N3 Mechanotechnology

Gateways to Engineering Studies - Chris Brink

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Gateways to Engineering Studies

Mechanotechnology N3

Chris Brink

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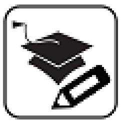
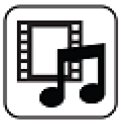
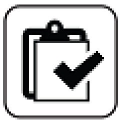
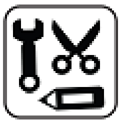
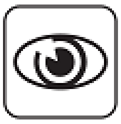
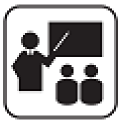
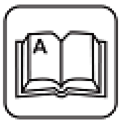
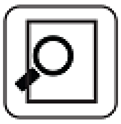
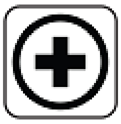
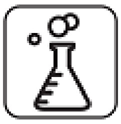
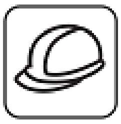
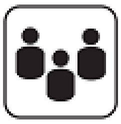
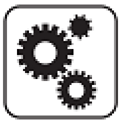
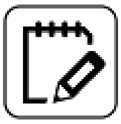
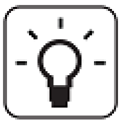
	Assessment / Activity		Multimedia
	Checklist		Practical
	Demonstration/ observation		Presentation/ Lecture
	Did you know?		Read
	Example		Safety
	Experiment		Site visit
	Group work/ discussions, role-play, etc.		Take note of
	In the workplace		Theoretical – questions, reports, case studies, etc.
	Keywords		Think about it

Module 1

Materials and Material Processes

Learning Outcomes
On the completion of this module the student must be able to:

- Explain the differences between ferrous and non-ferrous metals, and alloys
- Briefly describe the properties of metals
- State the purpose of colour coding and identify metals according to the colour coding system
- Briefly describe the purpose of basic heat treatment processes
- Briefly compare the effect that "work-processing" has on metals
- Differentiate between the main groups of polymers
- Identify and differentiate between basic characteristics of polymers, related to non-laboratory tests

1.1 Introduction

In engineering, most parts and components are made from metal. Metal has been used to make tools as far back as the Iron age. For thousands of years man has been tampering with metal processes, which today include the modern heat treatment processes.

In this module we will discuss properties of metals, heat treatment of plain carbon steels and polymers.

The study of engineering materials is very important and the choice of the correct material for a particular job demands a thorough knowledge of the properties of each material. (See **Table 1.1**) The main properties are as follows:

Properties of metals	Description
Tenacity	The power to resist fractures by a stretching force, and is possessed by all materials.
Flexibility	The property of bending a flexible material is a material that remains bent after the applied pressure has been removed.

Molecular structure	The definite structure the molecules take up in order to maintain the characteristics of the material.
Compressibility	The power to resist fracture by a force that tends to shorten the material.
Hardness	The property of resisting abrasion by scratching, cutting or rubbing.
Ductility	The property that allows a metal to withstand considerable elongation under tension before rupture. The property of ductility depends largely upon tenacity. Fairly soft materials are, as a rule, the most ductile.
Fusibility	That characteristic which certain materials have of being reduced to fluidity by heating.
Conductivity	The property of a material to convey heat or electricity from one point to another.
Malleability	Metals which have the property of being permanently extended in all directions by hammering or rolling without cracking, are said to be malleable
Elasticity	The property of a material of returning to its original shape after the applied force has been removed. This force may be applied to produce bending, stretching, compression or twisting.
Brittleness	The character shown by a hard material of snapping off or crumbling to pieces when a sudden force or shock is applied.
Toughness	The character of a material of resisting fracture when subjected to continuous bending forces in opposite directions.

Table 1.1 Properties of engineering materials

1.1.1 Colour coding of metals

There are a large variety of different metals that are manufactured. There metals need to be identified and distinguished from each other. **Table 1.2** shows the standardised colour code laid down by the South African National Standards (SANS).

These colour codes are commonly used in industry and will be identified accordingly.

METAL	COLOUR CODE
Low carbon steel	Orange
High carbon steel	Brown
Case hardened steel	Orange
Low alloy steel	Light purple
Structural steel	Red
Steel for pressure vessels (containers)	White
Stainless steel	Black
Carbon steel	Black
Silicon chrome steel	Black
Cast Steel	Blue
Pipeline steel (pipes and tubes)	Grey
Steel for lifting machines	Green

Table 1.2 SANS standardised colour codes for metals

1.2 Ferrous metals

Metals are generally divided into two groups: metals containing iron and metals which contain no iron. Metals which contain iron are called **ferrous metals** and those which contain no iron are called **non-ferrous metals**.

Ferrous metals generally fall into the following groups:

- Cast iron
- Low, medium and high carbon steel, and
- Alloy steels.

1.2.2 Iron and steel

Iron and steel play a very important part in our daily lives; there are few applications where iron or steel are not used. In the transport and building industry, defence, machining and agriculture, the use of iron and steel is of great importance.
Iron (also called ferrite) is obtained from iron ore, which is mined in the form of rocks and then smelted in a blast furnace together with an amount of coke and limestone. Pure iron is a soft metal and has a crystalline structure, with very few practical uses.

Steel is an alloy of iron and carbon, with the carbon content varying up to 1, 5% in some steels. Plain steels are classified according to their carbon content. The higher the carbon content, the harder the steel, but the less shock-resistant it is.

Metals can be divided into ferrous and non-ferrous metals. Ferrous metals are metals that have iron as the basic constituent of the metal.

1.2.3 Plain carbon steels

Steel may be classified according to the amount of carbon present - into three groups. (See **Table 1.2**)

- Low carbon steel (mild steel),
- Medium carbon steel, and
- High carbon steel.

Carbon level	Description	Properties	Uses
Low carbon steel	The carbon content is between 0,05% and . 0,3%. Properties	• Does not respond to normal heat treatment • Can be case-hardened.	Bolts and nuts, rivets, shafting and screws
Medium carbon steel	The carbon content is between 0,3% and 0,75%. Combination of high strength and toughness.	Combination of high strength and toughness	Drop forgings, connecting rods, gears and shafts.

High carbon steel	The carbon content is between 0, 75% and 1,5%. High carbon steel has a low and high carbon range. The low range varies from 0, 75% to 1% and is used for hand-tools, forging dies and springs. High carbon steel with a carbon content of between 1% and 1,5% is used for cutting tools, dies and razor blades.	• Very hard • Wear-resistant • Can be hardened • Shock-resistant	Cutting tools, dies and razor blades.

Table 1.2 Plain carbon steels

1.3 Non-ferrous metals

Non-ferrous metals are metals that do not contain iron as a basic metal. The important non-ferrous metals are given in the following paragraphs. **Table 3.3** shows details of the various non-ferrous metals

Non-ferrous metals	Description	Characteristics	Uses
Copper	This metal is easily distinguished by its red colour. It is mined as copper ore and then smelted and purified. Although it becomes harder when hammered or drawn, it can be annealed again by heating it and then quenching it in water. Copper is a very useful metal but its alloys are even more widely used in the engineering fields.	• It is soft, ductile and malleable • It is corrosion-resistant • It has high thermal and electrical conductivity.	Pipes, soldering irons, wire, electrical equipment and stays
Zinc	Zinc is mined as zinc ore and then smelted and purified.	• It is brittle at normal temperatures but can be malleable when heated • It is corrosion-resistant • It has good castability and machinability.	Galvanising, automobile components, bathroom fittings and zinc sheets.
Tin	Tin is mined as tin stone and is silvery white in colour.	• It has a low melting point • It is very malleable • It is corrosion-resistant	Galvanising, automobile components, bathroom fittings and zinc sheets.
Lead	Lead is mined as lead ore, and then smelted and purified.	• It has a low melting point • It is very heavy and soft • It is a poor conductor of electricity and heat • It is very malleable • It offers good resistance to corrosion	Pipes, cables, bullets, battery plates and as an alloying element.

Aluminium	Aluminium is obtained from alumina which is prepared from a mineral called bauxite.	• It is light, malleable, ductile and soft • It is corrosion-resistant, and forms an oxide film on the surface • It is a good conductor of heat and electricity.	Automotive components, castings, cooking utensils and electrical cables.
Antimony	Antimony is a silver-white metal that is obtained by smelting and purifying antimonite.	• It is very hard and brittle • It is good alloying metal • It is a poor conductor of heat and electricity.	Alloyed with copper, tin and lead to produce anti-friction metal; bullets and toys.

Table 1.3 Non-ferrous metals

1.4 Non-ferrous alloys

A non-ferrous alloy is produced by alloying two or more non-ferrous metals with one another to produce a new non-ferrous alloy metal. **Table 3.4** shows details of the various non-ferrous alloys.

Non-ferrous alloys	Description	Characteristics	Uses
Brass	Alloy of copper(+ 70%) +zinc(+ 30%).	• It is corrosion resistant • It is soft and ductile.	Electrical appliances, marine construction, gears, bushes and household appliances.
Bronze	Alloy of copper(+ 88%) +tin(+ 12%), or copper (+ 88%) + tin (+ 10%) + zinc (+ 2%)	• It is corrosion-resistant • It is wear-resistant.	Castings, water fittings, bushes, valves, marine construction.
Duralumin	Alloy of aluminium + copper + magnesium + silicon.	• Can be heat-treated, • Has high tensile strength, • It is corrosion-resistant.	Aircraft and automobile components.
White metal	Alloy of copper+ tin + antimony, or copper + tin + antimony + lead.	• It is a low anti-friction alloy • It is corrosion-resistant • It is wear-resistant • It has low strength and is soft.	Aircraft and automobile components
Solder	Alloy oflead + tin.	It has a low melting point.	Soft soldering, electrical repairs and coating of metals

Table 1.4 Non-ferrous alloys

Activity 1.1

1. List FIVE properties of metals.
2. Define the terms ferrous and non-ferrous metals.
3. Ferrous metals generally fall into THREE groups, list them.
4. Name FOUR non-ferrous alloys.
5. Name FOUR non-ferrous metals.
6. Define the following terms:
   - Maleability
   - Ductility
   - Toughness
   - Compression
7. Give TWO properties of high-carbon steel.

1.5 Heat-treatment processes: carbon steels

Heat treatment is a process whereby the physical properties of a metal may be changed by heating it and then cooling it.

Toughness, hardness and wear resistance are a few of the characteristics that can be obtained through various heat-treatment processes.

To obtain these characteristics, processes such as hardening, quenching, annealing, tempering, normalising and casehardening are used. Before any heat treatment is done, consider the following:

- The chemical composition of the steel,
- Heating time,
- Heating temperature,
- Carbon content,
- Quenching media, and the purpose for which the steel is required.

1.5.1 Hardening

The purpose of the hardening process is:

- To harden the steel
- To enable the steel to resist wear
- To enable it to cut other metals.

Hardening consists of two stages:

- Heating
- Cooling.

The steel is heated to a predetermined temperature (Ac1), depending on the carbon and alloy content of the steel. To obtain a maximum hardness, the steel is then quenched rapidly in a quenching medium. Care must be taken to ensure that the steel is properly and evenly heated at a slow rate.

The critical temperatures have a direct bearing on the hardening process, for hardening will not occur before the temperature reaches the decalescence (cooling- off) point.

The steel should be quenched rapidly before the temperature reduces to the decalescence point. This sudden cooling of the steel by plunging it into a bath of water ensures the forming of a new structure, giving the steel its property of hardness.

Precautions to be observed when hardening steel:

- The steel must not be overheated
- The steel must be heated at a uniform rate
- The steel must be heated thoroughly
- It must not be quenched at higher temperatures than those specified.

Effects of incorrect heating:

- If the steel has been overheated, it is described as "burnt", i.e. oxides have been formed and the steel is ruined. If only slightly overheated, it can be partially restored by annealing the steel and starting afresh, but this will not give the same results as when correctly heated from the start.
- There is irregular expansion and the steel is liable to crack when quenched, due to the hotter portions expanding more rapidly.
- Cracks and distortion occur when hardened due to uneven contraction when quenched.
- Distortion and a greater risk of cracking

1.5.2 Quenching

The purpose of quenching is to harden the steel. Every tool or workpiece requires special consideration with regard to the best quenching method if cracking and distortion are to be minimised.

To transform the austenite into martensite efficiently, the cooling must be done rapidly, which involves the problems of cracking and distortion. There are two reasons for this:

- When the steel is quenched, it generally does not contract uniformly.
- When the steel cools through the critical range, an expansion of the inner core takes place while the outer layer is suddenly cooled.

It is therefore advisable to quench long work lengthwise, and flat work edgewise. The normal quenching media used are oil, water, salt solutions and air blast.

1.5.3 Annealing

Annealing has the opposite effect to hardening. The purpose of annealing is:

- Annealing of carbon steel is done to soften the steel so that machining processes may be carried out more easily.
- Annealing also helps to relieve internal stresses that have been set up during previous working of the metal.
- It also refines the grain structure and reduces brittleness.

Method

Annealing is done by slowly heating the steel too slightly above its critical temperature.

It is then left at this temperature to "soak" for a short time, before being allowed to cool very slowly.

The cooling should be done inside the furnace. The heat must be turned off as soon as the metal has "soaked" long enough. Keep the door of the furnace closed; the workpiece then cools down with the furnace.

1.5.4 Tempering

Many tools are too brittle after hardening, and must be tempered.
The purpose of the tempering process is:

- To remove stresses and strains induced by the hardening process,
- To reduce brittleness, and
- To introduce toughness.

Method

The steel is heated in its hardened state to a suitable tempering temperature, which is lower than that for hardening. The steel is then quenched in water or oil. The temper temperature depends on:

- The carbon content of the steel, and
- The purpose for which the steel is to be used.

1.5.5 Normalising

The purpose of normalising is:

- To refine the structure of steel
- To obtain a uniform structure in the steel,
- To remove strains and stresses caused by cold working, and
- To improve the strength of the steel.

Method
The steel is slowly heated to a suitable non-alising temperature, which depends on its carbon content. The steel is then allowed to cool in air.

1.5.6 Case-hardening
This is a method to produce a hard surface skin on the steel. The hard outer skin will present a good wearing surface, while the strong and tough inner core can resist all the shock-loads to be carried by the work piece.

The depth of case depends on the case-hardening substance used, as well as on the type of treatment applied. Steel with a carbon content of below 0, 3%, such as mild steel, will not respond to heat treatment because of its low carbon content.

Activity 1.2

1. Name the TWO materials/additives to form the alloy brass.
2. Explain TWO Heat-treatment processes of carbon steels
3. Give any TWO reasons for tempering steel.
4. Explain the hardening process of steel.

There are methods to achieve this:

1. Carburisation (box method)
2. Cyaniding (bath method)
3. Nitriding (gas method).

- **Pack carbunsing** (box method of casehardening)

This method is used when a large number of small workpieces such as coupling pins, bushes and links have to be case-hardened.

Method
The bottom of the cast-iron rectangular box is covered with a layer of the carburising mixture, then a layer of the articles to be case-hardened, then another layer of the carburising mixture as shown in **Figure 1.1**.

The articles must be apart from one another and surrounded by the mixture. It is closed, the lid sealed, and then placed in a furnace. The temperature used for casehardening is usually between 850°C and 950°C, depending on the thickness of the outer skin required.

The box with its contents is left to soak in the furnace for three to five hours. After the carburising process, the articles are removed from the box, and quenched in oil or water to supply a soft core and a hard outer skin of approximately 1mm.

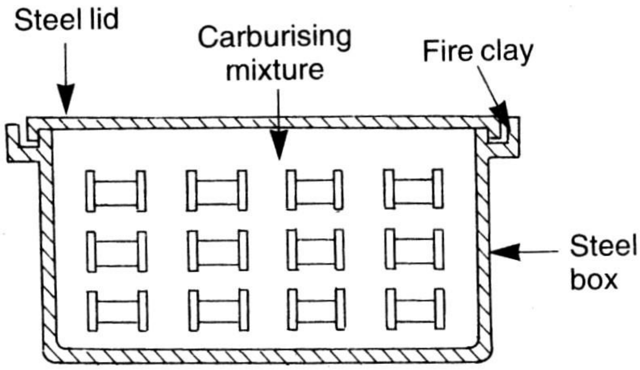


Figure 1.1 Pack carburising

- **Cyaniding** (bath method of case-hardening)

This method is also called liquid carburising. It consists of heating sodium cyanide or potassium cyanide in a suitable container, normally made of nickel-chrome steel.

The components to be case-hardened are placed in a basket and immersed in the molten cyanide solution and boiled for approximately 20 minutes at a temperature of about 750°C, depending on the depth of case required.

The components are then removed from the container and quenched in water. The normal depth of the case is approximately 1mm. Care should be taken when immersing the components, since the cyanides are very poisonous. (See **Figure 1.2**)

- **Advantages of the cyanide method**

1. Compared to pack carburising, it takes less time (packing of articles takes time)
2. Less distortion of components
3. Corrosion resistance higher due to nitrogen content
4. Greater hardness
5. More articles can be done simultaneously, and
6. Smooth surface finish after treatment.

- **Disadvantages of the cyanide method**

1. Cyanide is highly toxic and therefore requires careful handling
2. Only small articles like bolts, pins and spindles can be case-hardened.

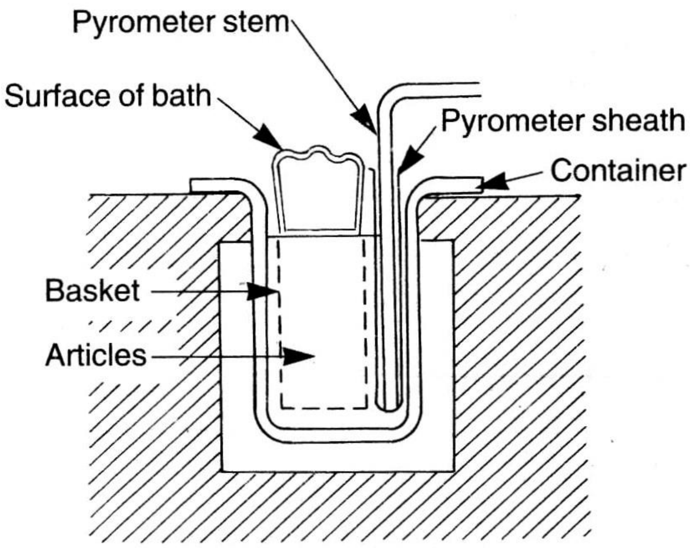


Figure 1.2 Cyaniding

- **Gas carburising (nitriding)**

This is a surface-hardening process used for low carbon steel. The articles are heated in a carburising furnace with a nitroge..: nous atmosphere. The furnace is sealed to prevent air (oxygen) from coming into contact with the articles.

Ammonia gas (a chemical combination of nitrogen and hydrogen), is admitted through a special inlet so that it will come into contact with the articles. Provision is made for the used gas to be discharged through an outlet. (See **Figure 1.3**)

At increased temperatures the ammonia gas is split into its two elements (hydrogen and nitrogen). The nitrogen then combines with the surface of the steel to form nitrides whose hardness exceeds that achieved by any carbon-hardening process.

Nitride steel is hard enough to cut glass; this cannot be said of carbon case-hardened steel. The soaking period takes about five hours at temperatures of between 550°C and 650°C.

- **Advantages of carburising**

1. Treatment can be done at low temperatures, there is little distortion at 550°C.
2. No harm is done to the surface of the article being treated - only slight discolouration
3. No quenching is necessary
4. Wear-resistant
5. Surface will stand temperatures of up to 500°C without losing hardness
6. Surface can just be polished after treatment.

- **Disadvantages of gas carburising**

1. Limited surface penetration
2. Special equipment is needed
3. A long treatment time is required to obtain reasonable surface penetration.

- **Prevention of carburisation**

Certain sections of the articles that are to remain soft and not be carburised, can be prevented from coming into contact with the carburising gases.

The surface or section which must not be carburised can be covered with a non-carburising material such as copper, nickel or fire clay.

Large surfaces may be covered by copper or zinc plates. The carburising mixture is then sprinkled on the uncovered sections only.

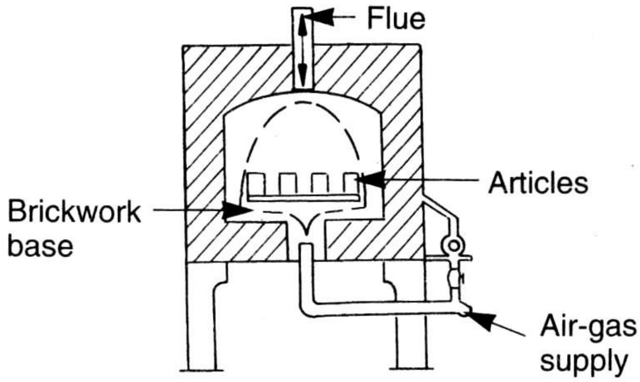


Figure 1.3 Gas carburising

1.6 Polymers

Plastic is a synthetic substance which is either manufactured from natural gases or produced as a by-product during oil refinement.

Celluloid was the first plastic material developed and it came onto the commercial market in about 1860. The first plastics were not very durable and of little use in engineering. Today, however, plastics play an indispensable role in engineering.

Plastics are ordinarily divided into two main groups, namely thermoplastics and thermosetting plastics. (Thermosetting plastics are commonly called thermosets). Although there are many types of plastics, only a brief discussion of specific aspects will be given here.

1.6.1 Characteristics of Polymers from non-laboratory tests

The majority of manufactured polymers are thermoplastic, meaning that once the polymer is formed it can be heated and reformed over and over again. This property allows for easy processing and facilitates recycling. The other group, the thermosets, cannot be re-melted. Once these polymers are formed, reheating will cause the material to ultimately degrade, but not melt.

Every polymer has very distinct characteristics, but most polymers have the following general attributes. Characteristics of Polymers:

1. Low Density.
2. Low coefficient of friction.
3. Good corrosion resistance.
4. Good mouldability.
5. Excellent surface finish can be obtained.
6. Can be produced with close dimensional tolerances.
7. Economical.
8. Poor tensile strength.
9. Low mechanical properties.
10. Poor temperature resistance.
11. Can be produced transparent or in different colours.

Other characteristics are:

1. Polymers can be very resistant to chemicals.
2. Polymers can be both thermal and electrical insulators.
3. Generally, polymers are very light in weight with significant degrees of strength.
4. Polymers can be processed in various ways.
5. Polymers are materials with a seemingly limitless range of characteristics and colours.
6. Polymers are usually made of petroleum, but not always.
7. Polymers can be used to make items that have no alternatives from other materials.
8. Polymers can be made into clear, waterproof films.

When distinguishing between different polymers the following non-laboratory tests can be performed:

- Touch (feel)
- Sound (when dropped)
- Hardness or softness (bending or stretching)
- Flame colour (burning)
- Odour (by smell when burned)

1.6.2 Thermoplastics

Thermoplastics are plastics which have the ability to repeatedly change into a plastic (semi-liquid) state. The material thus becomes soft when it is heated and can repeatedly be softened · by heat. A list of the more generally known types of thermoplastics and their characteristics and uses is given in **Table 1.5**

Thermoplastic	Characteristics	Uses
Nylon	Tough, strong and has a low coefficient of friction.	Generally used in gears, bushes ropes and washers.
Perspex	Transparent and easily machined	Used to manufacture window panes and aircraft components
PVC	Soft and non-flammable. It is a good electrical insulator and shows a good resistance to chemicals	Used to insulate electrical cables, for sewerage pipes at chemical plants. It can also be used as a floor-covering

Table 1.5 Thermoplastics

Thermoplastics are materials that are usually moulded while hot as they can be reshaped by heating. Some common thermoplastics are:

- Perpex
- Nylon
- Polyvinyl chloride (PVC)
- Polythene

1.6.3 Thermosetting plastics (thermosets)

Thermosets undergo a chemical change when they are first heated and form the final product. They cannot be softened again. The two types of thermosetting plastics which are more commonly known are given in **Table 1.6**

Thermoset	Characteristics	Uses
Bakelite	Brittle and a good electrical insulator	Used in electrical fittings such as plugs and insulators.
Epoxy resins	Strong and show excellent bonding characteristics	Used in adhesives. Epoxy resin and fibreglass are used for manufacturing boats, bodies of motor cars, containers and corrugated sheets.

