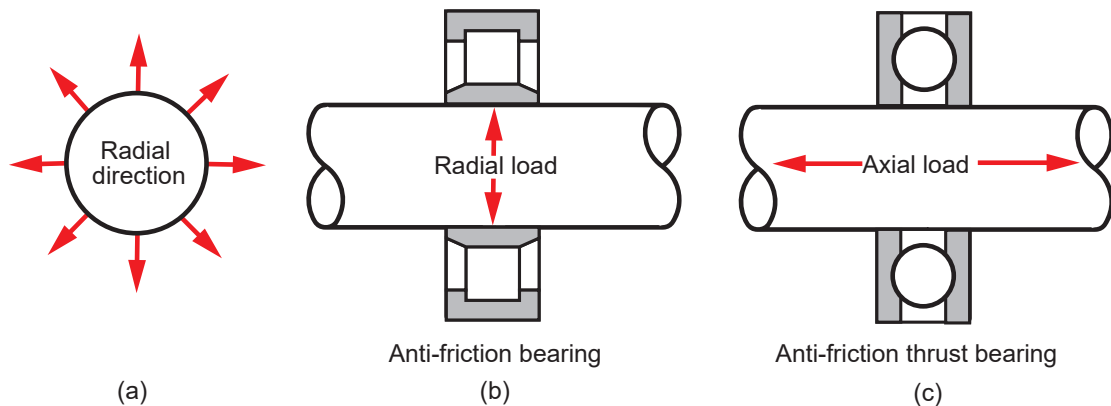
Shafts exert forces on bearings in two main directions:

- Radial direction
- Axial direction

Radial forces (or radial “loads”) are forces exerted perpendicular to the axis of the shaft (Figure 6(a) and (b)). These loads are primarily due to the weight of the shaft. Internal combustion engine and reciprocating compressor crankshaft bearings also carry additional load from the force exerted by reciprocating parts connected directly to the crankshaft.

Axial forces are referred to as “thrust” forces. Axial thrust is a force parallel to the axis of the shaft; it acts in the same direction as the shaft (Figure 6(c)). Thrust forces may occur due to shaft orientation (vertical versus horizontal), or force imbalance that occurs with some pumps, fans, and turbines.

**Figure 6 – Forces on Bearings**



Bearings that are designed to handle axial thrust are categorized as “thrust bearings.” Bearings designed to handle radial loads are “radial bearings.” Thrust and radial bearings come in a wide variety of designs, including:

- Plain sleeve (or shell) bearings
- Antifriction bearings
- Tilting pad bearings

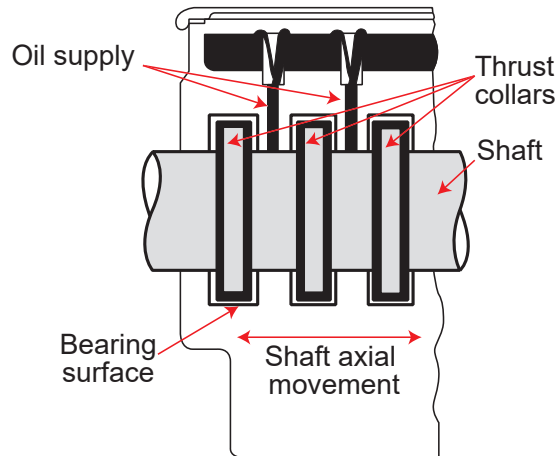


## AXIAL THRUST BEARINGS

The purpose of a thrust bearing is to prevent a rotating shaft from moving in an axial direction. A simple type of thrust bearing, known as a collar thrust, is shown in Figure 7.

The machinery housing has cast-in bearing material (babbitt) in the locations where the thrust collars intersect. The collars are an integral part of the shaft. The entire collar surfaces press against the bearing surface, so there is no room for an oil wedge to be formed. Therefore, lubrication is of the boundary type. The load that this type of bearing can carry is limited.

**Figure 7 – Collar Thrust Bearing**



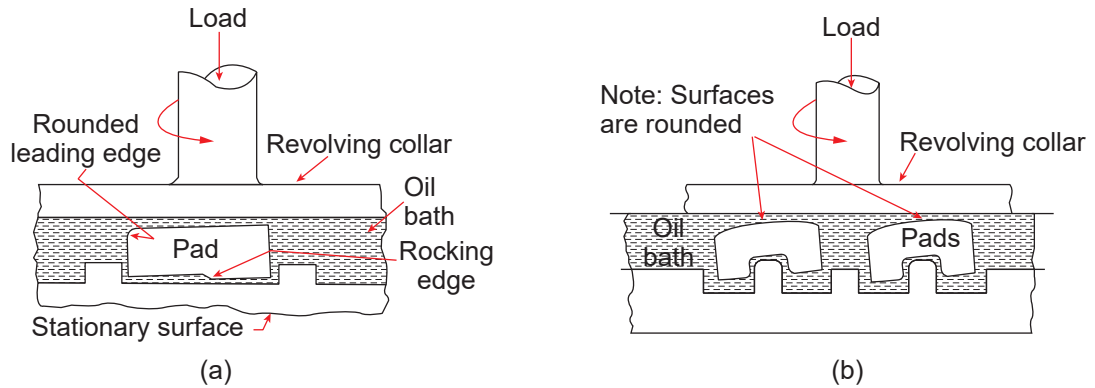
## TILTING PAD BEARINGS

Tilting Pad Bearings are capable of handling extreme axial and radial loads. These bearings do not permit metal-to-metal contact; they establish oil wedges that carry the entire load.