Table 1.6 Thermosetting plastics

Thermosetting plastics are shaped by chemical action and harden on heating. Their molecular structure is cross linked which gives the material hardness and rigidity. Some common thermosetting plastics are:

- Epoxy resin
- Glass fibre
- Bakelite

Activity 1.3

1. Briefly describe the purpose of basic heat treatment processes.
2. State the purpose of colour coding and identify metals according to the colour coding system.
3. Differentiate between the TWO main groups of polymers. Name them and describe them.
4. List uses of each in the above question.
5. Identify and differentiate between basic characteristics of polymers, related to non-laboratory tests.

Self-Check

I am able to:	**Yes**	**No**
• Explain the differences between ferrous and non-ferrous metals, and alloys		
• Briefly describe the properties of metals		
• State the purpose of colour coding and identify metals according to the colour coding system		
• Briefly describe the purpose of basic heat treatment processes		
• Briefly compare the effect that "work-processing" has on metals		
• Differentiate between the main groups of polymers		
• Identify and differentiate between basic characteristics of polymers, related to non-laboratory tests		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 2

Internal Combustion Engines

Learning Outcomes

When you have completed this module, you should, from given drawings, be able to:

1. Make comparisons, and describe the respective basic operations of petrol and diesel engines of:
   - o Four stroke: Inlet- compression- power- exhaust
     - – Method of fuel supply, and maintenance costs
     - – Diagrammatic layout of carburettor and injection fuel systems
   - o Two stroke: Blow and exhaust valves
     - – Advantages and disadvantages (petrol and diesel)
2. Use petrol and diesel engines in:
   - Open, confined, hazardous locations, with regard to:
     - – Exhaust fumes, noise, general maintenance

2.1 Introduction

In this module, you will learn more about internal combustion engines. You will learn about the respective basic operations of petrol and diesel engines.

Any engine which uses the heat produced by a fuel to develop mechanical power is called a heat engine. One in which the fuel is burnt inside the engine is called an internal combustion engine. Internal combustion engines can use any one of a variety of fuels such as petrol or diesel.

If petrol is used it must be vaporised and mixed with a suitable quantity of air in the correct proportions. This is done by a carburettor, which is fitted to the outer end of the inlet port. The inlet and exhaust ports are normally closed by valves which are mechanically opened at the correct times.

With diesel as well as petrol engines a distinction must be made between four-stroke and two-stroke operation. To perform a full cycle of operations (changing the contents of the cylinder and effecting the combustion) the four-stroke engine requires four, and the two-stroke engine requires two strokes of the piston.

2.2. Introducing internal combustion engines

We use the term 'internal combustion engine' to refer to an engine that burns fuel inside the engine. This type of engine is designed to transform the chemical energy of burning petrol or diesel into mechanical energy inside its structure.

An internal combustion engine works in the following way: a small amount of high-energy fuel, like petrol, is put into a small, closed space and ignited. This causes a lot of energy to be released as gas, which is converted into mechanical energy. This mechanical energy can be used to do tasks such as drive a motor car, truck, lawn mower, chain saw, scooter, power boat, and so on.

SOMETHING TO KNOW

Fossil fuels are fuels that have been formed over millions of years, from the shells, skeletons and tissue of dead animals and plants. Fossil fuels are a non-renewable resource. This means that when we have used up all the supplies of fossil fuels, we cannot replace them. For this reason, we must use fossil fuels like crude oil (used to make diesel and petrol) and coal as efficiently as possible, and try not to waste them.

Internal combustion engines are commonly used for convenience because they are fairly easy to refuel. But their exhaust emissions cause air pollution, and their use of fossil fuels is a cause for concern in terms of resource depletion.

There are two main types of internal combustion engines, namely a spark ignition and a compression ignition engine:

3. The spark ignition engine is also called a petrol engine, because it uses petrol as fuel. The petrol is mixed with air and compressed by pistons, and the air-fuel mixture is ignited by sparks from spark plugs.

4. The compression ignition engine is also called a diesel engine, because it usually uses diesel as fuel. First the air is compressed, causing it to heat up. Then the diesel is injected and the mixture of hot diesel and fuel ignites spontaneously.

Both types of engine convert the fuel energy into mechanical (moving) energy. This energy moves pistons up and down, inside the cylinders. The pistons are connected to a crankshaft and the up and down movement makes the crankshaft turn.

SOMETHING TO KNOW
There are also external combustion engines, but they are not very common these days. For example, old fashioned trains and steam boats used an external combustion engine. The fuel, which could be wood, coal or oil, is burned outside the engine, to create steam. The steam creates motion inside the engine. External combustion engines need a lot of fuel. It is hard to imagine a motor car with an external combustion engine!

2.3 Spark ignition engine

We mentioned that spark ignition (SI) engines use petrol as fuel. The fuel is mixed with air in a small space, and ignited with the spark of a spark plug.
The important thing is to ignite the fuel at exactly the right or optimum time. This will allow the expanding gases to do the most amount of useful work. If the ignition system fires at the wrong time, a lot of fuel will be wasted. **Figure 2.1** illustrates a spark ignition engine.

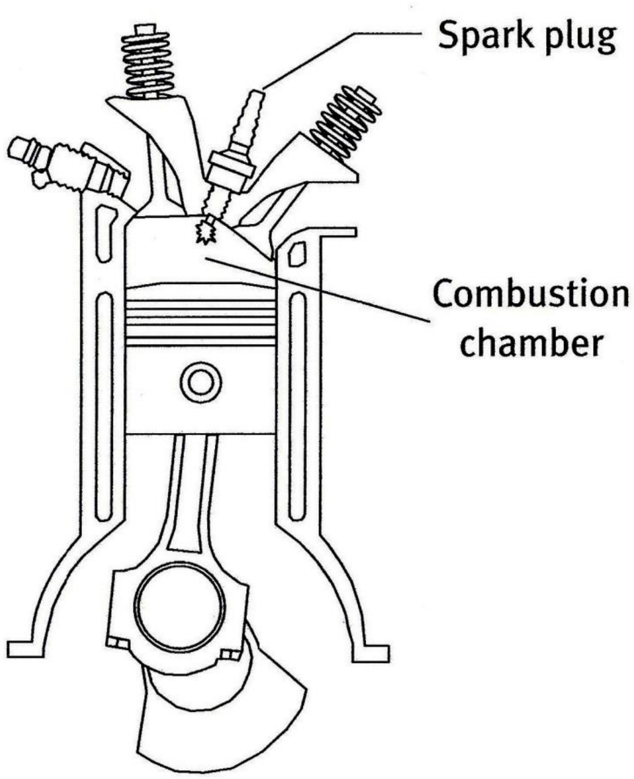


Figure 2.1 Spark ignition engine

2.4 Compression ignition engine

You already know that a compression ignition engine is an internal combustion engine that uses diesel as fuel.

Some years ago, diesel engines were mostly used only for heavy vehicles, but they are becoming more popular for light motor vehicles now. This is partly because they use relatively less fuel.

The most important thing to note about the diesel engine is that it uses the heat of compressed air to ignite the diesel. Look at **Figure 2.2** to see the parts of the diesel engine, and then read the explanation that follows.

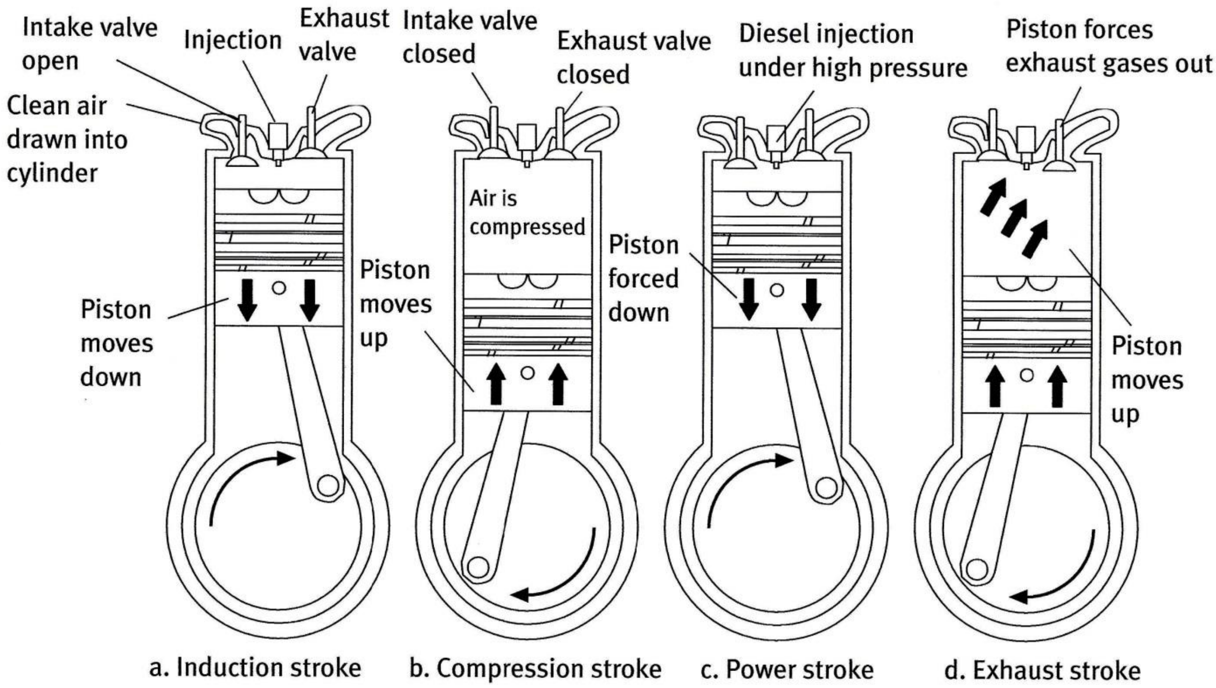


Figure 2.2 Compression ignition engine

At first the engine only draws air into its cylinders on the down stroke (known as the induction stroke).

In the second stroke of the cycle, the air is compressed. This causes the temperature of the air to increase, just before the third stroke of the engine, called the power stroke, the fuel is injected into the hot air.

It ignites and this causes the piston to be driven down and deliver power to the engine. During the fourth and last stroke, the exhaust gases are emitted through the exhaust valve.

You will learn more about the different strokes when we discuss four-stroke engines later in this module.

2.5 Comparing energy efficiency of spark ignition (SI) engines and compression ignition engines

Energy efficiency refers to how well an engine converts its fuel source into mechanical energy or torque. In a spark ignition (SI) engine or petrol engine, the spark plug ignites a mixture of fuel (petrol) and air to create an explosion in the combustion chamber. This explosion then drives the piston down.

However, when a petrol engine is running at low revolutions, a small vacuum is created in the combustion chamber immediately after the explosion that drives the piston. This is because less fuel and air get used at lower revolutions. The vacuum that is created acts like a brake and it reduces the efficiency of the engine.

A compression or diesel engine does not use spark plugs. Instead, it uses compression to ignite the mixture of fuel (diesel) and air. Each time the piston pushes to the top of the combustion chamber, the air and fuel mixture explodes. This is a more efficient method of combustion, especially at low revolutions.

SOMETHING TO KNOW
At high revolutions, exactly the correct amount of fuel and air combine. This makes the SI engine very efficient when the engine is working hard at high revolutions.

However, just because compression engines are generally more energy efficient than SI engines does not necessarily make them more popular. This is because each type of engine has its own advantages and disadvantages.

2.5.1 Advantages of spark ignition (petrol) engines

Here is a list of the **advantages** of spark ignition (petrol) engines:

- They are usually smaller and tighter than diesel engines. A petrol engine will give more power than a diesel engine of the same size.
- They need less torque in order to start.
- They do not produce such dirty fumes.

2.5.2 Advantages of compression ignition (diesel) engines

Here is a list of the advantages of compression ignition (diesel) engines:

- They use less fuel than a petrol engine doing the same work, because they are more efficient and because diesel provides more energy than the same volume of petrol.
- They do not have an electrical ignition system, which makes them more reliable, particularly under damp conditions.
- They generally last longer than a petrol engine, because they have fewer parts than a petrol engine, and also because diesel is a better lubricator than petrol.
- Diesel is a safer fuel than petrol, because it is less volatile.

SOMETHING TO KNOW
Diesel engines on average use about 30% less fuel than petrol engines.

2.6 Parts and function of a SI internal combustion engine

Let us find out about the different parts of the SI internal combustion engine, and how they work together, look at the diagram in **Figure 2.3 (a)** , and then read the section that follows.

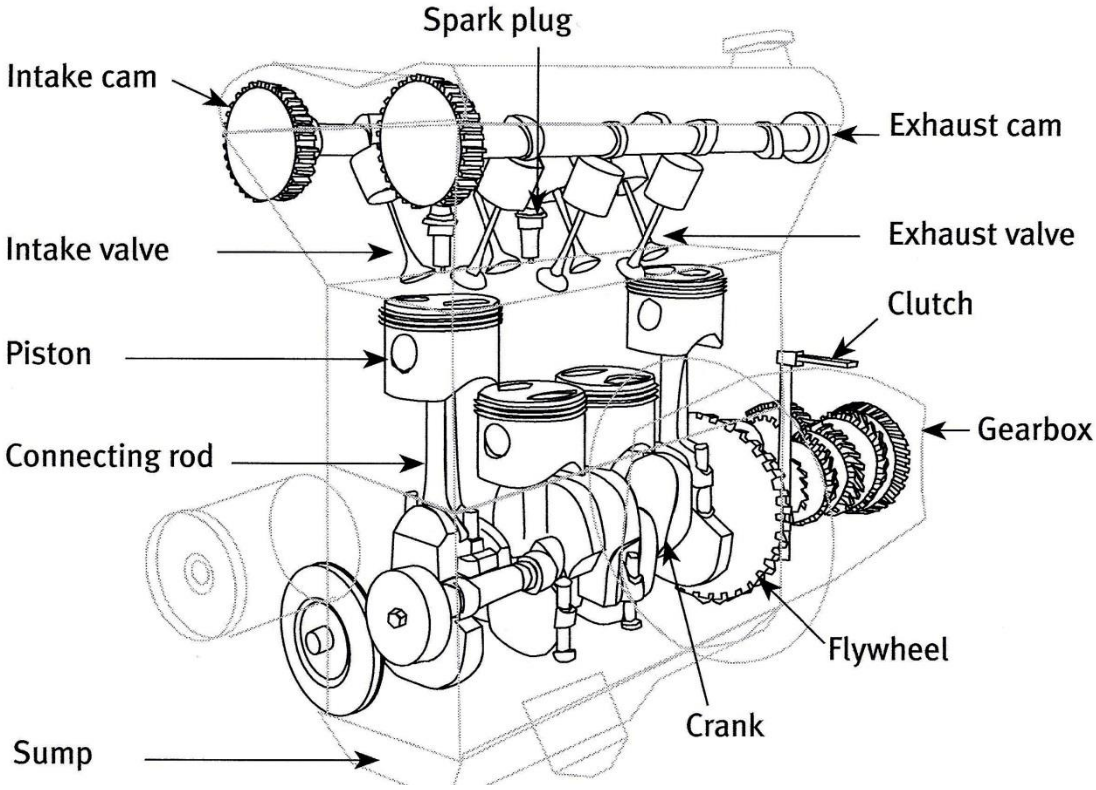


Figure 2.3 (a) Parts of the internal combustion engine

Most of the motor cars, trucks, taxis and other vehicles that we use every day have a four-stroke combustion cycle to convert fuel energy into mechanical energy. We also get two-stroke engines, and you will learn more about them a bit later in this module.

Look at **Figure 2.3 (a)** to see the components of a basic internal combustion engine. The engine is made up of two main parts which are bolted together. The upper part is the cylinder head, and the bottom part is the cylinder block.

The cylinder head contains the combustion chamber, two valve ports, and at least two valves for each cylinder. In motor cars and trucks, there can be four, six or eight cylinders.

2.6.1 Cylinder block

The cylinder block is normally in one piece with the crankcase. The cylinder block contains the cylinders and it also carries the crankshaft. You can see a cylinder block in the picture in **Figure 2.3 (b)**.

The starter motor is what sets the engine in motion. The starter motor is usually operated electrically, and it turns the flywheel and the crankshaft. This starts the pistons and the connecting rods moving up and down. The petrol and air is mixed in the carburettor and drawn into a combustion chamber at the top of each cylinder. The spark plug provides the spark that ignites the mixture of air and fuel in the combustion chamber. You will learn more about spark plugs later in this module.

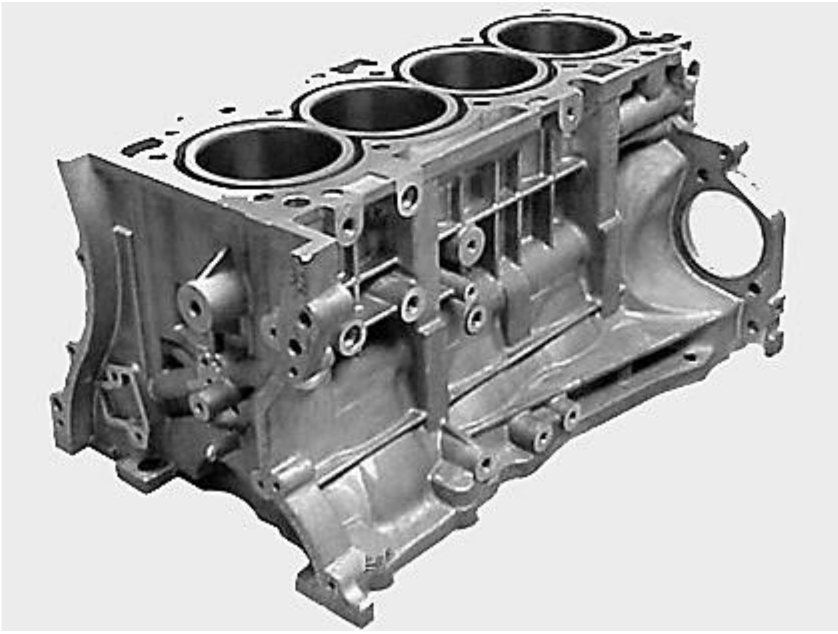


Figure 2.3 (b) A typical cylinder block

The pistons are cylindrical in shape, and move up and down inside the cylinders. The pistons compress the mixture of air and fuel, which is then ignited by the spark of the spark plug.

As the mixture burns, it expands. This forces the piston down on its power stroke. The piston rings provide a sliding seal between the outer edge of the piston and the inner edge of the cylinder, as you can see in the picture on the left.

The piston rings are important for two reasons: they prevent the fuel/air mixture and the exhaust from leaking into the sump during compression and combustion; and they prevent excessive amounts of oil in the sump from leaking into the combustion area. They also support the heat transfer from the pistons to the cylinder walls.

The connecting rod connects the piston to the crankshaft. This rod has bearings, called the 'big end' at the crank and the 'small end' at the piston end (see **Figure 2.4(a)**, allowing its angle to change as the piston moves and the crankshaft rotates. The up-and-down movement of the pistons is converted into rotary (turning movement) to drive the crankshaft. The crankshaft's rotation makes the engine go through its cycle. You will learn more about what happens in the cycle when we discuss four-stroke engines in more detail a bit later. The crankshaft transmits power to the wheels via the clutch, gearbox and final drive.

Figure 2.4 (a) Note the two 'ends' of the connecting rod

2.6.2 Gudgeon pin

In internal combustion engines, the gudgeon pin (as shown in **Figure 2.4 (b)** connects the piston to the connecting rod and provides a bearing for the connecting rod to pivot upon as the piston moves.

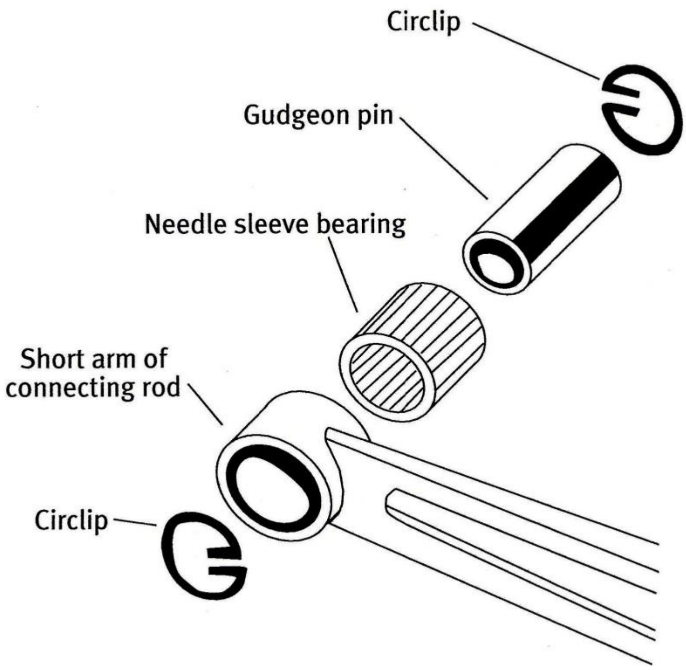


Figure 2.4 (b) The gudgeon pin connects the piston to the connecting rod

The gudgeon pin is typically a forged short hollow rod made of a steel alloy of high strength and hardness that may be physically separated from both the connecting rod and piston or crosshead.

The gudgeon pin has to operate under some of the highest temperatures experienced in the engine, with difficulties in lubrication due to its location, while remaining small and tight so as to fit into the piston diameter and not unduly add to the reciprocating mass.

2.6.3 Camshaft

The camshaft is driven via a chain, belt or gears, exactly at half the speed of the crankshaft. The camshaft activates the inlet and exhaust valves at the top of each cylinder. The inlet manifold lets air and fuel (only in a SI engine; diesel is injected into a combustion chamber) in, and the exhaust or outlet manifold lets exhaust gas out.

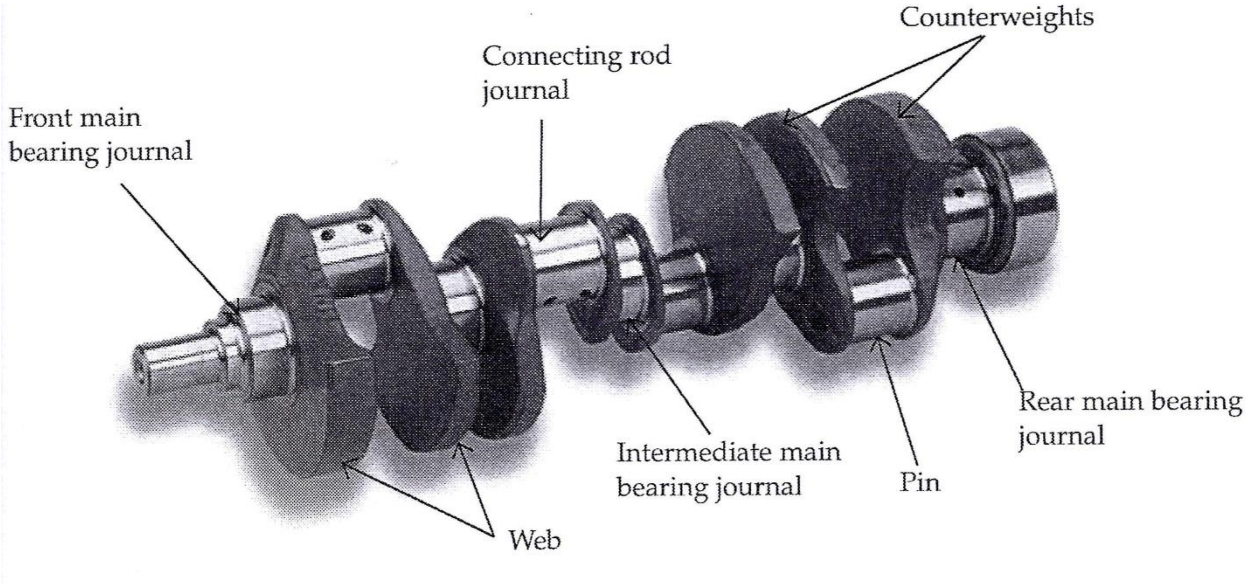


Figure 2.5 The camshaft

During compression and combustion, both these valves are dosed, so that the combustion chamber is completely sealed. The sump is attached to the bottom of the crankcase. It acts as a reservoir for lubricating oil. You will learn more about lubricating oil later in this module.

2.7 Comparing two-stroke and four-stroke cycle SI engines

Internal combustion engines can work on two strokes or four strokes. These days, four-stroke engines are more common, and are used to power most motor cars and trucks.

Two-stroke engines are used to power machines such as chain saws, small motor cycles, lawn mowers, motor boats, jet skis and so on. We will look more closely at the two-stroke and four-stroke engine, and compare the advantages and disadvantages of each of these.

2.8 Four-stroke engine

2.8.1 Operation of four-stroke petrol engine

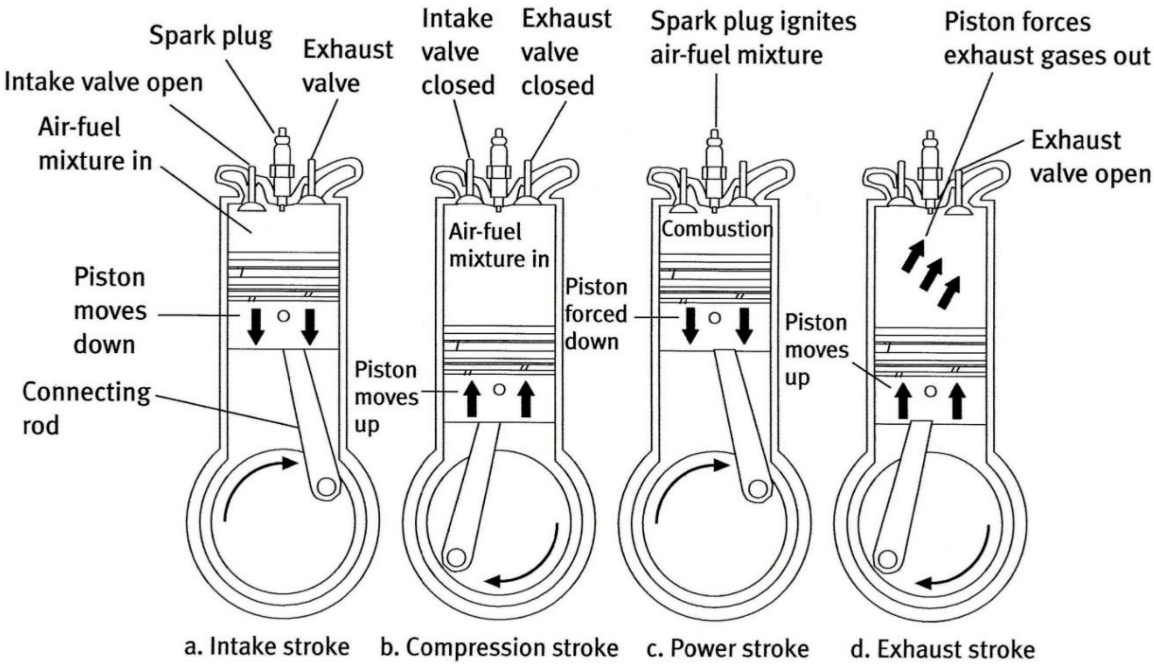


Figure 2.6 The operating cycle of a four-stroke spark ignition engine

Starting with the piston at top dead centre as the crankshaft rotates; the method of operation is as follows.

1. Induction stroke

The piston moves down the cylinder with the inlet valve open and the exhaust valve closed, filling the cylinder with a mixture of petrol vapour and air. As the piston moves down a vacuum is created in the chamber which lets the mixture of petrol vapour and air in through the open inlet valve.

2. Compression stroke

The piston moves up the cylinder with both valves closed, compressing the mixture into the combustion chamber at the top end of the cylinder.

3. Power stroke

Near the end of the compression stroke, an electric spark is made to jump across a small gap on a sparking plug screwed into the end of the cylinder. This spark ignites the petrol vapour which burns very rapidly, heating the gas in the cylinder to a high temperature and considerably increasing the pressure.

The pressure forces the piston down the cylinder, both valves remaining closed. As the piston reaches close to top dead centre, the spark plug ignites the mixture. The pressure in the cylinder increases and forces the piston downwards.

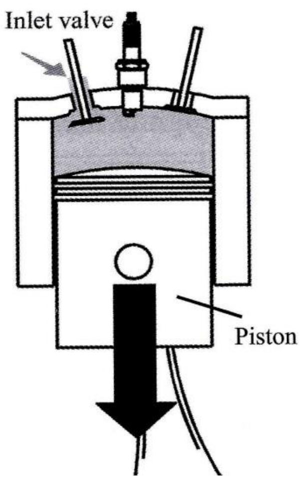


Figure 2.7 (a) Induction stroke

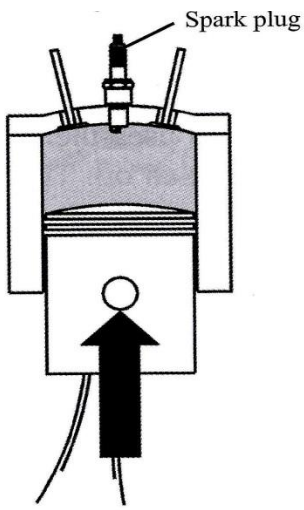


Figure 2.7 (b) Compression stroke

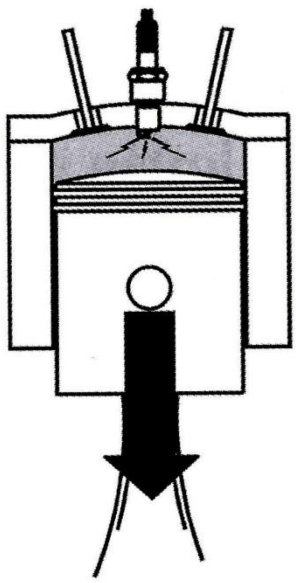


Figure 2.7 (c) Induction stroke

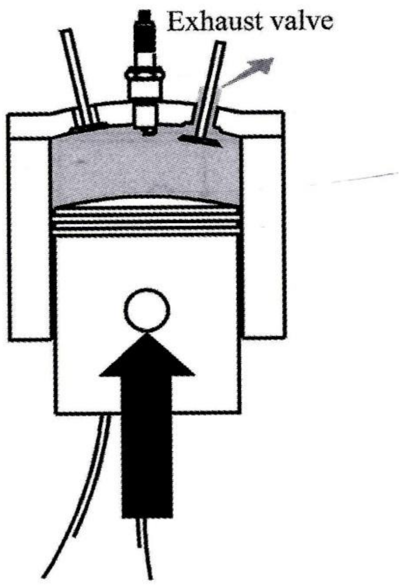


Figure 2.7 (d) Compression stroke

4. Exhaust stroke

The piston returns up the cylinder with the inlet valve still closed but the exhaust valve open, expelling the burned gases from the cylinder. This is the exhaust stroke.

At the end of this stroke the exhaust valve closes and the inlet valve re-opens ready for the next induction stroke. As the piston moves upwards the exhaust valve opens and the spent mixture is forced through the valve and thus clearing the chamber.

2.8.2 Operation of four-stroke diesel engine

A diesel engine uses the same principles as the petrol engine, although the fuel is not petrol but oil. There is also no spark plug to ignite the fuel mixture. See **Figure 2.8 (a) to (d)**.

Air is compressed to a high degree, and as it heats up, the diesel is sprayed into the cylinder and the ensuing explosion forces the piston downwards. The oil is supplied through injectors.

Diesel engines are more expensive to produce because they have to compress their air/fuel mixture to about twice the pressure of that in a petrol engine and so require a more robust construction, but they tend to last longer.

1. **Induction stroke**

The piston is moving downwards creating a partial vacuum in the cylinder. Pure air is forced through the open inlet port by atmospheric pressure.

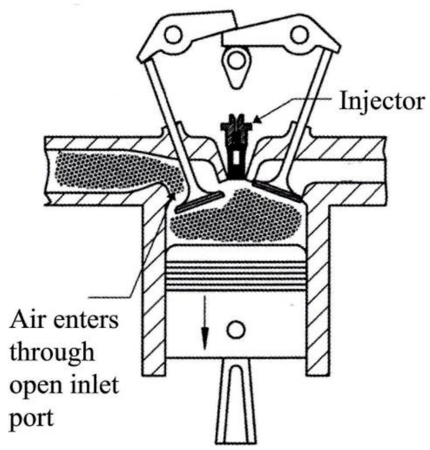


Figure 2.8 (a) Induction stroke

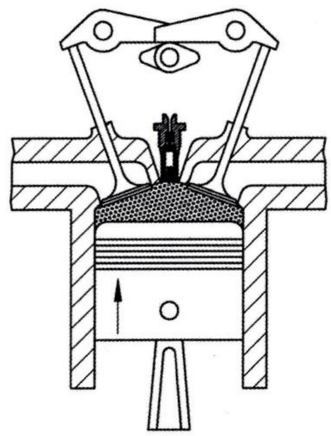


Figure 2.8 (b) Compression stroke

2. **Compression stroke**

Both valves are closed which compresses the air in the cylinder due to the upward moving piston. With compression the air temperature is raised.

3. **Power stroke**

Just before the piston reaches top dead centre, the injector sprays diesel oil under pressure into the cylinder which has both ports closed. The diesel ignites with the hot air and the resulting explosion forces the piston downwards

4. **Exhaust stroke**

The exhaust port opens and the upward moving piston forces the burnt gases out of the cylinder.

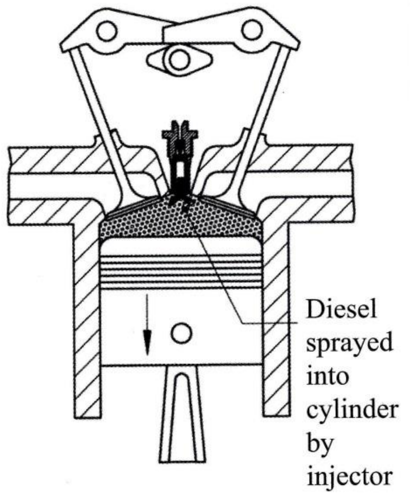


Figure 2.8 (c) Induction stroke

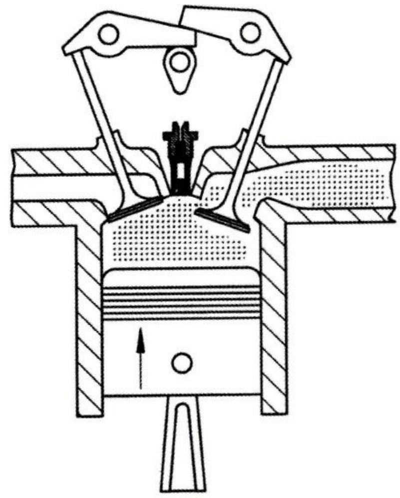


Figure 2.8 (d) Compression stroke

2.9 Two-stroke engines

Two-stroke engines are a type of internal combustion engine that completes the entire thermodynamic cycle in two strokes or movements of the piston (i.e. one single revolution of the crank).

They do this by using the beginning of the compression stroke and the end of the combustion (power) stroke at the same time, to perform intake and exhaust. Two-stroke engines are used in diesel engines, for example, some large industrial machines and construction machines.

2.9.1 Operation of two-stroke petrol engine

In **Figure 2.9** you can see a diagram of a two-stroke engine and its different parts, look at it carefully as you read how it works.

In the two-stroke engine, the spark plug fires once on every cycle or revolution. The air and fuel in the combustion chamber get compressed, and when the spark plugs fires, the mixture of fuel and air ignites.

This causes an explosion, which forces the piston downward. As the piston moves down, it compresses the air and fuel mixture in the crank case. As the piston gets to the bottom of its stroke, the exhaust outlet is uncovered.

The pressure in the cylinder forces most of the exhaust gases out of the cylinder. But, each time the fuel and air mixture is sucked into the combustion chamber, some of it escapes un-burnt through the exhaust outlet.

You will often notice a slick of oil in the water around a two-stroke boat motor, which is caused by the escaping fuel. This wasted fuel is one of the reasons why a two-stroke engine is less efficient than a four-stroke engine.

The two-stroke engine is simpler mechanically than the four-stroke engine. The two-stroke engine delivers one power stroke every two strokes instead of one every four.

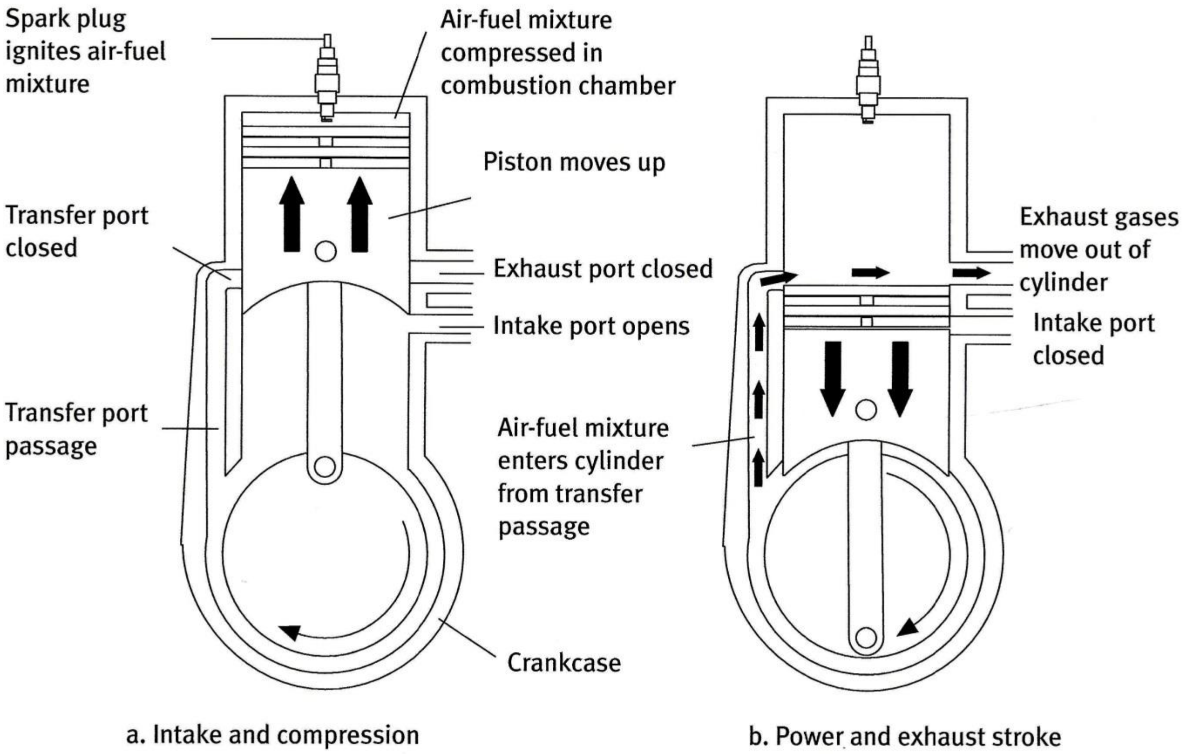


Figure 2.9 The two-stroke cycle in a spark-ignition engine

A two-stroke engine therefore revolves (revs) more quickly than a four-stroke engine and develops its power from fast revving. However, because fast-revving engines get very hot, they are not suitable for heavy vehicles such as motorcars or trucks.

1. **Power stroke**
   - The exhaust port is covered by the upward moving piston.
   - The air fuel mixture in the chamber is ignited by the spark plug.
   - The inlet port is opened and the crank is filled with mixture.

2. **Exhaust stroke**
   - The exhaust port is uncovered by the downward moving piston.
   - The mixture in the transfer port is forced into the cylinder.
   - The exhaust gases are forced out of the cylinder by the mixture.

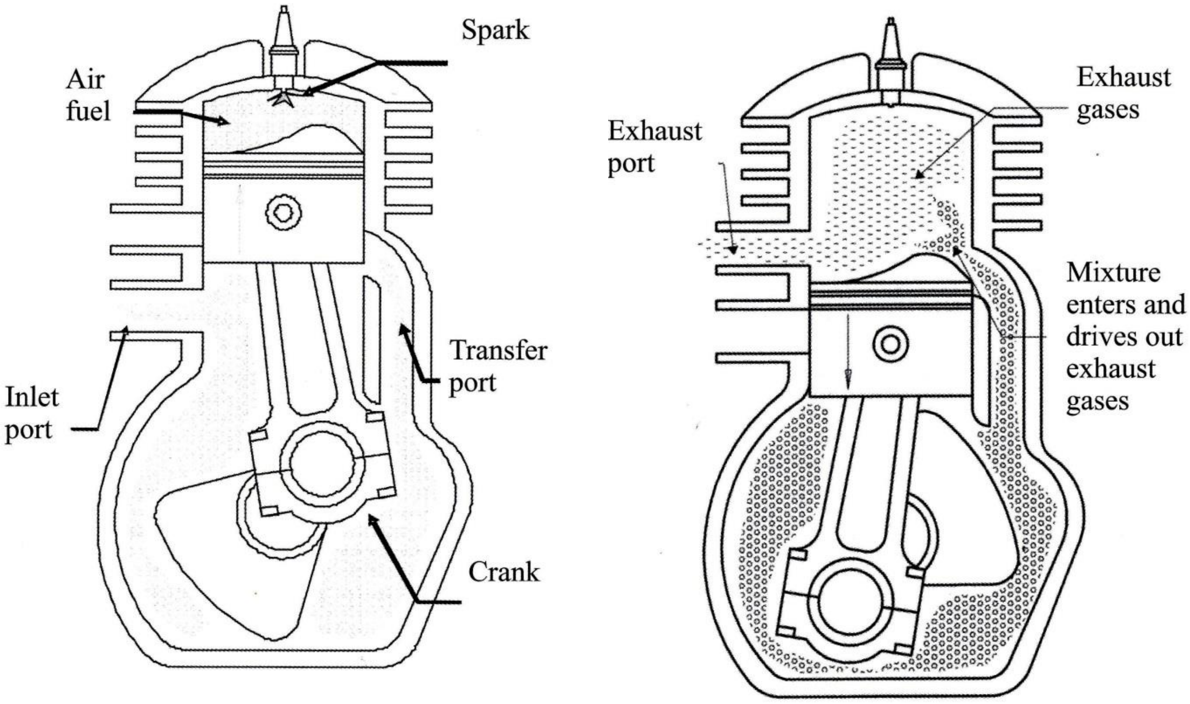


Figure 2.10 (a) Power stroke   Figure 2.10 (b) Exhaust stroke

2.9.2 Two stroke diesel engine

Figure 2.11 (a) and **(b)** show the operation of the two stroke diesel engine, low and high speed respectively.

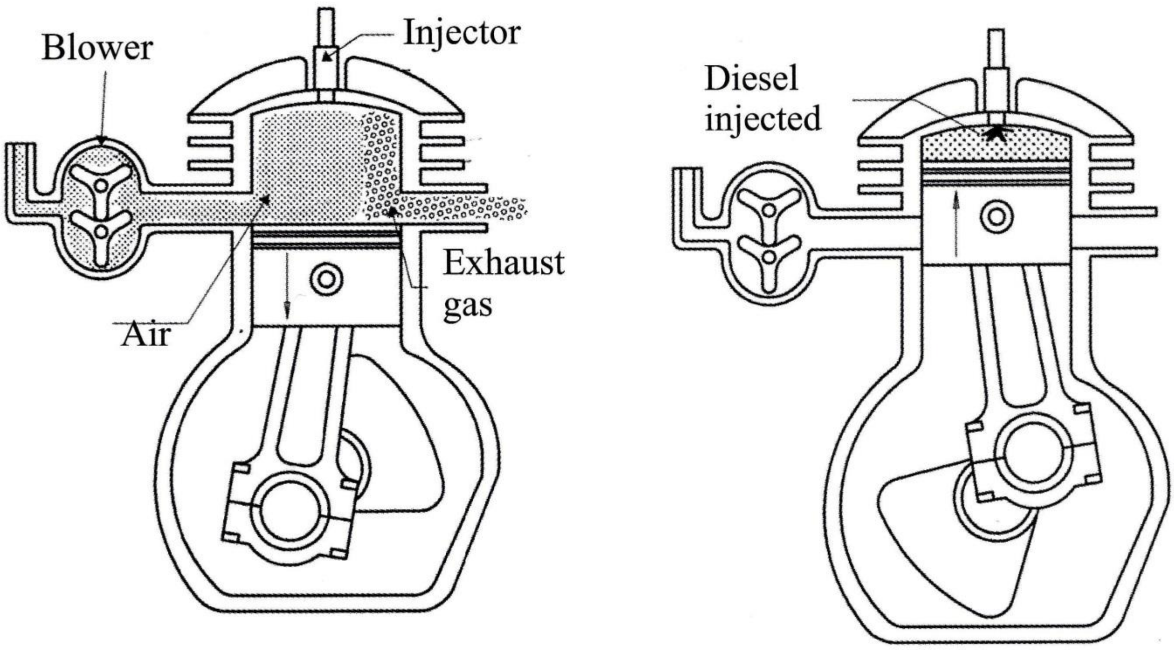


Figure 2.11 (a) Induction/exhaust stroke   Figure 2.11 (b) compression/power stroke

2.10 Energy efficiencies of two-stroke and four-stroke engines

Let's compare the advantages and disadvantages of two-stroke and four-stroke engines.

2.10.1 Two-stroke engines

- They do not have valves, so their structure is simpler, and their weight is less.
- They can produce more power than a four-stroke engine of similar size, into the same space, because there are two strokes for every revolution, so their power-to-weight ratio is higher than most four-stroke engines.
- They produce more pollution than a four-stroke engine, and does not burn fuel efficiently.
- A two-stroke engine is more expensive to run.

SOMETHING TO KNOW

Interestingly, a two-stroke marine diesel engine is one of the most efficient engines produced. In the 1950s, these engines achieved efficiencies of over 40%, and today they are probably even better.

2.10.2 Four-stroke engines

- They last longer than two-stroke engines. One reason for this is that they have a dedicated lubrication system.
- They use petrol more efficiently than two-stroke SI engines.
- They cause less pollution than two-stroke engines.
- A four-stroke engine consumes less oil than a two-stroke one.
- A four-stroke engine is cheaper to run.

2.11 Fuel distribution systems of petrol and diesel engines

Let us look at the two different fuel distribution systems, namely the carburettor and the fuel injector.

2.11.1 Carburettor

The carburettor works on Bernoulli's principle: the faster air moves, the lower its static pressure, and the higher its dynamic pressure.

The throttle (accelerator) linkage does not directly control the flow of liquid fuel. Instead, it actuates carburettor mechanisms which meter the flow of air being pulled into the engine.

The speed of this flow, and therefore its pressure, determines the amount of fuel drawn into the airstream.

Under all engine operating conditions, the carburettor must:

1. Measure the airflow of the engine
2. Deliver the correct amount of fuel to keep the fuel/air mixture in the proper range (adjusting for factors such as temperature)

3. Mix the two finely and evenly

This job would be simple if air and gasoline (petrol) were ideal fluids; in practice, however, their deviations from ideal behaviour due to viscosity, fluid drag, inertia, and so on require a great deal of complexity to compensate for exceptionally high or low engine speeds.

A carburettor must provide the proper fuel/air mixture across a wide range of ambient temperatures, atmospheric pressures, engine speeds and loads, and centrifugal forces:

- Cold start
- Hot start
- Idling or slow-running
- Acceleration
- High speed / high power at full throttle
- Cruising at part throttle (light load)

In addition, modern carburettors are required to do this while maintaining low rates of exhaust emissions.

The carburettor has three functions:

1. It atomises the fuel, in other words it converts or changes the liquid fuel into a gas or vapour.
2. It measures the correct amount of fuel and mixes it with air in the correct ratio.
3. It controls the engine speed.