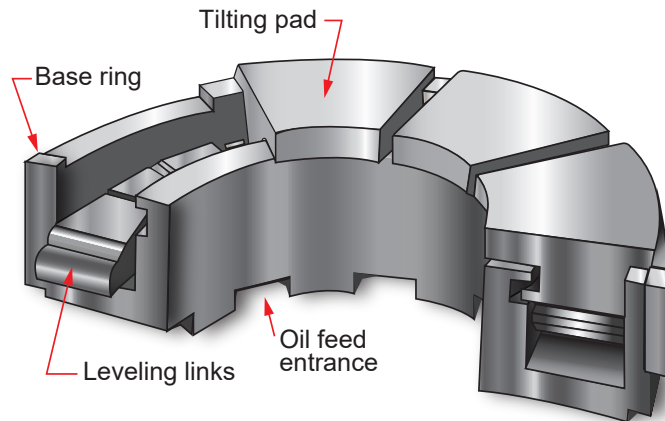
A tilting pad thrust bearing has the bearing surfaces in the form of pads which are free to tilt. This feature permits them to establish oil wedges to separate the bearing pads from the shaft collar. These are commonly used in large industrial steam turbines, where shaft position is critical and axial thrusts are great.

Figure 8 shows two types of tilting pad thrust bearings, the **Michell Thrust Bearing** in Figure 8(a) and the **Kingsbury Thrust Bearing** in Figure 8(b). These bearings are manufactured by the Michell and Kingsbury bearing companies respectively.

**Figure 8 – Tilting Pad Thrust Bearings**



**Figure 9 – Kingsbury Thrust Bearing**



## ANTIFRICTION BEARINGS

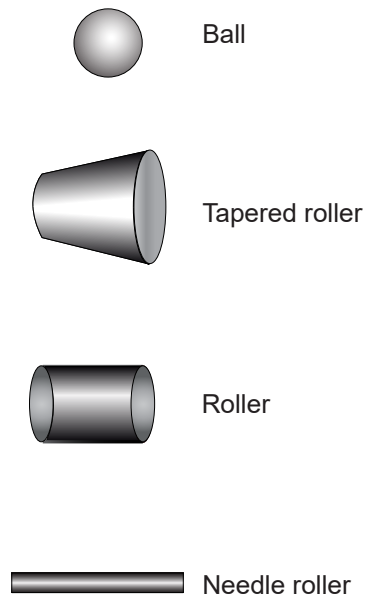
**Antifriction bearing** is the term applied to a group of bearings that replace sliding friction with rolling friction. Rolling friction results in far less friction force than sliding friction does, for a given load. Because sliding friction is nearly eliminated in these bearings, the name “antifriction bearing” applies. Antifriction bearings may be:

- Ball bearings
- Roller bearings
- Needle bearings
- Tapered roller bearings



The name refers to the shape of the rolling element. See Figure 10.

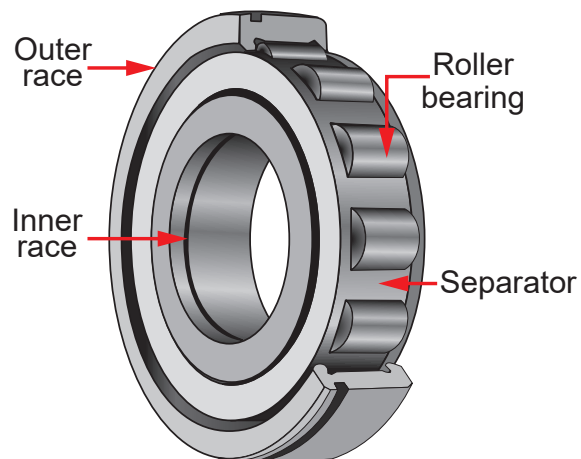
**Figure 10 – Antifriction Bearing Rolling Elements**



In an antifriction bearing, the rolling elements travel between two circular metal rings, known as “races.” The rolling elements are uniform in shape and have hard and highly polished surfaces. The races, too, have hard and polished surfaces. This is to ensure the bearings operate as smoothly as possible, for a long period of operation.