The carburettor is the part of the engine where the fuel and the air are mixed. This provides a vapour which will burn and expand in the cylinder, and power the pistons. Many engines are used only intermittently, and stored between uses. These include portable generators, poker vibrators, power floats and plate compactors.

They have carburettors, which can become clogged and blocked if they are not drained before storage, because the volatives in the petrol evaporate and the remaining additives become solidified as an insoluble gum or varnish which can block jets.

TAKE NOTE
The carburetor atomises the fuel and mixes it with air, and controls the delivery of the correct mixture to the engine.

There are different types of carburettors, but most have a reservoir or float chamber, a float and needle valve which control the amount of fuel in the carburettor, jets which regulate the amount of fuel being mixed with air, a mixing chamber, a choke, and a throttle control valve. You can see a typical carburettor in **Figure 2.13**.

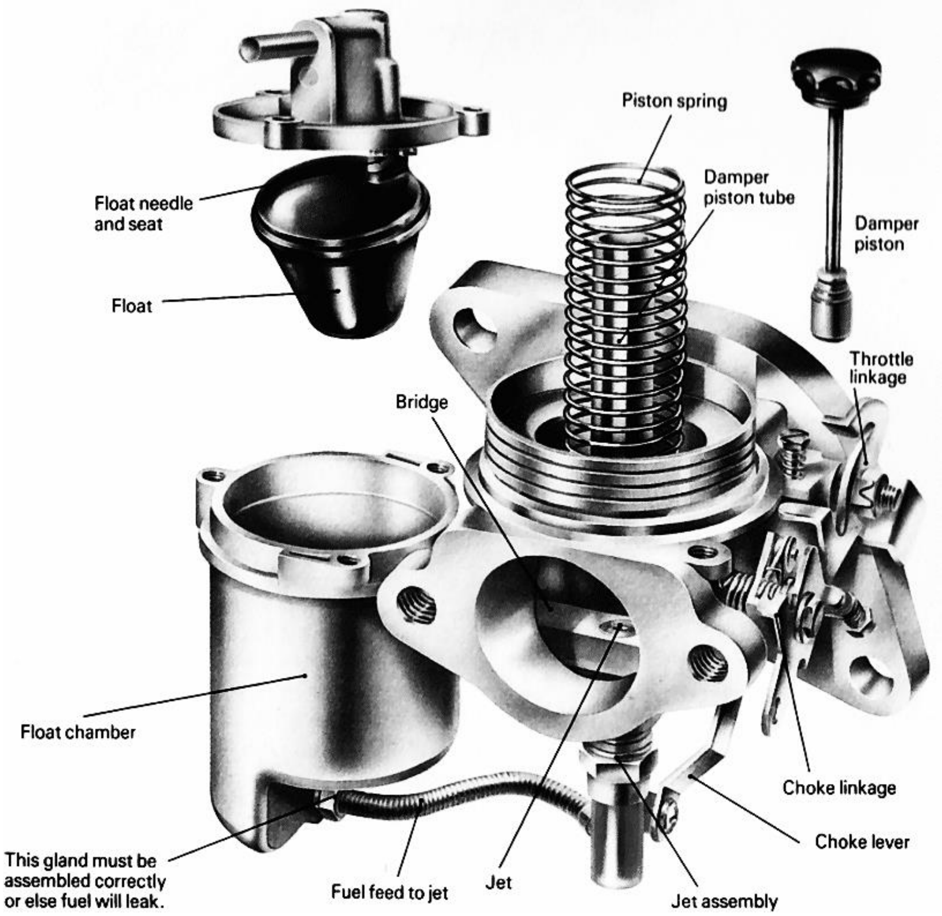


Figure 2.12 Typical carburettor cut-away sectional view

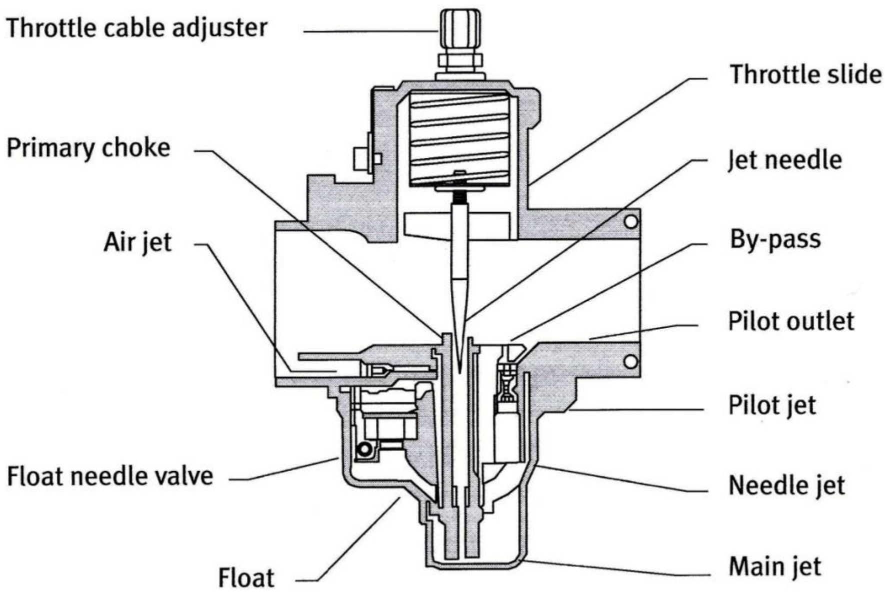


Figure 2.13 Parts of a carburettor

If the carburettor is stored full of petrol, the fuel forms layers or deposits in the carburettors float chamber and can block the jets.

Over a short period of time, the carburettor can get blocked by these fuel deposits. These deposits become a problem, because they prevent the fuel from flowing through the jets, and then the engine cannot start. To avoid this happening, you need to run the carburettor dry before storage.

To run a carburettor dry you need to completely drain the fuel tank, so that it has no fuel. Then, start and run the engine, to make sure that there is no fuel remaining in the fuel system.

2.11.2 Fuel injector

Fuel injection is a system for admitting fuel into an internal combustion engine. It has become the primary fuel delivery system used in automotive engines, having replaced carburettors during the 1980s and 1990s. A variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary difference between carburettors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburettor relies on suction created by intake air accelerated through a Venturi tube to draw the fuel into the airstream.

Figure 2.14 Fuel injector

The function of the injector is to inject the diesel fuel into the compressed air in the form of a fine spray. **Figure 2.15** shows the function of the injector.

Modern fuel injection systems are designed specifically for the type of fuel being used. Some systems are designed for multiple grades of fuel (using sensors to adapt the tuning for the fuel currently used). Most fuel injection systems are for gasoline or diesel applications.

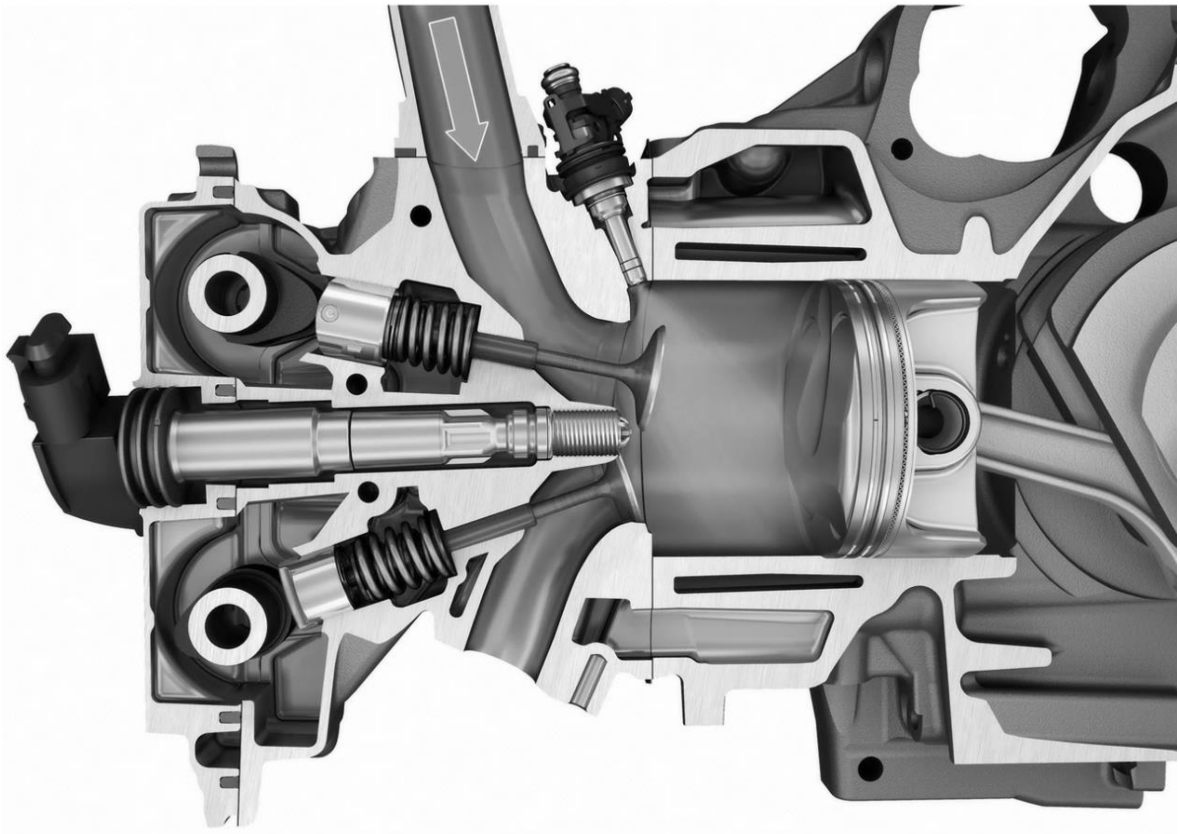


Figure 2.15 Function of the injector

Figure 2.16 shows a complete fuel injector cut-away sectional view.

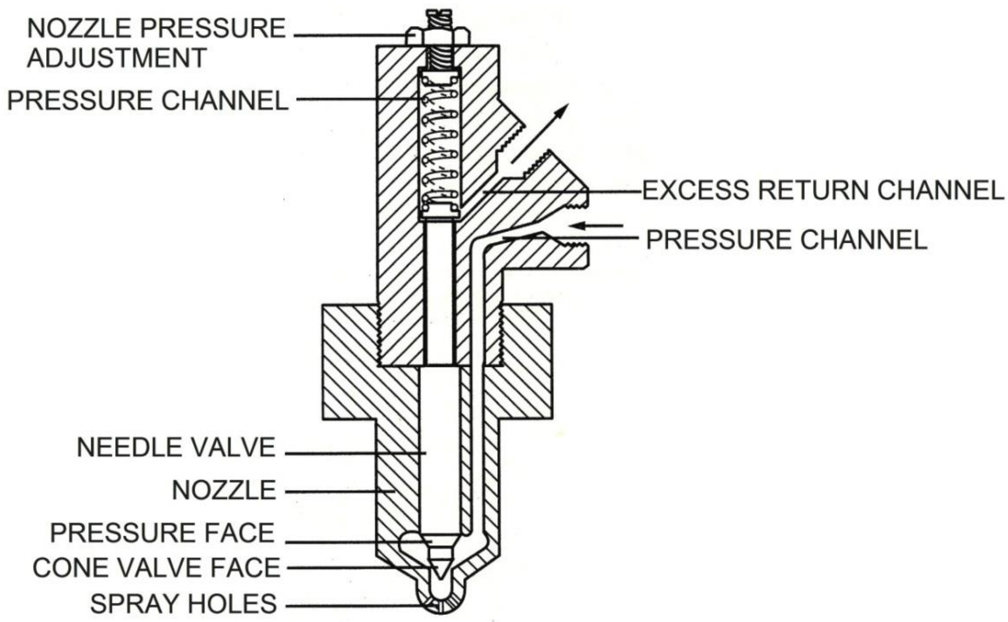


Figure 2.16 Complete fuel injector cut-away sectional view

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system is optimized. There are several competing objectives such as:

- Power output
- Fuel efficiency
- Emissions performance
- Ability to accommodate alternative fuels
- Reliability
- Driveability and smooth operation
- Initial cost
- Maintenance cost
- Diagnostic capability
- Range of environmental operation
- Engine tuning

The modern digital electronic fuel injection system is more capable at optimizing these competing objectives consistently than earlier fuel delivery systems (such as carburettors). Carburettors have the potential to atomize fuel better.

2.12 Turbo and blower

The turbo and the blower improve the efficiency of a petrol or diesel engine by increasing the volume of air forced into the cylinder. This increases the pressure in the cylinder and thus the efficiency of the engine.
Let's look at how each works.

2.12.1 Turbo

The turbo is used to obtain a higher air pressure in the cylinders of a petrol or diesel engine. The efficiency and power output of the engine depends directly on the volume of air the engine transfers per given period of time.

The purposes and functions of the turbo are:

- Increase the power output of an engine without adjusting the engine itself. Typically, an engine would have to be made larger and consequently heavier to gain power; on the other hand, a turbo charger is much smaller and lighter.
- Additionally, a turbo charger is powered by the exhaust gases of the engine, which would normally just leave the engine and vehicle unused.
- To ensure that the cylinder is filled with an intake load at a pressure that is higher than atmospheric pressure.
- To raise the compression pressure in the cylinder.
- To improve the volumetric efficiency of the engine. In other words, to make the engine more efficient without increasing the volume of its cylinders.

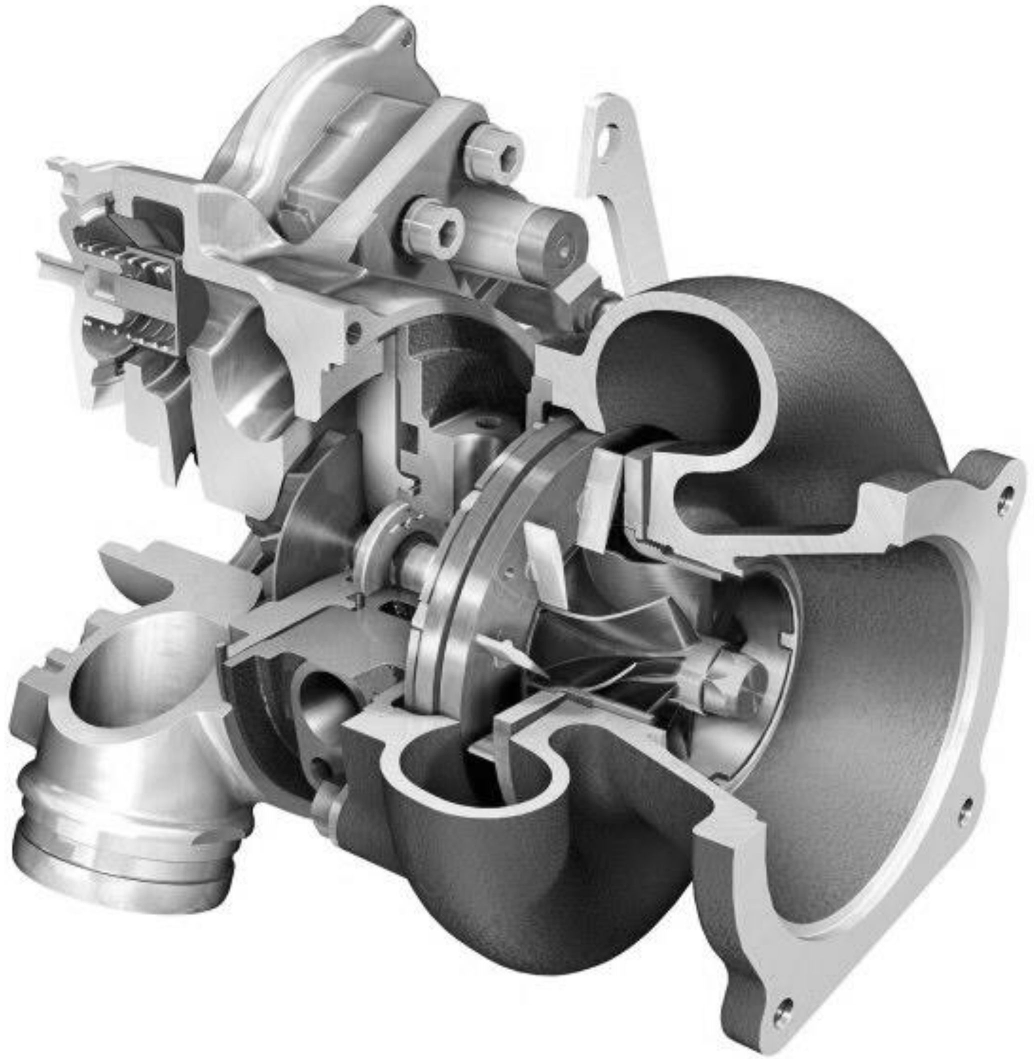


Figure 2.17 Turbo cut-away view

Figures 2.18 (a) and **(b)** show the turbo and how it works in a four-stroke petrol engine.

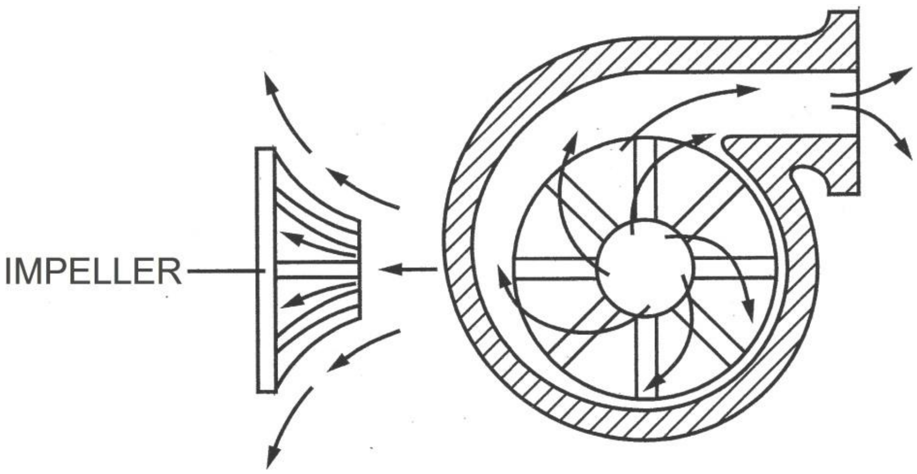


Figure 2.18 (a) The Turbo

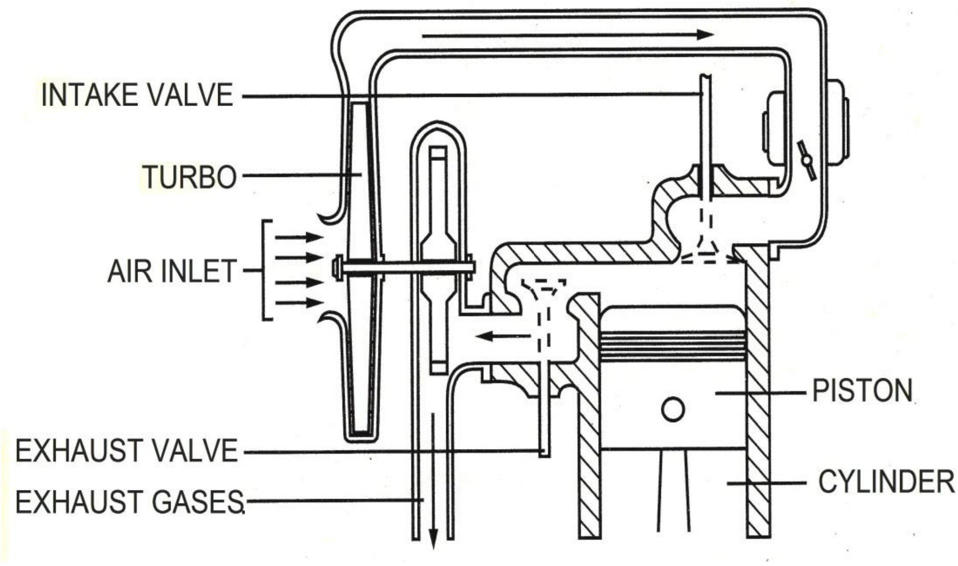


Figure 2.18 (b) Four-stroke engine with turbo

2.12.2 Blower

A blower is an air pump that is driven by the engine by means of a belt. Because the two-stroke diesel engine does not have a separate induction stroke and exhaust stroke, the blower helps to fill the cylinder with a clean load of air. A blower can be used on any engine. **Figure 2.19** shows a two-stroke diesel engine with blower.

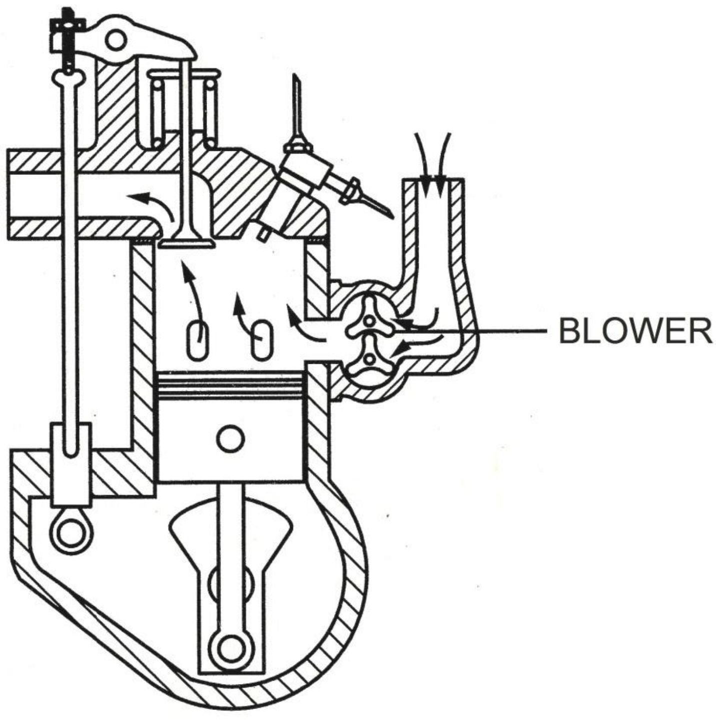


Figure 2.19 Two-stroke diesel engine with blower

2.16 Diagrammatic layouts of the fuel system

The fuel system stores fuel for present use and delivers it as needed. We will now look at different diagrammatic fuel layouts on petrol and diesel engines.

2.16.1 Diagrammatic layout of the fuel system in a petrol engine with carburettor

The simple fuel supply system for a petrol engine consists of:

- Storage (fuel) tank;
- Petrol (fuel) pump;
- Petrol (fuel) filter; and
- Carburettor.

If you look at **Figure 2.20** you will be able to follow the direction of the fuel flow in a petrol engine until it reaches the carburettor.

- **Operating function of the fuel system in a petrol engine with carburettor**

The fuel system of an internal combustion engine is intended to produce a combustible mixture composed of the fuel stored in the fuel tank and atmospheric air, and then deliver both to the cylinders.

Petrol engine use light grade gasoline fuel while the Diesel Engines utilize heavy diesel fuel, therefore fuel supply systems and their differ greatly in petrol and diesel engine fuel pump is used to supply petrol from the petrol tank to the carburettor.

The fuel pump may be of mechanical or electrical type. If mechanical fuel pump is employed, it has to be placed on the engine since it is driven by the engine camshaft through an eccentric. However, the electrically operated fuel pump may be placed anywhere on the vehicle.

When the engine is cranked (started), vacuum is produced inside the cylinder. The atmospheric air rushes in to the vacuum through the air cleaner.

Carburettor is the main device in this system. It vaporizes the petrol and mixes it with air in desired proportions depending upon the requirements of operating conditions. The charge (Air + fuel mixture) now flows into the inlet valve opens. It is ignited by spark that occurs due to an ignition system.