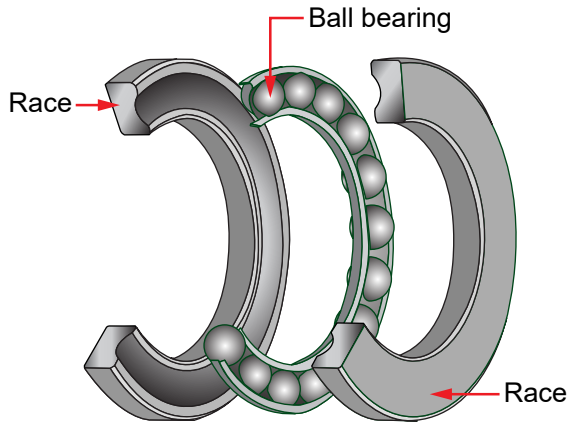
In many bearings, a separator is used to prevent the rolling elements from coming into contact with each other. Most of the sliding friction that occurs in an antifriction bearing is from the rolling elements contacting the separator. Figure 11 shows the construction of an antifriction bearing with roller elements.

**Figure 11 – Roller Bearing**



Ball and roller bearings may be arranged to handle axial or radial loads. Figure 12 shows an antifriction thrust bearing design.

**Figure 12 – Ball Thrust Bearing**

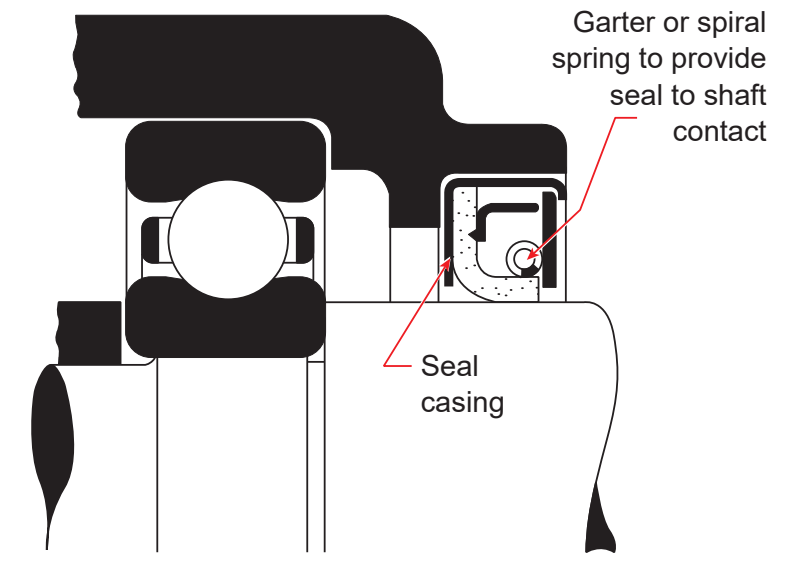


### Bearing Seals

In order to prevent foreign matter (dust, grit, water) from entering the bearing housing and the lubricant from leaving the housing, seals are installed on the shaft where it enters the bearing housing. These seals consist of felt, synthetic rubber, or leather rings, enclosed by their own steel casing and sometimes fitted with a light spring to force the seal against the shaft.

Figure 13 shows a seal mounted in the housing of a ball bearing which can be either oil or grease lubricated.

**Figure 13 – Ball Bearing with Seal**





## Lubricating Antifriction Bearings

In the plain or shell bearings, the main purpose of the lubricant is to separate the surfaces by means of a lubricating film. The film may be microscopic in thickness, as in the case of boundary lubrication, or thick enough to float the shaft, as in the case of fluid film lubrication.

In the lubrication of antifriction bearings, the principle is different. In these bearings, the main purposes of lubrication are to:

- a) Protect the accurately machined and highly polished surfaces of the balls, rollers, and raceways from corrosion. The smooth, low friction operation of these types of bearings depends largely on the highly finished surfaces of the components. If corrosion and consequent roughening of the surfaces occur, the bearing will fail rapidly.
- b) Provide a seal to prevent the entrance of dirt or other impurities into the bearing housing.
- c) Serve as a heat transfer medium to conduct away any heat generated at the contact points of rollers or balls.
- d) Provide lubrication to reduce the small amount of sliding friction, which is present even in the antifriction bearings.

Ball and roller bearing lubricant may be either oil or grease, depending upon operating conditions. In general, oil is preferred for the following conditions:

- a) For light machines or instruments where resistance to rotation must be kept to a minimum.
- b) Where high speeds are necessary and the use of grease will produce excessive heating due to the work done in churning or displacing the grease.
- c) For high operating temperatures. In some cases, **steam cylinder oil** may be necessary.
- d) Where bearings are located adjacent to other parts which require oil lubrication.
- e) Where ambient temperatures are low.