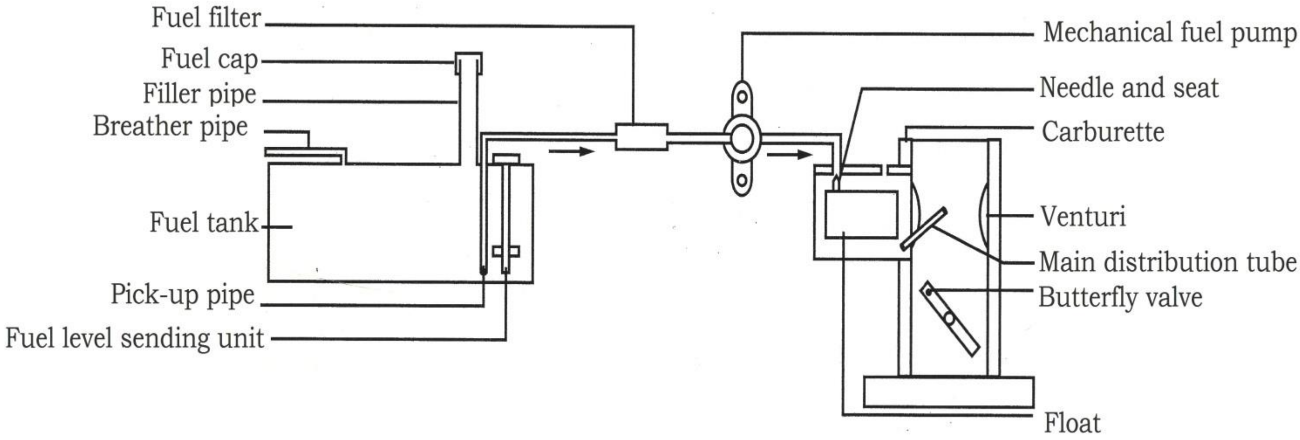


Figure 2.20 Diagrammatic layout of the fuel system in a petrol engine with carburettor

2.16.2 Diagrammatic layout of the fuel system in a petrol engine with fuel injection

If you look at **Figure 2.21** you will be able to follow the direction of the fuel flow in a petrol engine with fuel injection until it reaches the injector.

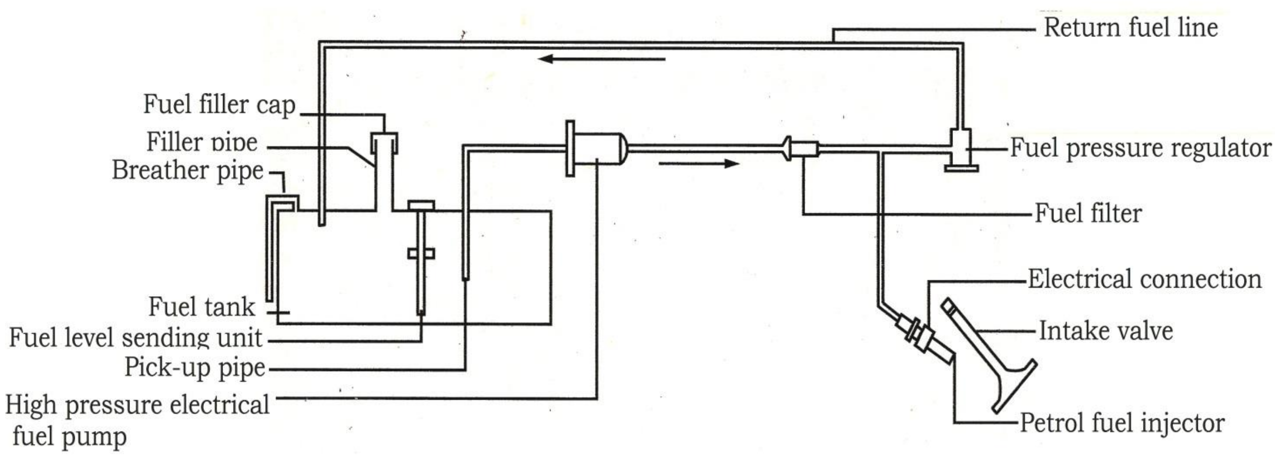


Figure 2.21 Diagrammatic layout of a fuel system in a petrol engine with fuel injection

2.16.3 Diagrammatic layout of the fuel system in a diesel engine

If you look at **Figure 2.22** you will be able to follow the direction of the fuel flow in a diesel engine until it reaches the diesel injector.

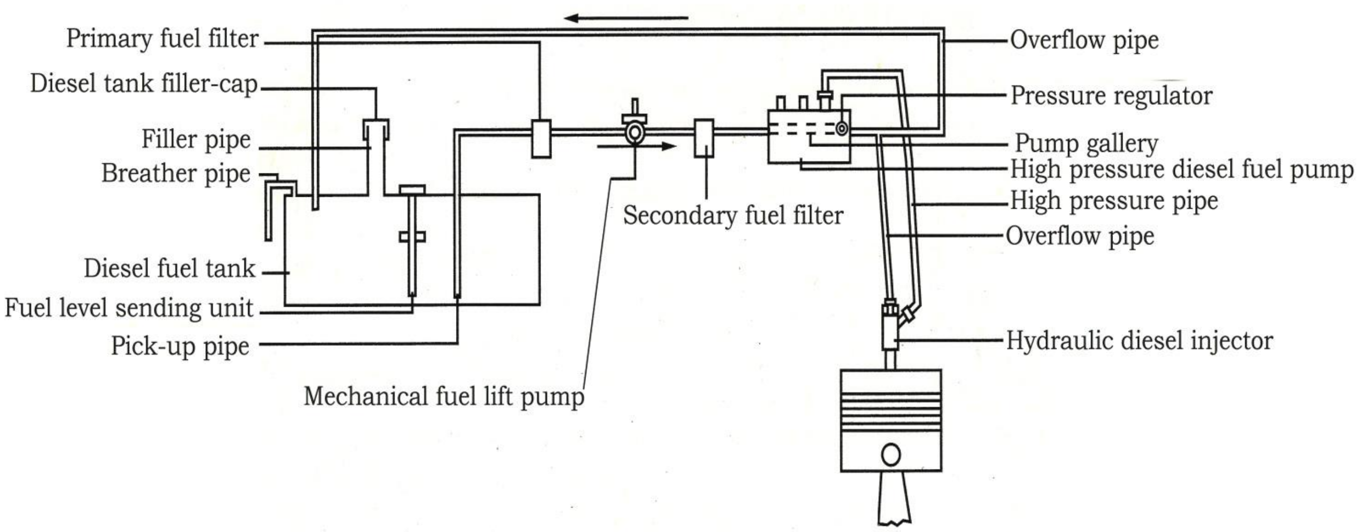


Figure 2.22 Diagrammatic layout of a fuel system in a diesel engine

2.17 The Petrol Engine compared to the Diesel Engine

We have already discussed that the petrol and diesel engines have certain things in common. Let us now look at some important differences between the two engines:

- The method of fuel supply;
- General maintenance costs;
- Construction;
- The differences in their cycles of operation; and
- The advantages and disadvantages of the diesel engine and the petrol engine.

2.17.1 General maintenance costs between four-stroke petrol and four-stroke diesel engines

- **Four-stroke Petrol Engine**
  1. Spark plugs are relatively cheap
  2. Fuel filters are cheaper
  3. The carburettor is much cheaper to overhaul
  4. A main service needs a short period of time
  5. Engine parts are much cheaper
  6. Engine oil is cheaper
  7. Air filters are smaller and cheaper

- **Four-stroke Diesel Engine**
  1. Needs very expensive fuel injector
  2. Fuel filters are more expensive
  3. The fuel injector is very expensive to overhaul
  4. A main service needs a longer period of time
  5. Engine parts are very expensive

6. Engine oil is more expensive
7. Air filters are much bigger and more expensive

2.17.2 Construction differences between petrol and diesel engines

- **Petrol engine**
  1. Uses a carburettor
  2. Uses a spark plug as part of the ignition system
  3. Combustion chamber is relatively large
  4. Accelerator butterfly is directly connected to the accelerator pedal
  5. Engine parts are lighter in weight

- **Diesel engine**
  1. Uses an injector pump
  2. Uses a fuel injector as part of the ignition system
  3. Combustion chamber is relatively small
  4. Equipped with an engine governor
  5. Engine parts are much heavier

2.17.3 The differences in their cycles of operation

- **Petrol engine cycle**
  1. During the induction stroke the petrol engine takes in a mixture of air and fuel.
  2. During the compression stroke the air and fuel mixture is compressed.
  3. Combustion takes place by means of an electric spark over the electrodes of the spark plug.

- **Diesel engine cycle**
  1. During the induction stroke the diesel engine takes in clean air only.
  2. During the compression stroke only.
  3. Combustion takes place when diesel fuel is injected by means of a fuel injector into compressed hot air.

2.17.4 The advantages and disadvantages of the diesel engine and the petrol engine the clean air is compressed

- **Advantages of the diesel engine over the petrol engine**

The diesel engine has the following advantages over the petrol engine:

- In the diesel engine the thermal energy, which is the energy generated by heat, is much greater. This helps to save fuel.
- The high combustion rate in the combustion chamber of the diesel engine means that there is no need to advance the injection. In the petrol engine the time of the spark has to be advanced. This means that the spark has to occur before the piston reaches the top dead centre.
- The cylinder pressure in a diesel engine is high when the engine speed is low. This results in a high thermal efficiency. In a petrol engine the opposite

is true. This is because thermal efficiency in petrol engines is obtained only when the engine speed is high.
- o The warm-up period of the diesel engine is shorter because the combustion temperature is very high and the fuel arrives in the combustion chamber in an atomised form.
- o Each cylinder of a diesel engine receives the correct quantity of fuel which depends on the speed and power requirements. The carburetor system of the petrol engine is less efficient.
- o In the diesel engine a compression ratio of 40:1 is not unusual. In a petrol engine, on the other hand, a 17:1 ratio will cause the valves to burn.
- o The fuel consumption of a diesel engine is lower because the air-fuel ratio is lower and the thermal efficiency higher.
- o The low combustion rate of diesel reduces the fire hazard. In other words, diesel does not catch fire as easily as petrol.
- o The torque of a diesel engine is much higher than that of a petrol engine. Maximum torque is reached at approximately 2 000 revs per min.

- **Disadvantages of the diesel engine compared with the petrol engine**

The diesel engine has the following disadvantages compared with the petrol engine:

- o The power output of the diesel engine is lower.
- o The manufacturing costs are very high due to the expensive fuel injection system of a diesel engine.
- o A diesel engine causes more pollution than a petrol engine.
- o A diesel engine makes much more noise than a petrol engine.

2.18 Hazardous or flammable areas

Let us compare the petrol and diesel engines regarding exhaust fumes, noise and general maintenance in open, confined and hazardous areas.

2.18.1 Open areas: Petrol engine

- **Exhaust fumes -** No real danger because the fumes are absorbed into the atmosphere.
- **Noise -** No real problem in an open area
- **General maintenance** - Friction in a petrol engine means that periodic maintenance is often necessary

2.18.2 Open areas: Diesel engine

- **Exhaust fumes -** No real danger because the fumes are absorbed into the atmosphere.
- **Noise -** No real problem in an open area
- **General maintenance** - Maintenance is needed less often because diesel contains a lubricant that lubricates the moving parts.

2.18.3 Confined areas: Petrol engine

- **Exhaust fumes** – The fumes are not as dirty but have a high health danger. Fumes must therefore be removed through an exhaust or by extractors. They must also be removed because the engine consumes a large volume of air for combustion.
- **Noise** – Lower noise level. A silencer is used to lower the noise level to the required decibel reading.
- **General maintenance** – Friction in a petrol engine means that periodic maintenance is necessary.

2.18.4 Confined areas: Diesel engine

- **Exhaust fumes –** The health danger is not as high but the fumes are very dirty and create a black smoke. Fumes must therefore be removed through an exhaust pipe or by extractors. They must also be removed because the engine consumes a large volume of air for combustion.
- **Noise -** A much higher noise level, which must be lowered to the required decibel reading by using a silencer.
- **General maintenance** - Maintenance is needed less often because diesel contains a lubricant that lubricates the moving parts.

2.18.5 Hazardous areas: Petrol engine

- **Exhaust fumes** –Petrol is highly flammable. Exhaust fumes are very dangerous and can be ignited or it. The exhaust fumes are set alight by a spark.
- **Noise** – Lower noise level. A silencer is used to lower the noise level to the required decibel reading.
- **General maintenance** – Continual maintenance is necessary. Leakage of flammable fluids or fumes must be prevented.

2.18.4 Hazardous areas: Diesel engine

- **Exhaust fumes –** Diesel is not as highly flammable. It needs an open flame to ignite it. The exhaust fumes are therefore not as dangerous.
- **Noise –** A much higher noise level, which must be lowered to the required decibel reading by using a silencer.
- **General maintenance** - Not as important as on the petrol engine. Regular maintenance is required. Diesel contains a lubricant that provides lubrication to the moving parts.

Activity 2.1

1. Describe, with the aid of simple sketches, the principle of the four-stroke petrol engine.
2. Describe, with the aid of simple sketches, the principle of the two-stroke petrol engine.
3. Describe, with the aid of simple sketches, the principle of the diesel engine.

4. State the advantages and disadvantages of the diesel engine compared to the petrol engine.
5. Briefly describe the successive strokes in the operation of the:
   (a) Two-stroke petrol engine.
   (b) Two-stroke diesel engine.
6. Make simple drawings with labels to illustrate what you have described in question 5 (a) and (b). Show the positions of:
   (a) The piston, in relation to the ports.
   (b) The spark plug or injector, in relation to ignition.
7. Briefly describe the purpose of the following:
   (a) The fuel injector.
   (b) The carburetor.
8. Briefly describe the purpose and function of the turbo.
9. Briefly describe the purpose and function of the blower in the two-stroke diesel engine.
10. Compare the petrol and diesel engines as regards:
    (a) General maintenance cost.
    (b) Method of fuel supply.
11. List the main construction differences between the petrol engine and the diesel engine.
12. List the differences between the cycle of the petrol engine and the cycle of the diesel engine.
13. Briefly describe the advantages and the disadvantages of the diesel engine over the petrol engine.
14. Draw and label diagrammatic layouts of the fuel systems of the following:
    (a) Four-stroke petrol engine with carburetor.
    (b) Four-stroke petrol engine with fuel injection.
    (c) Four-stroke diesel engine.

Self-Check

I am able to:	**Yes**	**No**
4. Make comparisons, and describe the respective basic operations of petrol and diesel engines of:		
o Four stroke: Inlet- compression- power- exhaust		
– Method of fuel supply, and maintenance costs		
– Diagrammatic layout of carburettor and injection fuel systems		
o Two stroke: Blow and exhaust valves		
– Advantages and disadvantages (petrol and diesel)		
5. Use petrol and diesel engines in:		
• Open, confined, hazardous locations, with regard to:		
– Exhaust fumes, noise, general maintenance		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 3

Hydraulics and Pneumatics

Learning Outcomes

When you have completed this module, as a learner you will be able to:

- Explain in simple terms, where hydraulic systems are commonly used
- State Pascal's Law, and the Hydrostatic principle in basic terms
- Define viscosity, and state the effects of low and high viscosity on the operation of a system
- State the three characteristics of a hydraulic fluid
- Explain these factors - pressure, area, flow rate - in terms of hydraulic systems
- State the two important functions and characteristics of hydraulic fluid (water or oil)
- Explain "Pressure in Liquids", its formula, and do calculations of pressure and force
- Describe the functions of these components in a hydraulic system:
    - Motor - Pump - Reservoir - Valves - Pipes - Actuator- Accumulators
- Identify the following symbols in a basic hydraulic system:
    - Motor (vane, gear and piston piston-type) - Pump - Pressure gauge - Pressure relief valve (directional control and flow control)- 4 port 2 position directional control valve - Actuator (cylinder, motor)- Reservoir-Filters - Accumulators
    - Design a basic hydraulic circuit using the components stated above
    - Calculate the pressure, area and force in a hydraulic system from given information
- Explain in simple terms, and name:
    - how a pneumatic system can be used where pneumatic systems are commonly used
- State the main difference between a pneumatic and a hydraulic system
- Explain the following important factors to consider in a hydraulic system:
    - Pressure - Flow rate -Area
- State the two important functions and characteristics of hydraulic fluid
- State the three characteristics of the fluid in a hydraulic system
- Describe the functions of these basic pneumatic components:

- Compressor - Air receiver - Air pressure gauge - Relief valve - Service unit - 4 Port 2 directional control valve (DCV) -Pipes - Actuator (motor, cylinder)
- Identify the following symbols in a basic pneumatic system:
  - Compressor - Air receiver - Pressure gauge - Relief valve - Service unit - 4 Port 2 directional control valve (DCV) - Actuator (motor, cylinder)
- Design a basic pneumatic circuit using the components given above

3.1 Introduction

Pneumatic and hydraulic systems basically work in the same way, and are used to provide powerful linear movement. The only difference is that hydraulic systems use pressurised oil or water to operate, while pneumatic systems use compressed air to operate.

Hydraulics is the physical science and technology of the static and dynamic behaviour of fluids. Hydraulics provides a useful method of performing work in industry since hydraulic systems are often smaller, less expensive, and safer than mechanical and electrical systems.

Modern hydraulics is based on Pascal's principle which states that confined fluids transmit power, and this power can be used to multiply force and modify motions.

Pneumatic power is used to drive a wide range of tools and machines, both machines requiring rotary motion (such as drills) and those requiring reciprocating motion (such as hammers). Pneumatic tools are driven by air motors, which are powered by compressed air.

3.2 Hydraulic systems

Hydraulics is the physical science and technology of the dynamic behaviour of fluids. Modern hydraulics is based on Pascale's principle.

SAFETY PRECAUTIONS

To prevent personal injury when working with hydraulic systems, take the following safety precautions:

- Do not operate hydraulic equipment without pump and motor guards in place.
- Wear gloves to prevent burns from hot lines and components.
- Wear safety goggles when opening any hydraulic system.
- Ensure that the system has been shut down and all pressure has been relieved before opening the system.
- Do not touch or work on operating equipment.
- Warn personnel in the area before starting any equipment.
- Observe all plant safety rules

3.3 Principles of hydraulics

Many types of hydraulic systems are used in industry today. Although the systems differ in many ways, the basic principles of hydraulics remain the same. To understand how a hydraulic system works, you must first understand several basic principles, which include the following:

- Pressure
- Work
- Energy
- Pascal's law
- Fluid power
- Fluid flow
- Cavitation
- Bernoulli's principle
- Fluid expansion

3.4.1 Pressure

Hydraulics refers to the movement of fluid in an enclosed space. For a hydraulic system to operate, a pump must supply enough force to push the fluid through the system. When fluid is forced through an opening, pressure is created. This pressure is a form of energy that is used to perform work.

Pressure is the amount of force exerted against a specific area. Pressure is normally measured in Newton per square meter (N/m^2). The amount of force in Newtons divided by the number of square metres that the force is in contact with equals the pressure in N/m^2.

The most important points to remember about pressure in liquids are:

- Pressure in a liquid increases with depth, and is directly proportional to depth.
- The pressure exerted by a liquid is proportional to the density of the liquid. The higher the density, the higher the pressure.
- Pressure has the same magnitude in all directions at any point in a liquid.
- The pressure in a liquid is the same at all points on the same horizontal plane in its container.
- Pressure in a liquid is independent of the size and shape of the container.
- An external force applied to the surface of a liquid is transmitted with the same intensity throughout the liquid in all directions.

Pascal's law
Pascal's law states that the pressure in a confined fluid is equal throughout the fluid and acts in all directions

Pascal's Law (from Blaise Pascal 1623 to 1662), comprises a set of principles formulated in 1648 and states that pressure applied to a confined fluid at any point is transmitted undiminished throughout the fluid in all directions and acts upon every part of the confining vessel at right angles to its interior surfaces and equally upon equal areas.

This is the basic principle behind any hydraulic system - pressure applied anywhere to a body of fluid causes a force to be transmitted equally in all directions, with the force acting at right angles to any surface in contact with the fluid.

To fully understand hydraulics and hydraulic applications, you must understand Pascal's law.

Pascal's law states that pressure produced in a liquid transmits force equally in all directions.

The containing walls of system components receive the same force at perpendicular angles. **Figure 3.1** illustrates Pascal's law**.**

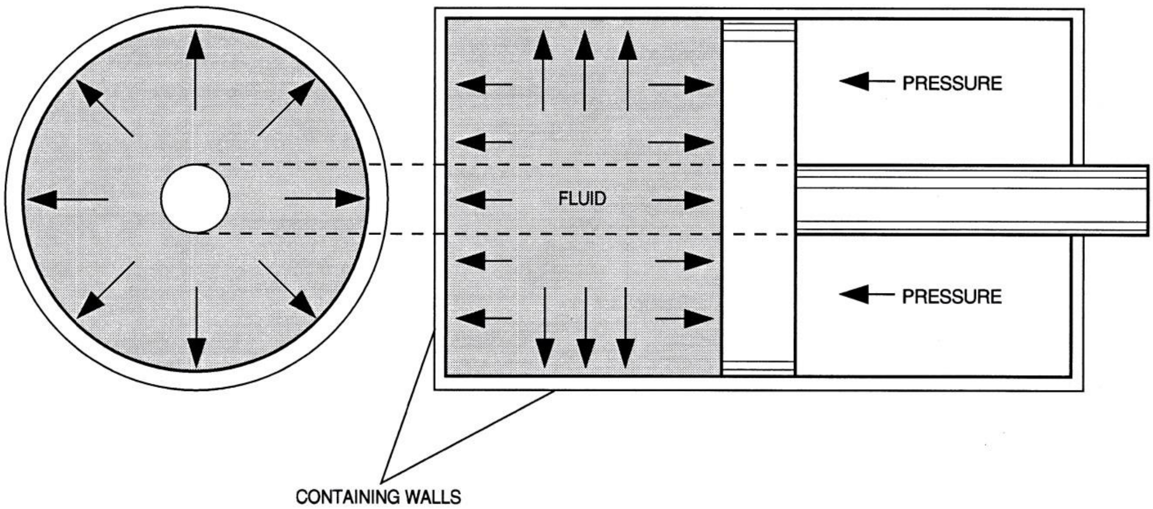


Figure 3.1 Application of Pascal's law

3.4.2 Flow rate

When water flows in a pipe, friction occurs between the flowing water and the pipe wall, and between the layers of water moving at different velocities in the pipe due to the viscosity of the water.

The flow velocity is zero at the pipe wall and maximum along the center line of the pipe. Velocity of flow means the average velocity over the cross section of the flow.

Both gas and liquid flow can be measured in volumetric or mass flow rates, such as liters per second or kilograms per second. These measurements can be converted between one another if the material's density is known.

The density for a liquid is almost independent of the liquid conditions; however, this is not the case for gas, the density of which depends greatly upon pressure, temperature and to a lesser extent, the gas composition

Flow rate is the measure of the volume of liquid which passes a point in a given time. It is usually measured in litres per second, l/s. Flow rate determines the speed at which the load moves, and therefore is important to the consideration of power.

3.4.3 Area

Area is a quantity that expresses the extent of a two-dimensional surface or shape. In the International System of Units (SI), the standard unit of area is the square metre (written as m^2).

The formula for the area is defined as:

Area (Cross-sectional area) = $\pi D^2 \div 4$

Where:

A = area in m2
F = force in N
P = pressure in Pa
D = diameter in m
π = 3,142

So, hydraulic pressure can be stated as the force exerted by a fluid on unit area, anywhere on the surface within the container.

3.4 Calculations for pressure, force and area in a hydraulic system

Pascal's law, when dealing with the variables of force, pressure, and area, is dealt with by way of the following formula:

Force = Pressure × Area

In this formula, the force is in units of pounds, the pressure is in pounds per square inch (psi), and the area is in square inches. By transposing the original formula, we have two additional formulas, as follows:

Pressure = Force ÷ Area
and
Area = Force ÷ Pressure

An easy and convenient way to remember the formulas for Pascal's law, and the relationship between the variables, is with the triangle shown in **Figure 3.2**.

If the variable we want to solve for is covered up, the position of the remaining two variables shows the proper math relationship.

For example, if the "A" (area) is covered up, what remains is the "F" on the top and the "P" on the bottom, meaning force divided by pressure.