In applications where speeds are moderate and temperatures are not extreme, greases may be preferred for the following reasons:

- a) Grease is less likely to be flung out or leak from the bearings. This helps keep the surrounding areas clean.
- b) Where the atmosphere is polluted with impurities, grease provides a better seal to prevent entrance of impurities into the bearing housing.
- c) Grease is better at protecting bearings from corrosion during idle periods. It does not drain away as oil tends to do.

To properly grease bearings, Power Engineers must know:

- a) What type of grease to use,
- b) How much grease to add,
- c) How often grease must be added, and
- d) How to add grease properly.

## Types of Grease

Greases may be calcium, sodium, lithium, or aluminum-based. The type of grease used will depend on:

- Shaft speed
- Exposure to moisture
- Expected bearing temperature, and
- Manufacturer's recommendations.

Plants often have several grease guns pre-loaded with different types of greases, and labelled so that the correct grease is always selected. Never mix different greases together.

## How Much Grease to Add

Bearing manufacturers provide information about how much grease to add to a bearing. Far too often, bearings are overfilled with grease. This can cause several issues.

- Bearing seals can be damaged or dislocated, which permits entry of foreign matter and premature bearing failure
- Energy loss occurs, due to increased fluid friction in the bearing
- The bearing can overheat, which results in loss of lubricant, as the hot grease leaks away.
- Electric motor windings can be damaged from contact with grease.

## How Often to Add Grease

The addition of grease depends on factors such as:

- Hours of operation
- Operating environment (including moisture, temperature, and airborne contaminants)
- Rolling element shape

Bearing manufacturers have web-based calculators that can be downloaded. These calculators help to determine how often the bearings need to be lubricated.

## How to Add Grease Properly

While applying grease to bearings, it is important to prevent contaminants from entering the bearing, and to prevent seal damage. Below are some guidelines.

- Select the right grease.
- Determine the correct re-greasing interval.

### CAUTION

Equipment is usually warmed up and in operation when grease is added. This helps distribute the grease throughout the bearing. **BE CAREFUL AROUND ROTATING OR MOVING EQUIPMENT WHILE ADDING GREASE.** It is easy for rags, clothing, or body parts to become entangled with moving shafts. Some workplaces may require lockout/tagout procedures to be followed before equipment can be lubricated.

- If the bearing housing has a drain plug, remove it first to purge old grease from the bearing. Clean old grease from the drain opening and from the bearing's grease fitting.

### CAUTION

Bearings that do not have drain plugs can become overpressurized by grease guns and cause seal damage. Add grease by pumping the gun slowly, and add only the correct amount of grease.

- Squirt some grease from the end of the gun to clear it from debris. Wipe the end of the gun clean. This will prevent contaminants from entering the bearing.
- Connect the grease gun to the fitting and pump the correct amount of grease into the bearing. Some old grease may appear at the drain opening.
- After adding the new grease, allow the machine to continue running. Some excess grease may be expelled through the open drain plug.
- Clean the grease outlet of excess grease and replace the drain plug.



## Automatic Lubricator

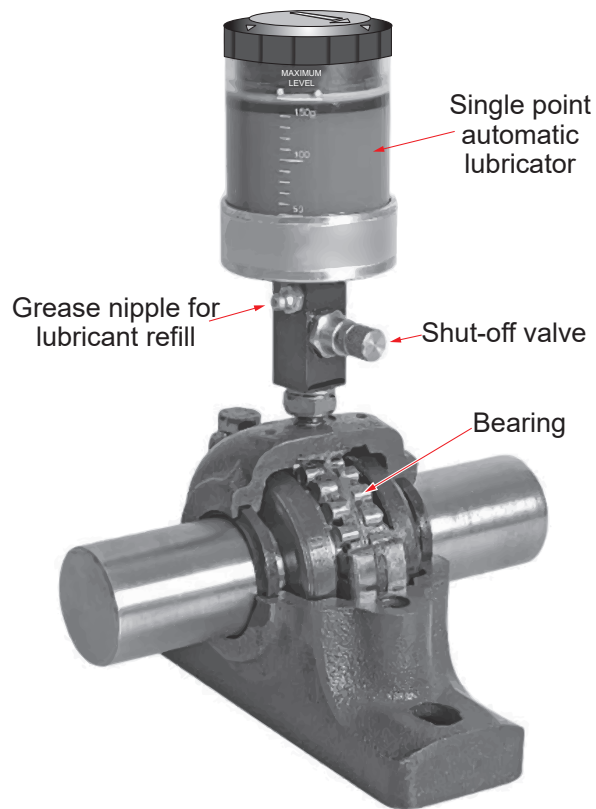
Some bearings that need grease are difficult to access and often expose workers to unsafe working conditions. Automatic lubricators are used to ensure:

- a) Worker safety, and
- b) The correct amount of lubricant is applied to the bearing at specifically required intervals.