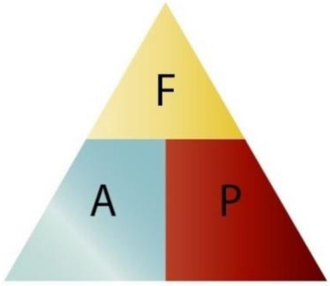
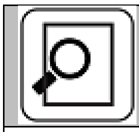


Figure 3.2 Relationship between, Force, Pressure and Area in a Hydraulic system

Let us look at some worked examples:



Worked Example 1

Calculate the pressure exerted on a piston in a hydraulic system which has a diameter of 120 mm and a supplied force of 1200 N.

Given:

d = 120 mm = 0,12 m
F = 1200N

SOLUTION

Find area (A) of the piston:

Area (Cross-sectional area) = $\pi D^2 \div 4$

$A = \pi \times (0{,}12)^2 \div 4$

$= 0{,}0113112 \text{ m}^2 \rightarrow$

Determine pressure (p):

Pressure = Force ÷ Area

p = F ÷ A

= 1200 ÷ 0,0113112

= 106 090,289 Pa

= 106, 090 Kpa→

Worked Example 2

If the pressure in a hydraulic system is 0,775 MPa and the diameter of the piston is 255 mm, calculate the force exerted by the piston in newton.

Given:

p = 0,775 MPa = 1 000 x 1 000 x 0,775 Pa
d = 255mm = 0,255m

Find area (A) of the piston:

Area (Cross-sectional area) = π D^2 ÷ 4

A = π x D^2 ÷ 4

= 3,142 x (0,255)^2 ÷ 4

= 0,05108m^2→

Determine force (F):

Force = Pressure × Area

F = p x A

= 0,775 x 1000 x 1000 x 0,05108

= 39 587 N→

3.5 Basic components of a hydraulic system

A simple hydraulic system consists of hydraulic fluid, pistons or rams, cylinders, accumulator or oil reservoir, a complete working mechanism, and safety devices.

These systems are capable of remotely controlling a wide variety of equipment by transmitting force, carried by the hydraulic fluid, in a confined medium.

Modern developments in hydraulics have involved many fields in engineering and transportation. These systems transfer high forces rapidly and accurately even in small pipes of light weight, small size, any shape, and over a long distance.

These systems play a vital role from small car's steering to supersonic aircraft's manoeuvring devices. More powerful and accurate systems are also used in manoeuvring huge ships.

3.5.1 A reservoir

The reservoir is a storage place for the hydraulic fluid until it is required for the operation of the system. The reservoir should be large enough to allow contaminants in the fluid to settle to the bottom and to dissipate heat generated in the system.

3.5.2 Pump

The function of the pump is to give mechanical energy to the hydraulic fluid, which in turn gives energy to the other components. Positive displacement pumps are used for this purpose.

3.5.3 An actuator

The actuator is any output mechanism of a hydraulic system. The nature, mode of operation, size and energy requirements needs to be considered as part of the design criteria of the total system.

These actuators take the form of various types of cylinders (in other words, number of cylinders, single or double acting, different valve configurations and so on). Actuators change the hydraulic liquid pressure into mechanical movement.

3.5.4 Pressure relief valve

Mechanical and electrical systems normally have built in safety devices to ensure that damage is minimised when things go wrong. Electrical systems are protected from overloads by means of a fuse.

Similarly, hydraulic systems must be protected from excessive pressure; this .is done by means of a pressure relief valve. Pressure relief valves are designed to open at a predetermined pressure to allow the hydraulic fluid to bypass the system safely until normal working pressure is restored.

3.5.5 Piping
The fluid under pressure is conveyed from the pump to the actuator through piping. The pipes are also referred to as lines. One of the most important design criteria for any hydraulic system is that the pipes must be able to withstand the pressure of the fluid.

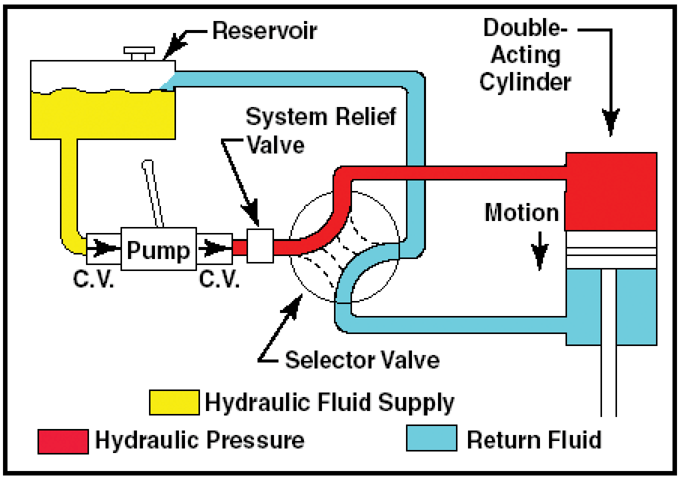


Figure 3.3 Hydraulic system and components

3.6 Functions of hydraulic oil
Hydraulic fluid (usually highly refined oil) has three functions in a hydraulic system. These are:

3.6.1 Power transmission
Power is transmitted via hydraulic fluid by the pressure that builds up in the fluid. This pressure provides the energy that can be transferred.

3.6.2 Lubrication
Mechanical hydraulic components are lubricated by hydraulic oil passing through it, eliminating the need for external lubrication.

3.6.3 Cooling
The hydraulic oil circulating in a system is an effective way of dissipating heat.

3.7 Examples of a simple hydraulic circuit
Figure 3.4 shows a basic form of a hydraulic system. We load the piston of a single piston pump with a certain force. Force divided by area results in the pressure. The more we press on the piston, i.e. the greater the force on the piston is, the higher the pressure raises. However, it rises only until, related to the cylinder area, it is in a position to overcome the load.

If the load remains constant, pressure does not increase further. Consequently, it acts according to the resistance, which is opposed to the flow of the fluid. The load can therefore be moved.

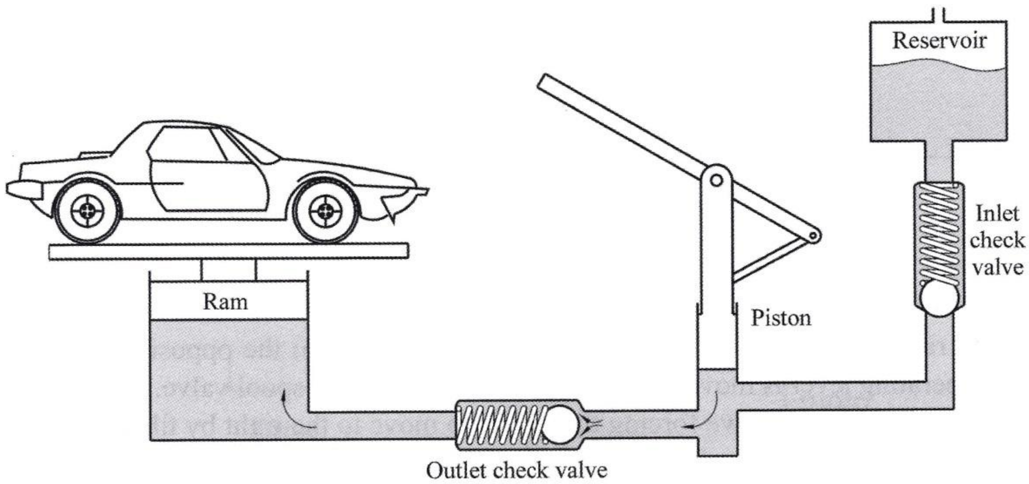


Figure 3.4 Basic form of a hydraulic system

The speed, at which the load moves, is dependant solely on the volume of fluid which is fed into the cylinder. This means that the faster the piston is lowered, the more fluid per unit time is supplied to the cylinder, and the faster the load will lift.

However, in practice we must enlarge on this system. We wish to fit devices, which can influence, for example, the direction of movement of the cylinder, the speed of movement of the cylinder and the maximum load of the cylinder. Also, we shall replace the manually operated piston pump with a continuously driven pump.

3.8 Simple hydraulic circuit

To make this easier to understand, a simple hydraulic circuit is shown in **Figure 3.5 (a)** and **(b).**

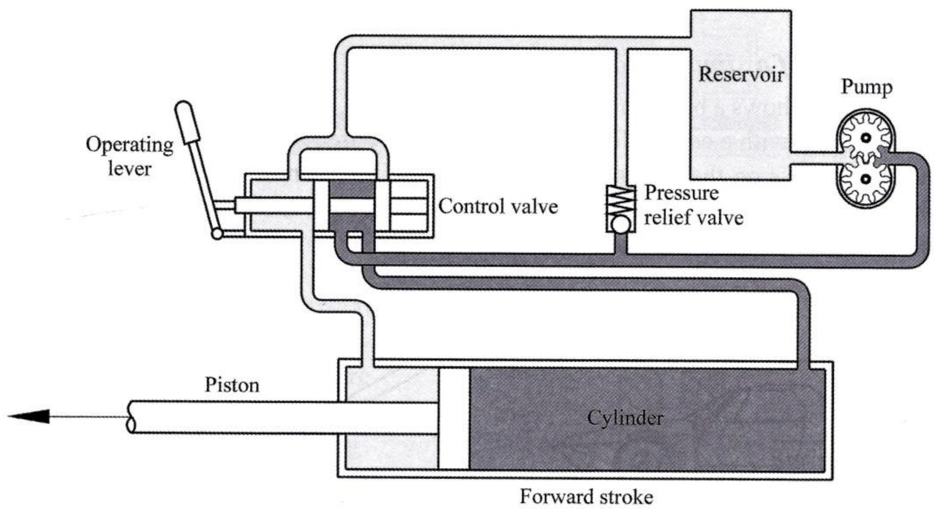


Figure 3.5 (a) Forward stroke

In the forward stroke, as shown in **Figure 3.5(a)**, the pump forces fluid into the cylinder via the spool valve by moving the piston towards the left. The fluid that is in the left hand side of the cylinder is forced back into the tank through the spool valve.

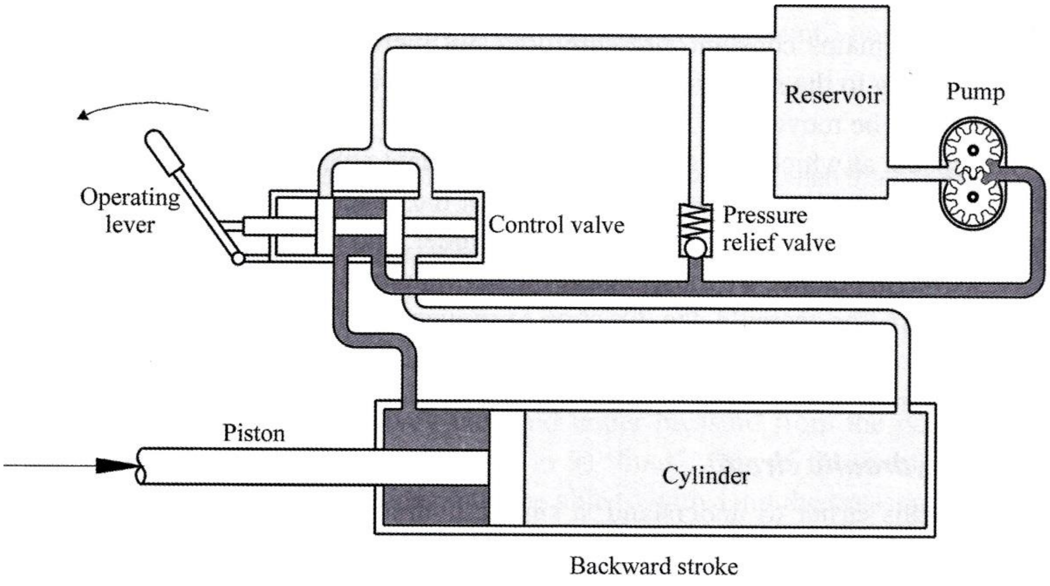


Figure 3.5 (b)Reverse or backward stroke

In the reverse or backward stroke shown in **Figure 3.5(b)** the opposite happens. The operating lever is moved, changing the position of the spool valve. The fluid is directed through the valve forcing the piston to move to the right by filling the left hand side of the cylinder. The fluid that is in the right hand side of the cylinder is forced by the piston back into the tank via the valve.

In practice, a hydraulic circuit is not shown graphically as in the previous diagrams. Symbols are used in place of drawings. The graphic representation of a hydraulic circuit with these symbols is called a circuit diagram. See **Figure 3.6**. The symbols are drawn according to the ISO 1219 standards.

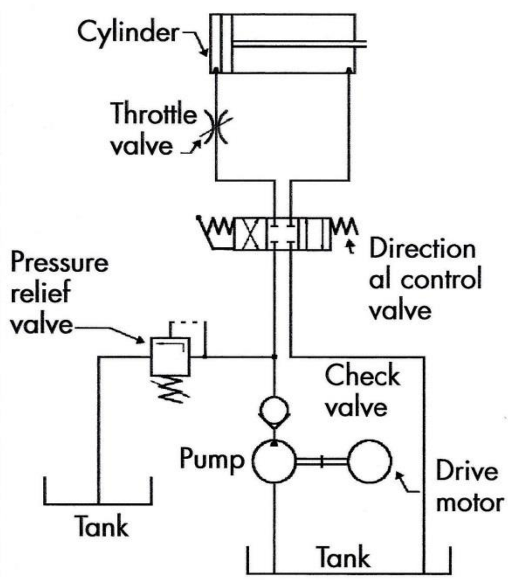


Figure 3.6 A basic hydraulic system (circuit diagram with symbols)

3.9 Symbols used in drawings of hydraulic systems

Symbols	Description	Symbols	Description	Symbols	Description
	Working line		Exhaust line		Enclosure for several components assembled in one unit
	Line connection		Lines passing each other without being connected		Direction of flow
	Flexible line		Pneumatic flow		Hydraulic flow
	Electric motor		Flow measuring instrument		Temperature gauge
	Check valve		Spring control		Filter
	Line back to reservoir – above fluid level		Line back to reservoir – below fluid level		Hydraulic pump
	Hydraulic motor		Hydraulic pump (variable capacity)		Hydraulic motor (variable capacity)
	Pressure gauge		Shut-off valve		Lubricator
	Single-acting cylinder, return stroke by external force		Double-acting cylinder		Throttle valve
	Dryer		Water trap automatic drain		Cooler
	Vacuum pump		Compressor		Pneumatic motor
	Electric pressure switch		Pressure source		Pressure regulator
	Safety valve		Sequence valve		Thermometer
	Non-return valve spring-loaded		Heat engine		Open tank
	Pressurised receiver		Single acting cylinder with return spring		

Table 3.1 Hydraulic and pneumatic symbols

3.10 Pneumatic systems

Air is everywhere and provides a useful source for fluid systems. Fluid systems using air are known as pneumatic systems. There are many advantages of using air as a power source:

- Air is free.
- It does not have to be stored.
- Fluid does not have to be added in a power system.

Pneumatic power is used to drive a wide range of tools and machines, both requiring rotary motion· (such as drills) and those requiring reciprocating motion (such as hammers). These tools are driven by air motors, which are powered by compressed air.

The air motor has the following advantages:

- It is physically small and light for the high torque and power that it delivers.
- It does not generate heat.
- It cannot be damaged by overloading.

The TWO most important factors in the functioning of a pneumatic system are pressure and volume.

There are many types of pneumatic system used in mining, industry and in other applications. Briefly, a pneumatic system is a circuit in which air under controlled pressure is sent or transmitted through piping. By sending pressure through piping the circuit transmits force to do work.

Figure 3.7 shows a basic pneumatic circuit.

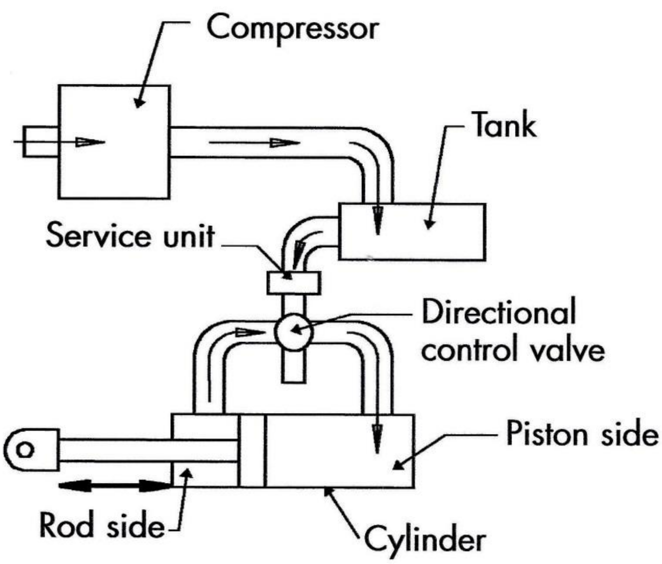


Figure 3.7 Basic pneumatic circuit

3.10.1 Factors responsible for the functioning of a pneumatic system

The THREE most important factors in the functioning of a pneumatic system are:

1. Pressure
2. Area
3. Flow.

Take Note:
The formulae used in pneumatics are the same as those used in hydraulics.

3.10.2 How do pneumatic systems work?

Pneumatic systems involve a source of compressed air that is controlled by valves and causes output devices such as cylinders to operate in a controlled way.

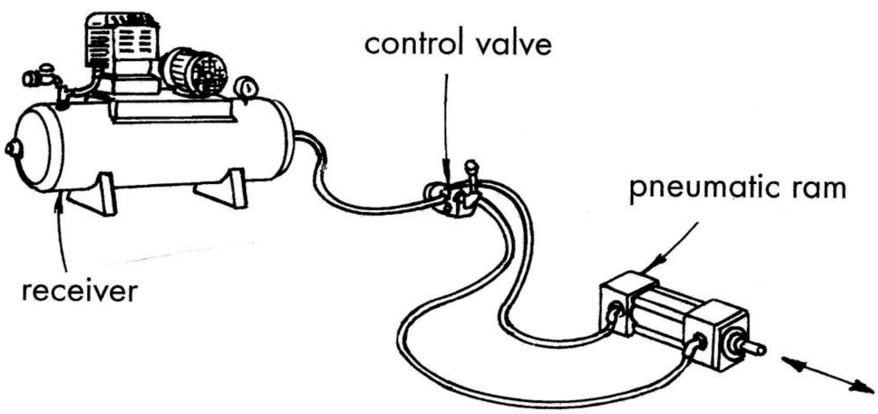


Figure 3.8 Pneumatic system

Compressed air is produced by a compressor. An open pneumatic control valve system uses an air compressor and valves which control the flow of air to the pneumatic ram (the piston and cylinder unit). A double-acting ram can exert a pushing or pulling force, depending on which side of the piston air is admitted.

3.10.3 How does a compressor work?

A pump, driven by an electric motor or an internal combustion engine, sucks air through filters and forces it into a strong metal tank called a receiver. The air moves along narrow plastic or metal pipes to valves, which control the routing of the compressed air. A range of actuators including levers, rollers and solenoids may control the valves.

The air is then passed on to cylinders, which convert the energy in the compressed air into linear motion.

Finally, the used compressed air is released into the atmosphere. During the process, the compressed air may pass through filters and lubricators to clean the air and add lubricants. It may also pass through regulators to control the amount of pressure available in the system.

3.11 Basic components of a pneumatic system

3.11.1 Control valves

These serve the same function as we have discussed in hydraulics.

3.11.2 Actuator (cylinder)

Principle of operation:

- When air is supplied to the cylinder through a control valve it enters the cylinder through the inlet port (A).
- The pressure in the cylinder starts to build up in the chamber (B) at the back of the piston.
- The piston then moves outwards until it reaches the end of its stroke.
- When the supply of air to the cylinder is cut off, the inlet port is vented to atmosphere by the control valve.
- The return spring now pushes the piston back until it returns to its initial position (see **Figure 3.9**).

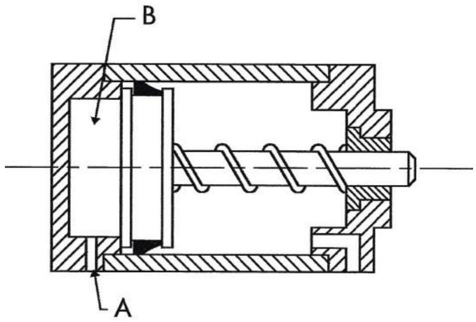


Figure 3.9 Principle operation of an actuator

3.11.3 Compressor

The main function of the compressor is to take in air, by means of the air filter, to compress it to a certain pressure, and then to force into a reservoir where it is stored for use.

3.11.4 Air receiver or tank

The function of the air receiver is to store the compressed air and provide large quantities of air to pneumatic equipment.

3.11.5 Piping

The function of piping in a pneumatic system is to transfer the air to be used to the specific point where it is needed for the application.

3.11.6 Service unit

The function of the service unit is to prepare the air for use in the system. It has three components:

1. The filter with water trap
2. The pressure reducing valve
3. The lubricator

1. The filter with water trap

In this first stage the unclean air enters the filter. A baffle causes it to rotate. Solid particles and drops of water fall below another baffle and are thus stopped from re-entering the air stream.

2. The pressure reducing valve

The compressed air must be kept at a constant pressure, even if the network fluctuates, or goes up and down. The pressure regulator automatically controls this pressure.

3. The lubricator

The third stage in air treatment at the inlet to a machine is lubrication of pneumatic components, so that the components will last longer.

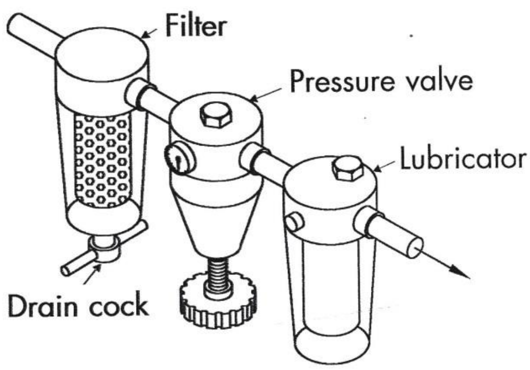


Figure 3.10 Service unit

3.12 Basic pneumatic circuit with symbols

A diagram of a basic pneumatic circuit, using symbols, is shown in **Figure 3.11**.

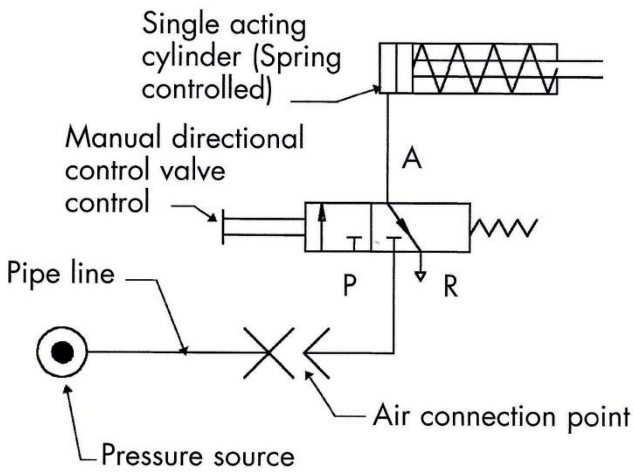
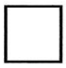
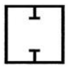
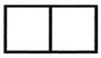
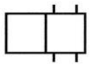
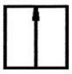


Figure 3.11 Basic pneumatic circuit with symbols

3.12.1 Control valve symbol description

The symbols are used by ISO 1219 and in general are similar for hydraulics and pneumatics. **Table 3.2** shows the control valve symbols used on pneumatic circuit diagrams.

Valve switching positions are represented as squares. 	Shut-off positions are identified in the boxes by lines drawn at right angles. 
The number of squares shows how many switching positions the valve has. 	The connections (inlet and outlet ports) are shown by lines on the outside of the box and are drawn in the initial or starting position. 
Lines indicate flow paths. Arrows show the direction of flow. 	