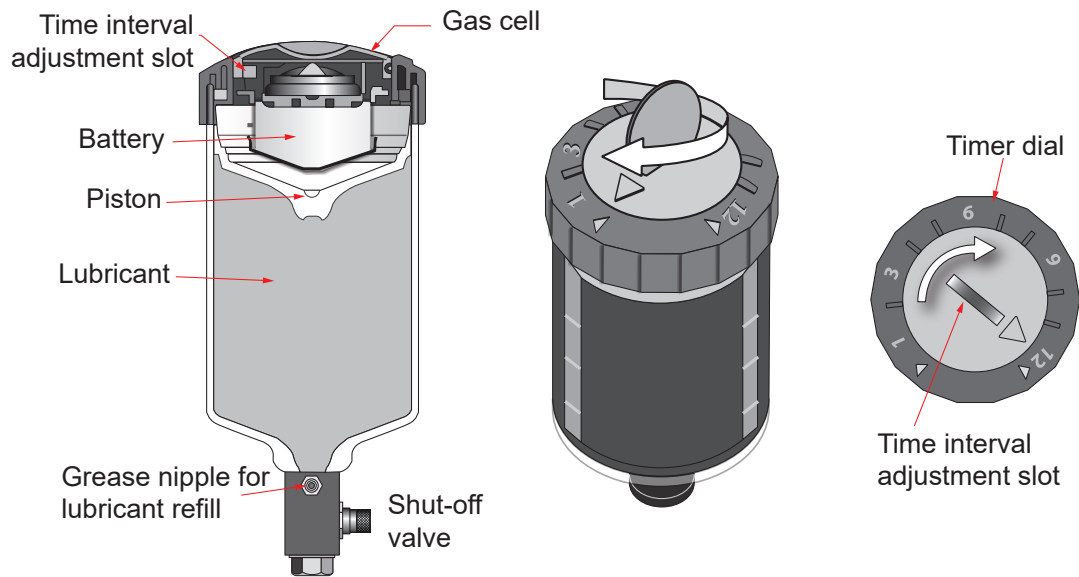
Multi point and single point automatic lubricators can be attached directly to the bearings. These small grease-filled canisters are charged with propellant gas. They automatically deliver the correct amount of grease to single or multiple lubrication points over a set time period.

Figure 14(a) shows a single point automatic lubricator supplying lubricant to a bearing. Figure 14(b) provides the basic components of a single point automatic lubricator and an illustration for setting lubrication intervals.

**Figure 14 – Single Point Automatic Lubricator**



(a)



(b)



## OBJECTIVE 4

*Describe how to clean and replace roller and ball type bearings.*

### CLEANING ANTI-FRICTION (BALL AND ROLLER) BEARINGS

Depending upon operating conditions, an oil lubricated bearing may need to be cleaned annually. A grease lubricated bearing, however, may need to be cleaned less often.

The best method to clean the bearing is to remove it from the shaft and dismantle it. If this is not possible or convenient, the bearing may be cleaned without dismantling.

#### Cleaning Without Dismantling

If removal of the end covers is possible:

1. Make sure all dirt has been removed from the outside of the bearing and the surrounding parts.
2. Remove the end covers, and spray a solvent into the bearing to flush out old lubricant and sludge.
3. Spray light lubricating oil into the bearing.
4. Replace the end covers and refill the bearing with the normal lubricant, either oil or grease as the case may be.

If it is not possible to remove the end covers:

1. Remove the drain plugs and drain the old lubricant.
2. Replace the plugs and fill the bearing with solvent.
3. Run the machine without load for a short period.
4. Stop the machine and remove the plugs to drain the solvent together with the loosened sludge and impurities. Repeat Steps 1 to 4 until only clean solvent drains from the bearing.
5. Fill bearing with light oil and run the machine again for a short period to remove any traces of solvent.
6. Drain off the light oil, and fill the bearing with its normal lubricant.

#### Cleaning by Dismantling

The most effective method to clean a bearing is to dismantle and remove it from the shaft. This way, the bearing can be thoroughly cleaned. In addition, it can be fully inspected for signs of wear or failure.

Care must be taken to avoid damage to the bearing when dismantling it. All dirt must be cleaned from the outside of the bearing and the shaft. The bearing should not be removed from the shaft by hammering directly on the inner or outer race.

As shown in Figure 12, the balls or rollers move in the races, which are rings. Frequently, the inner race is press-fitted on the shaft. Occasionally, the outer race is press-fit into the bearing housing. In either case, to prevent the bearing from being damaged, the force applied to remove the bearing must ONLY be applied to the press-fit race.

Some bearings have inside or outside snap-rings or circlips that secure the bearing in place. Snap rings must be removed prior to removing the bearing.

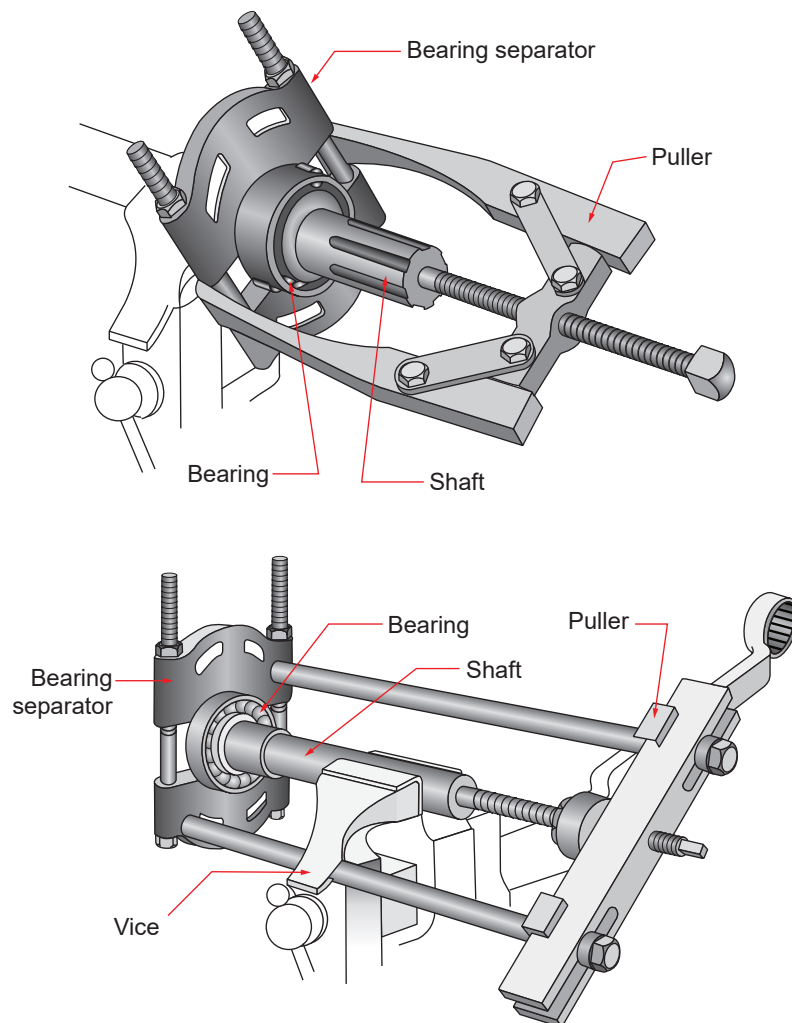
The best method to remove the bearing, especially if the bearing is to be used again, is to use a bearing puller. Figure 15 illustrates two different puller designs.

When using a bearing puller, the puller plate (also known as a bearing separator) must be positioned so that the pressure is evenly applied upon the press-fitted race and no load is exerted on the shield or separator. After the bearing has been removed, it should be soaked for a period of 12 to 16 hours in a container of clean solvent. It should then be rotated by hand while submerged in the solvent until all lubricant and impurities have been removed.

Never blow out the bearing with compressed air, as this will sandblast the polished bearing surfaces.

After removing the bearing from the solvent, it should be immersed in light oil and rotated by hand in order to coat all parts with the lubricant. The bearing can then be checked for roughness by slowly rotating it by hand. Roughness is usually a good indication that the bearing is no longer serviceable.

**Figure 15 – Bearing Pullers**



The bearing is also inspected visually for the following defects:

- Pitting or flaking of balls, rollers, or races
- Cracked balls, rollers, races, shields, or separators
- Rusting or corrosion
- Discoloration indicating overheating

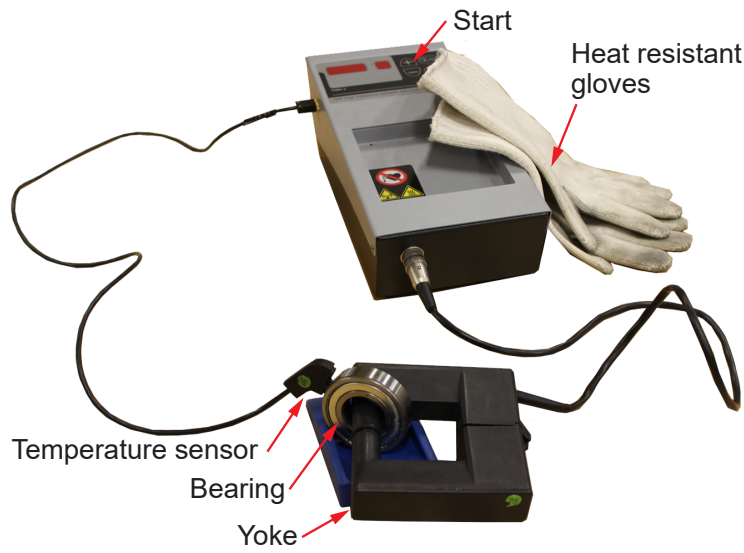


If the bearing is found to be in satisfactory condition, it can be reinstalled in the machine. If it is not immediately required, it can be stored. The proper way to store the bearing after it has been cleaned is to dip it in rust preventer and wrap it in greaseproof paper.