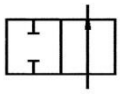
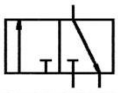
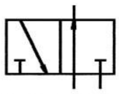
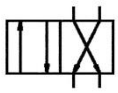
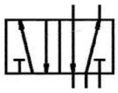
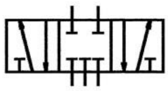
Number of ports Number of positions 2/2 Way directional control valve	
3/2 Way directional control valve. Normally closed	
3/2 Way directional control valve. Normally open	
4/2 Way directional control valve	
5/2 Way directional control valve	
5/3 Way directional control valve. Mid position closed	

Table 3.2 Control symbols used on pneumatic circuits

Activity 3.1

1. Explain in simple terms, where hydraulic systems are commonly used
2. State Pascal's Law, and the Hydrostatic principle in basic terms
3. Define viscosity, and state the effects of low and high viscosity on the operation of a system
4. State the three characteristics of a hydraulic fluid
5. Explain these factors - pressure, area, flow rate - in terms of hydraulic systems
6. State the two important functions and characteristics of hydraulic fluid (water or oil)
7. Explain "Pressure in Liquids", its formula, and do calculations of pressure and force
8. Describe the functions of these components in a hydraulic system:

a) Motor
b) Pump
c) Reservoir
d) Valves
e) Pipes
f) Actuator
g) Accumulators

9. Explain in simple terms, and name:
   a) how a pneumatic system can be used where pneumatic systems are commonly used
10. State the main difference between a pneumatic and a hydraulic system
11. Explain the following important factors to consider in a hydraulic system:
    a) Pressure
    b) Flow rate
    c) Area
12. State the two important functions and characteristics of hydraulic fluid
13. State the three characteristics of the fluid in a hydraulic system
14. Describe the functions of these basic pneumatic components:
    a) Compressor
    b) Air receiver
    c) Air pressure gauge
    d) Relief valve
    e) Service unit
    f) 4 Port 2 directional control valve (DCV)
    g) Pipes
    h) Actuator (motor, cylinder)
15. Identify the following symbols in a basic pneumatic system:
    a) Compressor
    b) Air receiver
    c) Pressure gauge
    d) Relief valve
    e) Service unit
    f) 4 Port 2 directional control valve (DCV)
    g) Actuator (motor, cylinder)
16. Design a basic pneumatic circuit using the components given above.

Self-Check

I am able to:	Yes	No
• Explain in simple terms, where hydraulic systems are commonly used		
• State Pascal's Law, and the Hydrostatic principle in basic terms		
• Define viscosity, and state the effects of low and high viscosity on the operation of a system		
• State the three characteristics of a hydraulic fluid		•

• Explain these factors - pressure, area, flow rate - in terms of hydraulic systems	•	•
• State the two important functions and characteristics of hydraulic fluid (water or oil)	•	•
• Explain "Pressure in Liquids", its formula, and do calculations of pressure and force	•	•
• Describe the functions of these components in a hydraulic system:	•	•
• Motor - Pump - Reservoir - Valves - Pipes - Actuator- Accumulators	•	•
• Identify the following symbols in a basic hydraulic system:	•	•
o Motor (vane, gear and piston piston-type) - Pump - Pressure gauge - Pressure relief valve (directional control and flow control)- 4 port 2 position directional control valve - Actuator (cylinder, motor)- Reservoir- Filters - Accumulators	•	•
• Design a basic hydraulic circuit using the components stated above	•	•
• Calculate the pressure, area and force in a hydraulic system from given information	•	•
• Explain in simple terms, and name:	•	•
o how a pneumatic system can be used where pneumatic systems are commonly used	•	•
• State the main difference between a pneumatic and a hydraulic system	•	•
• Explain the following important factors to consider in a hydraulic system:	•	•
o Pressure - Flow rate -Area	•	•
• State the two important functions and characteristics of hydraulic fluid	•	•
• State the three characteristics of the fluid in a hydraulic system	•	•
• Describe the functions of these basic pneumatic components:	•	•
o Compressor - Air receiver - Air pressure gauge - Relief valve - Service unit - 4 Port 2 directional control valve (DCV) -Pipes - Actuator (motor, cylinder)	•	•
• Identify the following symbols in a basic pneumatic system:	•	•
o Compressor - Air receiver - Pressure gauge - Relief valve - Service unit - 4 Port 2 directional control valve (DCV) - Actuator (motor, cylinder)	•	•
• Design a basic pneumatic circuit using the components given above	•	•
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 4

Belts and Chain Drives

Learning Outcomes
By the end of the module you should be able to:

- Explain the difference between a v (vee) and wedge belt (endless and segment type) in terms of power transmission and instruction of the belt
- Discuss the difference between wedge belt and chain drives in respect to pulleys, sprocket, slip, tension, maintenance, lubrication and centre distance
- Select wedge belts by means of:
  - basic calculations
  - using a catalogue
- Explain the installation procedure of wedge belt-, and chain drives

4.1 Introduction

We use drives to transmit mechanical power from one rotating shaft to another. This is done by means of a belt, rope; gear or roller-chain drive.

When you have to choose the best drive for a specific task, you must consider its advantages, and disadvantages under specific working conditions. You must also take into account economic factors such as the following:

- The initial costs of installing a particular drive.
- The maintenance costs.
- The working life of a particular drive.

Belt drives are a quiet, smooth, and economical form of power transmission. They are available in many forms and styles and are widely used in almost all industries. Belts are made of a combination of fabric, cord, and/or metal reinforcement vulcanized with natural rubber compounds.

4.2 Safety precautions to be taken when working with V-belts and transmission belts

- Fit guards to ensure that foreign objects like rags, pieces of metal or wood and tools do not make contact with the belt.

- Guards are also a safety feature to protect the operator's hands.
- Keep the mesh type of guard free from paper, rags, fluff or mud to allow sufficient air flow to the drive if it is necessary.
- Do not operate standard belts dose to radiators, furnaces and steam pipes or inside unventilated guards where they may become overheated.
- Never use lubrication or belt dressing on either V-belts or wedge belts.
- Always lock out and tag equipment according to safety plant policy before any guard is removed or any work is performed. Ensure that all safety policies and procedures are strictly followed.

4.3 Applications of V-belts

We use V-belts widely to transmit power from a motor or engine to a specific machine or unit, such as a fan. We call the motor or engine the driver and the machine or unit the driven. These endless belts have a trapezoidal cross section and run in V-shaped grooves. An endless belt is a continuous belt or conveyor travelling around a set of pulleys. A trapezoidal cross section means that the cross section of the belt is a four-sided figure with only two parallel sides.

Because V-belts are dependable on motors onto which pulleys are fitted, they can be used on machines where the distance between pulleys are not too far apart- but further apart than gears could handle. The main function of belts is then also to transfer driving motion from one shaft to another.
V-belts are found on some of the following machines:

- milling machines
- compressors
- lathes
- drilling machines
- pumps
- motor cars (not for primary transmission to wheels anymore)

4.4 Advantages and disadvantages of V-belt drives

4.4.1 Advantages of V-belts over chain drives

- They are simple. They are economical.
- Parallel shafts are not required.
- Overload and jam protection are provided.
- Operation is silent. Noise and vibration are damped out. Machinery life is prolonged because load fluctuations are cushioned (shock-absorbed).
- No lubrication is required. They are lubrication-free.
- They require only low maintenance.
- They are highly efficient (90–98%, usually 95%). Some misalignment is tolerable.
- They are very economical when shafts are separated by large distances.

4.4.2 Disadvantages of V-belts over chain drives

- The angular-velocity ratio is not necessarily constant or equal to the ratio of pulley diameters, because of belt slip and stretch.
- Heat buildup occurs. Speed is limited to usually 35 meters per second. Power transmission is limited to 370 kilowatts (500 horsepower).
- Operating temperatures are usually restricted to -35 to 85°C.
- Some adjustment of center distance or use of an idler pulley is necessary for wear and stretch compensation.
- V-belts have a shorter life span.
- V-belts cannot be lengthened.
- A means of disassembly must be provided to install endless belts.

4.5 V-belt drive terms and functions of components

Figure 4.1 shows the various components of a V-pulley drive.

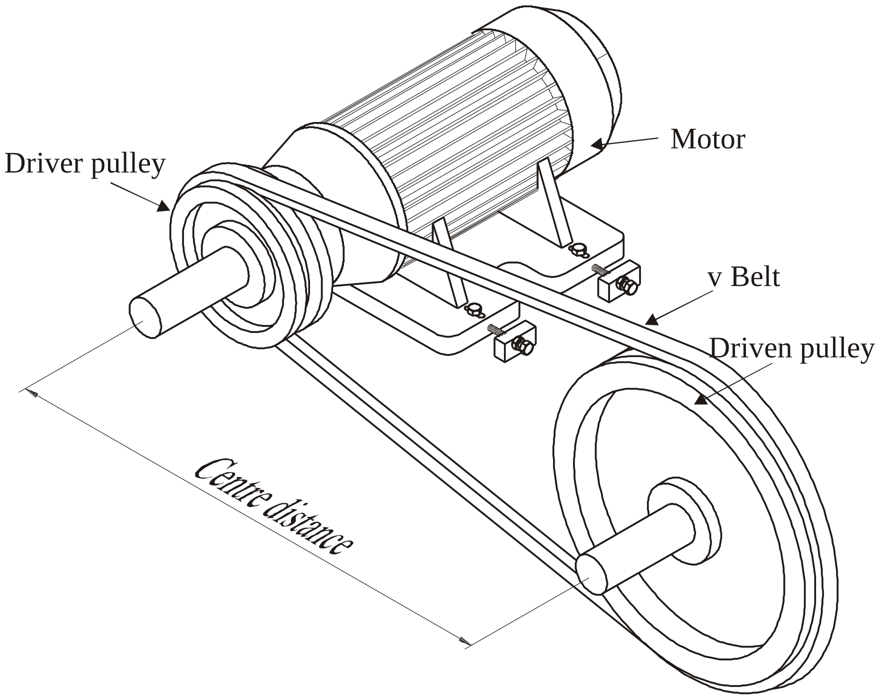


Figure 4.1 V-pulley drive components

- ***Drive pulley***

It is the pulley that is fitted to the motor from where the driving motion of the V-belt starts.

- ***Idler pulley***

The idler or guide pulley is also a pulley, but its function is not to transfer energy but to keep the tension of the V-belt constant, to keep it in place and also increase the arc of contact.

- ***Driven pulley***

This pulley is attached to the working part of a machine - for example: the spindle of a drilling machine.

- ***Pulley pitch diameter (effective diameter)***

The effective diameter of a pulley is where the velocity of the belt is measured. It is roughly midway between the outside of the pulley and the inside step of the pulley.

- ***Belt pitch length***

This is the length of a belt, but measured along the effective pitch line of the V-belt.

- ***Arc of contact***

It is that portion of the pulley that is in contact with the belt along its circumference. The larger the arc of contact (the longer the length of belt that is in contact with the pulley), the higher the power output and the lesser the likelihood of slip occurring.

- ***Centre distance***

The distance between the centre of the driving pulley to the centre of the driven pulley is termed the centre distance.

- ***Span length***

This the distance of the belt along the length between the centre of the driving pulley to the centre of the driven pulley is termed the span length.

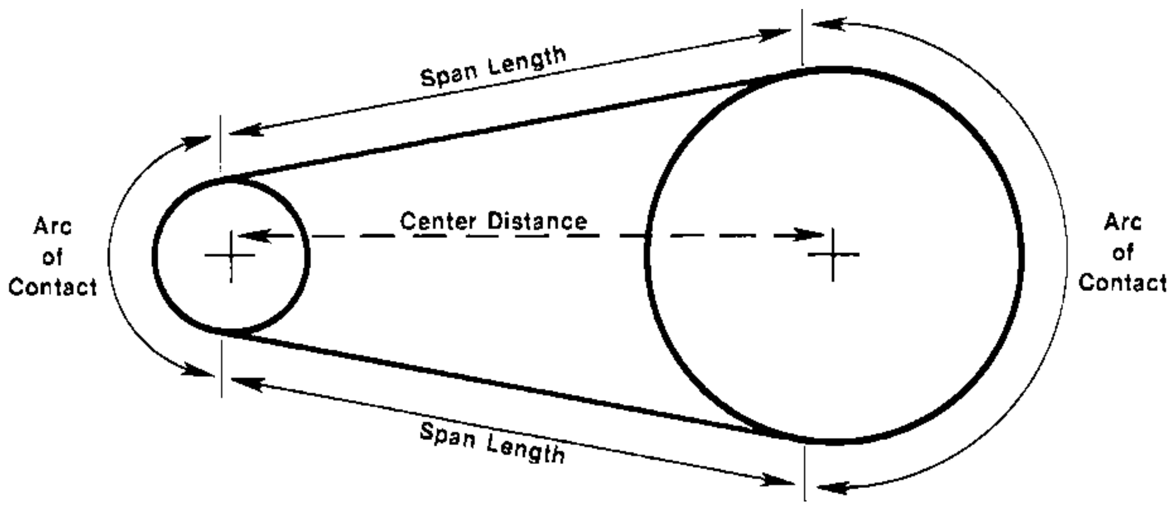


Figure 4.2 V-belt terminologies

4.7 Common and special V-belt types

The V -belt is the most common type of belt. It has a tapered shape that causes it to wedge firmly into the groove of the sheave when it is under load. A V-belt works through frictional contact between the sides of the belt and the tapered sheave groove. **Figure 4.3** shows the area of power transmission of a V -belt.

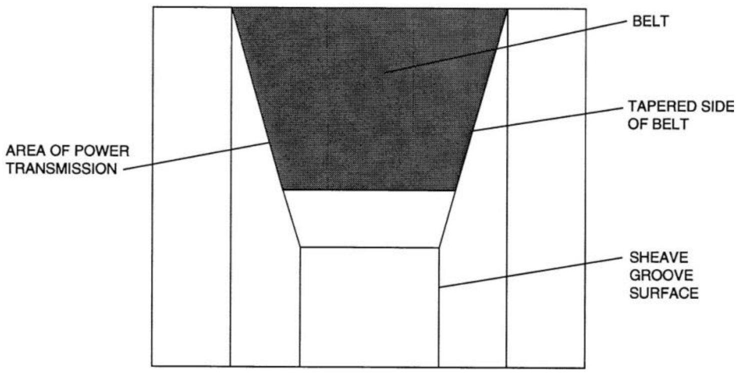


Figure 4.3 Area of Power Transmission of V-Belt

The six main types of V -belts are the following:

1. Fractional horsepower belts
2. Standard multiple belts
3. Wedge belts
4. Double-angle belts
5. Joined belts
6. Notched belts

4.7.1 Fractional Horsepower Belts

Fractional horsepower (FHP) belts are light-duty belts that are used in appliances and small machines in industry and in the home. They are usually used singularly instead of in sets of two or more, as is the case with other types of V -belts.

The size of FHP V -belts is indicated by a code printed on the outside of the belt. The first number and letter in the code tell the width of the belt. The next three numbers in the code tell the length of the belt. FHP belts are measured on the outside surface of the belt.

4.7.2 Standard Multiple Belts

Standard multiple belts are designed for the continuous service that is required in industrial applications. As the name implies, standard multiple belts are used in sets of two or more.

They are used for industrial drives with normal loads, speeds, sheave diameters, center distances, and operating conditions. A higher grade belt is used for severe conditions.

The size of standard multiple belts is indicated by a code printed on the belt. In the code for a standard belt, a letter indicates the width of the belt and a number indicates the length of the belt.
The length of standard belts is measured on the inside surface of the belt. This is called the standard length designation.

4.7.3 Wedge Belts

The wedge belt is an improved design V-belt that allows a reduction in size, weight, and cost of V-belt drives.

It is a type of multiple belts but has a smaller cross section per horsepower rating than standard multiple V-belts.

Also, it can be used on smaller diameter sheaves with shorter center distances than the standard belt. Wedge belts are not interchangeable with standard multiple belts and should not be run on sheaves for standard belts.

The code markings for wedge belts are similar to the markings for FHP belts. The first number and letter of the code indicate the width and cross section of the belt, and the last three numbers indicate the length of the belt.

A 3V500 belt is defined as a 3V cross section that is 1200 mm long. The length of a wedge belt is measured along the pitch line, which runs along the center of the belt thickness.

There is another code, called a match code that is separate from the regular belt number and is used to match multiple belts. The match code includes the belt codes and the manufacturer's name.

This code is used to ensure that replacement belts in a multiple belt application are all the same length. When selecting belts for a multiple-belt application, the belts must be made by the same manufacturer and have the same match code.

4.7.4 Double-Angle Belts

Double-angle belts are used on multiple-sheave drives that cause the belt to have reverse bends that would damage regular V-belts.

Double-angle belts are V-shaped on both sides and can handle reverse bends and still transmit the required power. **Figure 4.4** shows a double-angle V -belt.

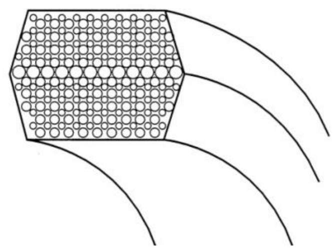


Figure 4.4 Double-Angle V-Belts

4.7.5 Joined Belts

Joined belts are standard or wedge V -belts that have a common back which joins them. They are used to provide extra stability on applications that experience severe shock loads by preventing the belts from turning over in the sheaves. The extra support of the back also helps keep all the belts in the multiple series the same length. **Figure 4.5** shows joined belts.

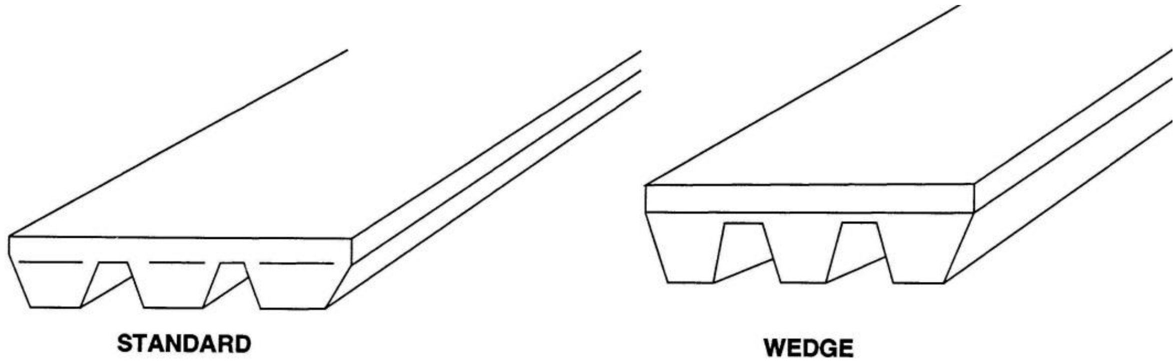


Figure 4.5 Joined Belts

4.7.6 Notched Belts

Notched belts are V-belts that have notches along the inner surface. The notches allow for more bend in the belt and relieve some of the bending stress. Notched belts are used on applications where the sheaves are very small. **Figure 4.6** shows a notched belt.

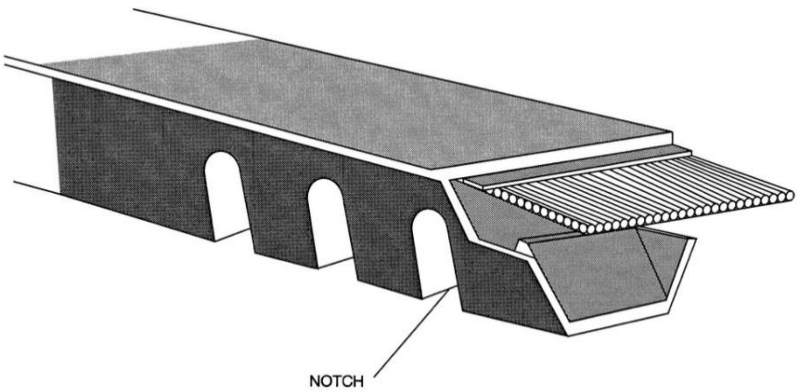
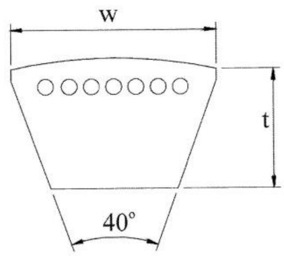


Figure 4.6 Notched Belts

4.8 Standard size of belts

Standard sizes of belts for power transmission have been adopted and designated by sizes A, B, C, D, and E (**Table 4.1**).



Designation	A	B	C	D	E
Top width (W) mm	10	13	17	22	32
Depth (t) mm	6	8	11	14	20

Table 4.1 Standard size of belts

4.9 Composition of a V-belt

4.9.1 V-Belts

Belts are made of cord and fabric soaked with rubber. The cord material is usually cotton, rayon or synthetic due to its strength, durability and flexibility. Steel is used as cord material in certain timing and variable speed belts.

The cords carry the main tensile load (tension) in the belt, whilst the lower portion undergoes compression as it supports the cords as the belt passes over the pulley. The upper portion is in tension. V-belts are used in high speed drivers operating at speeds so high that a flat belt would be in danger of coming off the pulley.

The wedging action ensures that the V-belt stays firmly on the pulley.

Figure 4.7 shows the construction of a V-belt which consists of the following:

- An improved heat and oil resistant cover.
- A polyester, nylon or rayon cord.
- A cord support cushion, in which the cord is embedded.
- A fibre loaded base for greater power transmission.

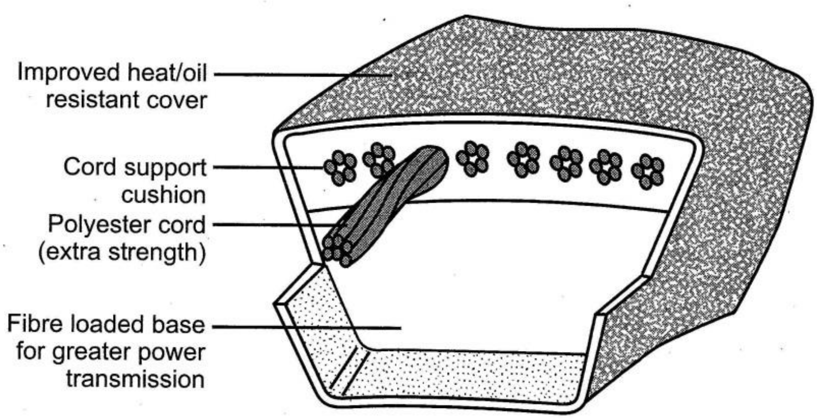


Figure 4.7 Construction of a V-belt

4.8.2 Wedge belts

Another type of belt designed as an improvement on the traditional V-belt is the wedge belt.

Figure 4.8 shows the construction of the wedge belt which consists of the following:

- A double cover for extra service and improved heat and oil resistance.
- A polyester or nylon cord for extra strength.
- A cord support cushion, in which the cord is embedded.
- A fibre loaded base for greater power transmission.

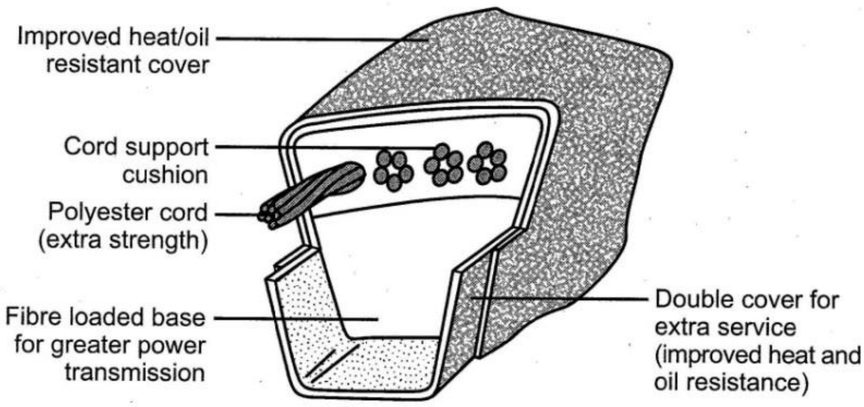


Figure 4.8 Construction of a V-belt

4.8.3 Differences between the construction of a V-belt and a wedge belt
The wedge belt is an improvement on the V-belt because it has:

- Longer sides.
- More reinforcement.
- A slightly round top surface to improve its stretching ability.
- A double cover for improved heat and oil resistance.