## Installing a Bearing

Before installing a bearing on a shaft or in housing, it is essential that the shaft or housing be absolutely clean. This ensures that the bearing can be pressed into place without scoring or scratching.

**Figure 16 – Induction Heater**



The entire bearing may be heated in an oil bath, a specialized hotplate, or with a specialized induction heater to prepare a bearing for installation on a shaft, shown in Figure 16, by expanding the bearing evenly. Never heat a bearing with a welding torch or propane torch, as these will produce uneven heating and distortion of the bearing. The ideal temperature for expanding a bearing to be installed on a shaft is between 80 and 100°C. Any hotter can damage the bearing material (hardness or structure).

To use the induction heater (as shown in Figure 16):

1. Slide the bearing onto the yoke.
2. Attach the temperature sensor.
3. Adjust the temperature set point.
4. Start the unit.
5. Once the bearing is at the set temperature, the unit will shut off, and on newer models will demagnetize the bearing. Using clean heat resistant gloves, remove the bearing and slide onto the shaft quickly until it seats firmly against the shoulder on the shaft.
6. Keep the special heat resistant gloves for bearing installation only, so that new bearings do not get contaminated.

## Re-Applying Grease

When first adding grease after cleaning an antifriction bearing, it should not be filled more than one-third full. More than this amount will result in excessive drag or fluid friction that will produce overheating. Care must be taken to ensure that dirt does not enter the bearing when applying the grease. The proper grease for the service conditions must be used.



## OBJECTIVE 5

*Explain the causes of bearing failure.*

### CAUSES OF ANTI-FRICTION BEARING FAILURE

Ball and roller bearings, even when properly maintained and lubricated, will eventually fail due to metal fatigue. However, certain detrimental operating conditions can cause premature bearing failure. Some of these conditions are discussed below.

#### Poor Quality, Incorrect, or Old Lubricant

If a lubricant, such as grease, forms a hard mass within the bearing, the rollers or balls will not be free to move and the bearing will wear. Also, hard pieces of lubricant will be pressed into the bearing surfaces producing flaking and pitting.

#### Improper Fitting

When a bearing is pressed into place on a shaft, if the force is applied through the balls or rollers, the surface under the balls or rollers will be indented or nicked. This condition is known as **brinelling** (or “true brinelling”), which will accelerate bearing failure.

An improper fitting procedure will also cause cracking or splitting of the bearing race. This splitting may be due to forcing the bearing onto a shaft that is too large.

Failure due to improper fitting may also be due to uneven force application to the race during installation.

#### Misalignment

Misalignment of a shaft will cause uneven loading of the bearing, which results in flaking of surfaces and excessive wear.

#### False Brinelling

**False brinelling** occurs in stationary bearings subjected to vibration. It produces indentations resembling brinelling in the race surfaces that contact balls or rollers.

#### High Operating Temperatures

Usually, anti-friction bearings can withstand operating temperatures up to 120°C. Above this, the metal tends to soften and excessive wear will result. It is advisable to control bearing temperatures to the manufacturer’s recommendations when possible. The generally accepted maximums are in the range of 65°C to 70°C, unless otherwise stated.



## CHAPTER SUMMARY

This completes the discussion on the types of bearing lubrication. Being familiar with the features and types of bearings, their care and maintenance is vital for the proper and safe operation of the lubrication system. Some of the important concepts for Power Engineers in their day-to-day activities were described as follows:

- a) Boundary and fluid film lubrication
- b) Construction and operation of thrust bearings
- c) Basic procedure to clean and replace ball and roller type bearings
- d) Causes of bearing failures.





## UNIT SUMMARY

This concludes the unit on lubrication and bearings. The following are the important areas discussed:

- a) Lubricant purposes.
- b) Classes and types of lubricants.
- c) Lubricant properties.
- d) Additives used.
- e) Lubricant selection criteria.
- f) Types of bearings and how to properly maintain them.
- g) Description and construction of thrust, sleeve, roller, and ball bearings.
- h) Bearing failure causes.
- i) Cleaning and replacing roller and ball type bearings.

This information is critical for preserving equipment integrity and maintaining its efficiency. It is the responsibility of the Power Engineer to protect the plant owner's investment and the lives of workers by understanding and applying this knowledge.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.









4th Class Edition 3.5 • Part B

# UNIT B-1

## KNOWLEDGE EXERCISES AND UNIT GLOSSARY

Chapter 1	Lubrication Principles	U1-9
Chapter 2	Types of Bearings and Lubrication	U1-11
Unit B-1	Unit Glossary	U1-13







## Chapter 1 (Cont.)

### Objective 2

3. Differentiate between solid and semi-solid lubricants. Give several examples of each.

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4. List the three classes of liquid lubricant. Briefly describe how mineral oil is produced from a fractionation tower.

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### Objective 3

5. List the different properties of lubricating oil. What are the properties desirable for oil intended for refrigeration compressors? What are the properties desirable for oil intended for steam turbines? Explain these choices.

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## KNOWLEDGE EXERCISES – CHAPTER 2

Name: \_\_\_\_\_ Date: \_\_\_\_\_

Instructor: \_\_\_\_\_ Course: \_\_\_\_\_

### Objective 1

1. Differentiate between boundary and fluid film lubrication.

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### Objective 2

2. Briefly describe the construction of a sleeve bearing. Why is it important to have oil grooves in bearings?

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### Objective 3

3. What is the purpose of a thrust bearing? Describe the construction and operation of a collar thrust bearing.

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## UNIT B-1 GLOSSARY

Term	Definition
<b>Antifriction bearing</b>	A bearing comprised of two pieces of metal that are separated by rolling elements.
<b>Babbitt</b>	A white bearing metal of non-ferrous material. It can contain several tin-based alloys, mainly copper, antimony, tin, and lead.
<b>Ball bearing</b>	An anti-friction bearing comprised of spherical metallic balls travelling between two metallic races.
<b>Bearing</b>	A low friction device for supporting and aligning a moving part.
<b>Boundary lubrication</b>	Refers to lubrication where the surfaces are separated by only a microscopic film thickness of the lubricant.
<b>Brinelling (also known as true brinelling)</b>	Brinelling is the formation of indentations caused when a bearing is pressed into place on a shaft, if the force is applied through the balls or rollers. The indentations cause rough operation and premature bearing failure.
<b>Eductor horn</b>	A venturi shaped air mover that uses compressed air as the working medium. As the compressed air is directed through the Venturi, it draws more air through the open end and exhausts the air it out at the larger end.
<b>False brinelling</b>	False brinelling occurs in stationary bearings subjected to vibration. It produces indentations in the surfaces that have contact with the balls or rollers and it resembles true brinelling.
<b>Fire point</b>	The temperature at which an oil produces enough vapour to continuously support combustion.
<b>Fixed oil</b>	A lubricant of animal or plant origin, which cannot be further distilled.
<b>Flash point</b>	The temperature at which a flammable liquid produces sufficient vapour to momentarily support combustion.
<b>Floc point</b>	The temperature at which paraffin precipitates from an oil.
<b>Fluid film lubrication</b>	Also called “flood lubrication,” occurs when the lubricating film between surfaces is thick enough to completely separate the surfaces. This condition will exist only if the bearing clearance space is flooded with oil and if the moving surface in the bearing is in continual motion.
<b>Grease</b>	A semi-solid lubricant, comprised of an oil and a thickening agent (soap).
<b>Kingsbury trust bearing</b>	A tilting pad type thrust bearing, similar to a Michell thrust bearing.
<b>Lubricant</b>	A material placed between two surfaces, to reduce friction.
<b>Lubrication</b>	The use of a lubricant to separate surfaces that move relative to each other, and which would otherwise make contact.
<b>Michell thrust bearing</b>	A bearing that locates the axial position of a turbine rotor. It consists of a collar on a shaft with white metal faced pads mounted on either side.
<b>Molybdenum disulfide</b>	A solid compound of molybdenum and sulfur, used as a lubricant or a lubricant additive, due to its low coefficient of friction.
<b>Oil ring</b>	In a bearing, a loose fitting ring that turns on a rotating shaft and hangs into an oil reservoir. As the ring turns, it picks up oil and transfers it to the shaft and bearing.
<b>Polyol ester oils</b>	A synthetic compressor lubricant, compatible with hydrofluorocarbon refrigerants.
<b>Pour point</b>	The temperature below which a liquid ceases to flow.



Term	Definition
<b>Roller bearing</b>	An anti-friction bearing comprised of cylindrical metallic rolling elements, travelling between two metallic races.
<b>Saybolt seconds universal (SSU)</b>	A measurement of oil viscosity, as determined using a Saybolt Viscosimeter.
<b>Saybolt viscometer</b>	A device that measures viscosity, based on the time in seconds for a fluid to discharge through a fixed orifice under the influence of gravity.
<b>Soapstone</b>	A soft, slippery metamorphic rock, used as a lubricant or lubricant additive due to its low coefficient of friction.
<b>SSU</b>	See <i>saybolt seconds universal</i> (SSU).
<b>Steam cylinder oil</b>	A high viscosity oil used in high heat applications such as steam engine cylinders. It can have a “viscosity weight” of 600 to 1000.
<b>Synthetic oils</b>	High-purity lubricating oil made artificially by breaking down and then rebuilding petroleum molecules.
<b>Viscosity</b>	The measure of the internal friction or the resistance to flow of a liquid (thickness).
<b>Viscosity index</b>	The measure of how much the viscosity of an oil changes with temperature.