The differences in construction between a V-belt and a wedge belt are:

- The sides or flanks of wedge belts are longer in order to transmit more power.
- There is more reinforcement in a wedge belt in order to make it a stronger drive.
- The top surface of a wedge belt is slightly round.
- A wedge belt has a double cover for improved service.

A V-belt drive and a wedge belt drive differ only slightly from each other in that the groove in the pulley for the wedge belt is slightly deeper than for the ordinary V-belt. Thus, V-belts and wedge belts can fit in the same groove.

4.9 V-belt pulleys for single and multi-belt drives
Multiple V-belts or wedge belts are usually used for the transmission of power in heavy-duty loads. 'Multiple' means that more than one belt is used in the drive.

The number of belts used is determined by the power the drive has to transmit, because each belt size has a limit to the amount of power it can transmit at a given centre distance. **Figure 4.9** shows a multi-groove pulley with grooves for three belts.

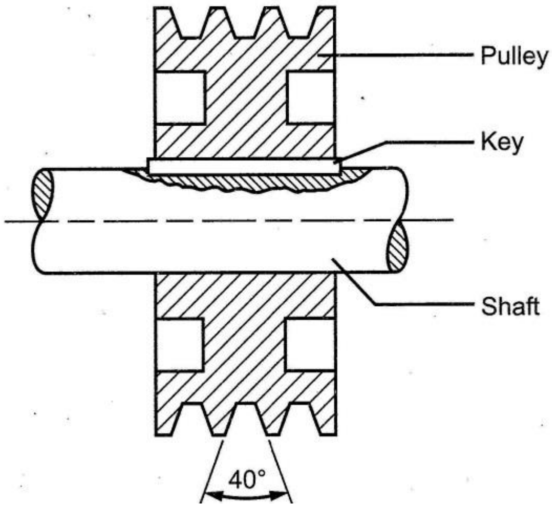


Figure 4.9 Multiple wedge or V-belt drive

Figure 4.10 shows that a V-belt should run with the top surface approximately in the same plane or level as the top of the pulley groove. The figure also shows that there should be a gap or clearance between the bottom of the belt and the base of the groove. V-belts are used on blowers, fans, compressors, pumps, belt conveyors, presses, vibrating screens and many other types of machinery.

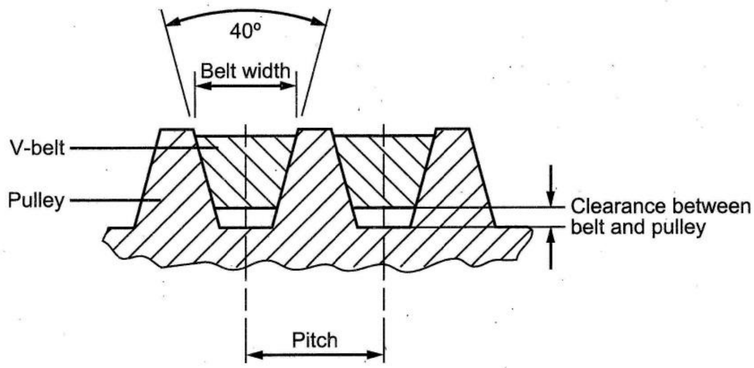


Figure 4.10 Multiple-groove pulley with belts

4.9.1 Advantages of V-belt and/or wedge belt drives

Advantages of V-belt and/ or wedge belt drives are:

- They can be used over short distances.
- You can buy V-belts in standard sizes and keep them ready for immediate replacements.
- V-belt drives and wedge belt drives are silent in operation.
- They need very little maintenance.
- They are able to absorb shock-loads.
- They operate at low bearing pressures.
- A number of V-belts running in a multi-groove pulley is suitable for heavy duty applications.

- If a V-belt breaks in a multiple V-belt drive, the machine can still run on the remaining belts. However, the drive should receive immediate attention.

4.10 Checking of V-belt sizes and lengths

When checking of V-belt sizes and lengths you need to select a suitable wedge belt drive, you must carefully consider the following important factors:

- The speed ratio.
- The service factor.
- The design power.
- The belt section.
- The minimum pulley diameter.
- The pulley pitch diameter.
- The centre distance
- The belt length.
- The correction factor.
- The basic power per belt.
- The additional power.
- The corrected power per belt.
- The number of belts required.

4.11 Maintenance, fault-finding and diagnosis

Adequate maintenance on V-belts and wedge belts is very important to ensure optimal operation and a long trouble free belt life.

You must take the following factors for the maintenance of V-belts and wedge belts into consideration:

- Check for damaged pulley contact surfaces that can cut or damage the belt.
- Check the condition of the belt and replace it when it has deteriorated.

Belts can deteriorate as a result of the following:

  - Small cracks due to excessive heat or chemical fumes.
  - Heat caused by slippage.
  - Incorrect tensioning of the belt.
  - Worn pulleys.
  - Fluid contamination that results in the swelling or softening of the belt.

- Follow the correct installation procedures. Avoid using a screwdriver or steel bar to lever the belt onto the pulley.
- Check the belt deflection at regular intervals, because belts tend to stretch.
- Check whipping of the belt during running. This can be the result of the following:

- o Incorrect tension, especially on long centre distances.
- o Critical vibration frequencies in the system.

- Store replaced sets of belts kept as spares under cool, well ventilated conditions to guard against over cure and resultant cracking and premature failure.

- The dressing creates a pull on the driving face or side flanks of the belt as it leaves the pulley. If you apply dressing to these belts, the jacket or cover of the belt will be pulled off after a short operating time and cause slip. Thus, slip must be overcome by:

  - o Replacing worn pulleys.
  - o Changing the belt tension.
  - o Getting rid of dust.
  - o Correcting the drive.

4.12 Installation of V-belt drives

If a belt is incorrectly installed it can cause excessive wear and uneven loads on the drive.

4.12.1 Centre distances

The centre distance between the driver and driven pulleys for a V-belt or wedge belt varies from approximately 200 mm to 4 800 mm depending on the pulley sizes used. A suitable centre distance is determined by the use and the physical requirements of the drive.

The centre distance can be read from centre distance tables in a catalogue or manual provided by the manufacturers of the belts. If the centre distance is not given in the tables, you can consider a drive with the smallest centre distance approximately equal to **D + d**.

As indicated in **Figure 4.11**, here **D** refers to the diameter of the bigger pulley while d refers to the diameter of the smaller pulley.

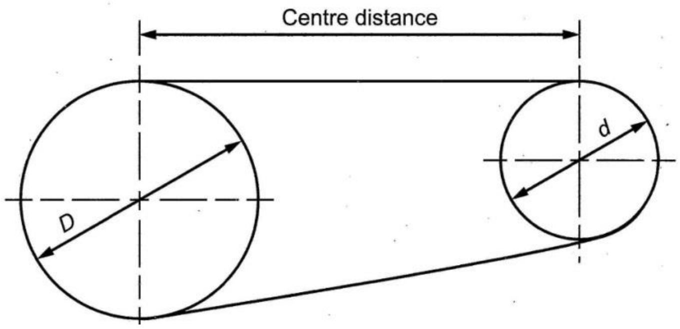


Figure 4.11 Centre distance between pulleys

4.12.2 Alignment and tensioning

Aligning shafts and pulleys is crucial to guarantee a trouble free drive. To check whether the pulleys and shafts are accurately set up and to align the shafts and pulleys you can hold a steel straight edge against the sides or flat surfaces of the pulleys.

Figures 4.12 and **4.13** show misalignment of shafts and pulleys. Misalignment can result in the following:

- Quick wearing of the belt flanks.
- Wearing of the pulleys.
- Uneven loads on the bearings.
- Excessive friction and heat between the belt and the pulley.

The following misalignments occur generally and you must avoid these when you install the shafts and pulleys:

- The shafts are not parallel to each other, as shown in **Figure 4.12**.

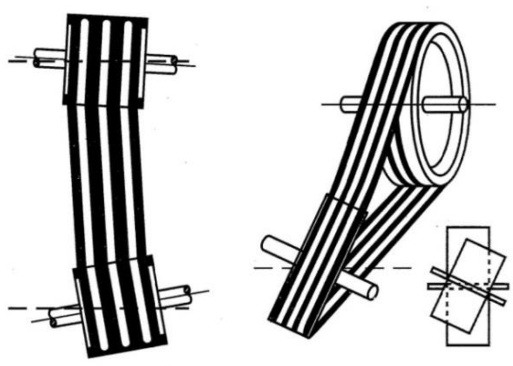


Figure 4.12 Shafts are not parallel

- The pulleys are not aligned as shown in **Figure 4.13.**

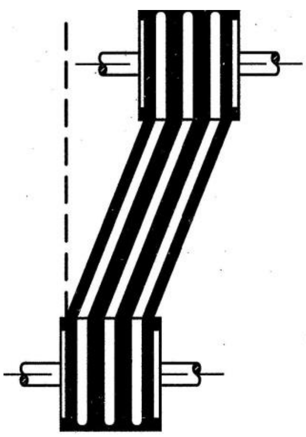


Figure 4.13 Pulleys are not aligned

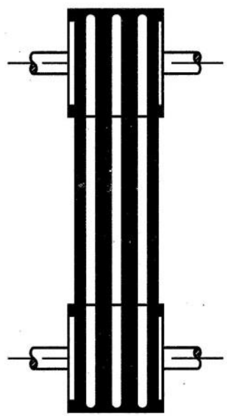


Figure 4.14 Shaft and pulleys are parallel and aligned

Figure 4.14 shows the correct way of installation to ensure that the shafts and the pulleys are parallel and aligned with one another.

4.12.3 Taking-up allowance, tension and slip on V- belts or wedge belts
Because V-belts and wedge belts are endless and have a fixed length, the only way to adjust them is to change the position of the motor. In other words, the centre distance between the pulleys can be changed.

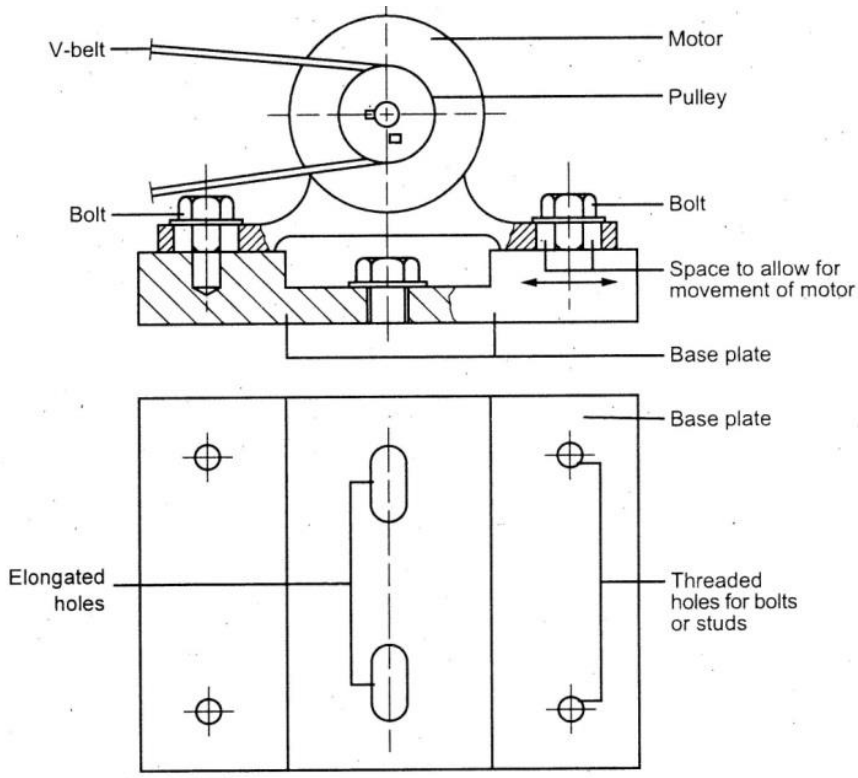


Figure 4.15 Tension on a V-belt or wedge belt
A common method of doing this is to mount the motor on an adjustable base plate or slide rails. **Figure 4.15 (a)** shows a motor that is mounted on a base plate.

Figure 4.15(b) shows a stud inserted into a threaded hole in the base plate.

We can move the base plate Stud backward or forward to adjust the centre distance between the drive and driven pulleys, or Base plate move the base plate sideways to align the pulleys. This is done by using the elongated holes or slots in the base plate as shown in **Figure 4.15(a)**. We then use studs to fix the base plate in position.

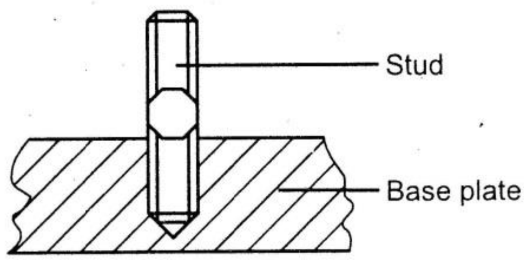


Figure 4.15 (b) A stud in position in the base plate

By loosening the bolts we can move the driving pulley closer to or further away from the driven pulley. In this way we adjust the tension on the belt, either by pulling the belt tighter or allowing the belt to slacken.

The amount of tension in the belt must be sufficient to prevent slip between the belt and the pulley and to ensure optimal operation. Slip means the unintentional movement between the belt and the pulley. Slip results in a loss of power and premature belt failure.

Belt deflection is the amount of movement or slackness in the belt. It must be measured under stationary conditions. To improve tension accuracy the drive should be run briefly to seat the belt before making the final measurement.

If you look at **Figure 4.16**, you will see that a straight edge should be put across the pulleys to act as a datum for measuring the amount of deflection.

Deflection of a belt is calculated in millimetres on the basis of 16 mm per metre of the centre distance.

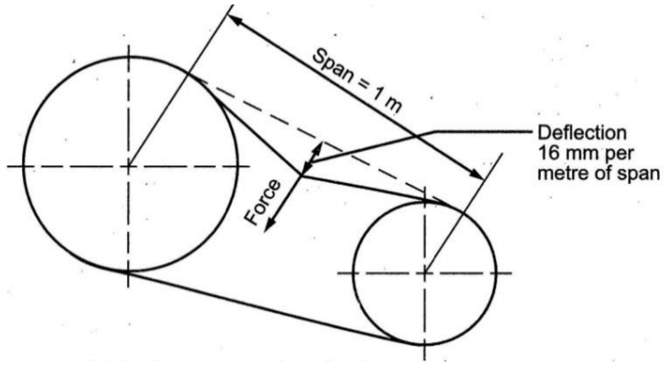


Figure 4.16 Deflection or movement on a V-belt or wedge belt drive

Deflection in mm = centre distance in mm x 16

V-belt tension gauges are also available.

4.12.4 The use of idlers on V-belts or wedge belts

An idler is a pulley installed between a driving pulley, or driver; and a driven pulley in order to take up slack in the belt and to guide and support the belt. You should never use idlers on V-belts or wedge belts in order to:

- Increase the arc of contact on the small pulley as shown in **Figure 4.17**.
- Increase the tension in the belt by adding pressure on the back of the belt.

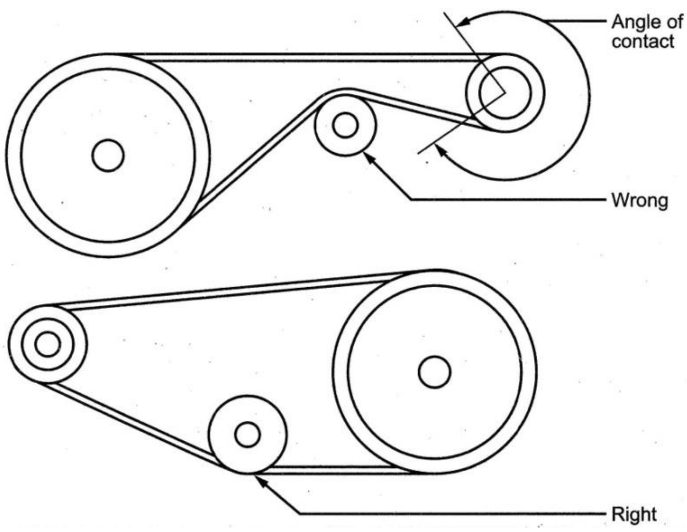


Figure 4.17 Position of the idler pulley

The arc of contact on the pulley must be compensated for by:

- Increasing the number of belts in the drive if there is no space to increase the centre distance.
- Using an idler on the inside of the belt. An idler on the back of the belt will cause cracks in the bottom or base section of the belt. The position of the idler pulley is shown in **Figure 4.17**.

Activity 4.1

1. List five the safety precautions that must be considered when working with belt drives.
2. Identify four uses for belts.
3. Name the types of belts available.
4. Describe the following V-belt terminology:
   - o Pulley pitch diameter
   - o Belt pitch length
   - o Arc of contact
   - o Centre distance
   - o Drive pulley
   - o Driver pulley
   - o Idler pulley
   - o Speed ratio
5. Describe the advantages of V-belt and wedge belt drives.
6. Describe the differences between the V-belt and wedge belt in terms of construction and power transmission.
7. Make neat drawings to show the construction of a V-belt and a wedge belt and name the materials that are used.
8. What is the purpose of a multiple wedge belt drive?
9. When you install a V-belt or a wedge belt drive, there are certain factors that you have to take into consideration. List and discuss these factors.
10. Explain the results caused by the misalignment of shafts and pulleys.
11. Name two ways in which the centre distance between the pulleys can be changed.
12. What is the result of slip on a V-belt or wedge belt drive?
13. Name the reasons why an idler should not be used on a V-belt or a wedge belt.
14. Describe the factors that you have to take into consideration for the maintenance of V-belts and wedge belts.
15. Explain the effect of belt dressing on V-belts or wedge belts.
16. During the selection procedure for a wedge belt drive, there are important factors that you must carefully consider. List these factors.
17. List the five different sections of wedge belts.

Self-Check

I am able to:	**Yes**	**No**
• Explain the difference between a v (vee) and wedge belt (endless and segment type) in terms of power transmission and instruction of the belt		
• Discuss the difference between wedge belt and chain drives in respect to pulleys, sprocket, slip, tension, maintenance, lubrication and centre distance		
• Select wedge belts by means of:		
• basic calculations		
• using a catalogue		
• Explain the installation procedure of wedge belt-, and chain drives		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 5

Gear Drives

Learning Outcomes
By the end of the module you should be able to:

- Explain the gear terms
- Identity and name gear types from given drawings
- Distinguish between the gear drives listed above in terms of constructional features and applications
- Differentiate between simple, compound and planetary epicyclic gear trains
- Explain the relationship between speed reduction and torque multiplication

5.1 Introduction

Gears are toothed cylindrical wheels used for transmitting mechanical power from one rotating shaft to another. Several types of gears are in common use.

Gear drives are positive methods of transmitting power. They are used under the following conditions:

- Where power is transmitted
- Where space is limited
- To change the direction of transmission
- Where a difference in speed is required
- Where high speeds are required.

5.2 Gear terms

5.2.1 Spur tooth gear profile

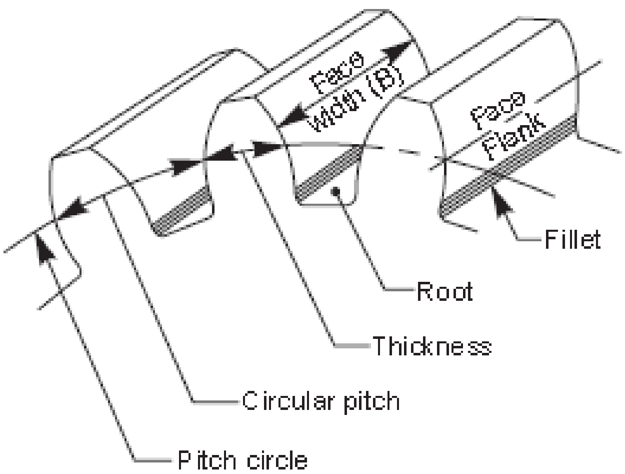
A number of curves may be used for the tooth profile. However, from a commercial stand point, cycloidal and involute curves are used. Of these two, involute form is extensively used because of its advantages from manufacturing and operational points of view.

5.2.2 Spur-gear terms

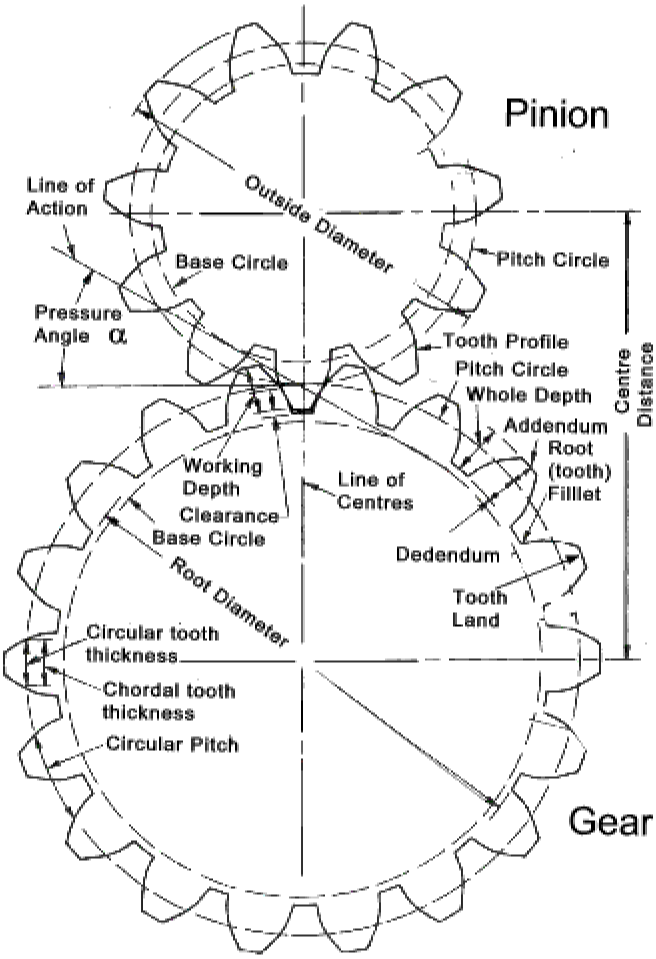
The gear ratio is the ratio of the number of teeth in the gear to the number of teeth in the pinion, the pinion being the smaller of the two gears in mesh.

The various spur gear terms are illustrated in **Figure 5.1(a) and (b)**

- The ***pitch-circle diameters*** of a pair of gears are the diameters of cylinders co-axial with the gears which will roll together without slip.
- The ***pitch circles*** are imaginary friction discs, and they touch at the *pitch point*.
- The **base circle** is the circle from which the involute is generated.
- The ***root diameter*** is the diameter at the base of the tooth.
- The ***centre distance*** is the sum of the pitch-circle radii of the two gears in mesh.
- The ***addendum*** is the radial depth of the tooth from the pitch circle to the tooth tip.
- The ***dedendum*** is the radial depth of the tooth from the pitch circle to the root of the tooth.
- The ***clearance*** is the algebraic difference between the addendum and the dedendum.
- The ***whole depth*** of the tooth is the sum of the addendum and the dedendum.
- The ***circular pitch*** is the distance from a point on one tooth to the corresponding point on the next tooth, measured round the pitch-circle circumference.
- The ***tooth width*** is the length of arc from one side of the tooth to the other, measured round the pitch-circle circumference.
- The ***module*** is the pitch-circle diameter divided by the number of teeth.



(a)



(b)

Figure 5.1 Gear terms

- The ***diametral pitch*** is the reciprocal of the module, i.e. the number of teeth divided by the pitch-circle diameter.
- The ***line of action*** is the common tangent to the base circles, and the path of contact is that part of the line of action where contact takes place between the teeth.

- The ***pressure angle*** is the angle formed between the common tangent and the line of action.
- The ***fillet*** is the rounded portion at the bottom of the tooth space.

5.3 Gear drives

5.3.1 Simple spur gears

In simple spur gears the teeth are straight and cut parallel to the axis of the shaft. When a small wheel drives a larger wheel, the small wheel is called the pinion, while the larger wheel is called the spur wheel. Spur gears are used for medium speed drives (See **Figure 5.2**).

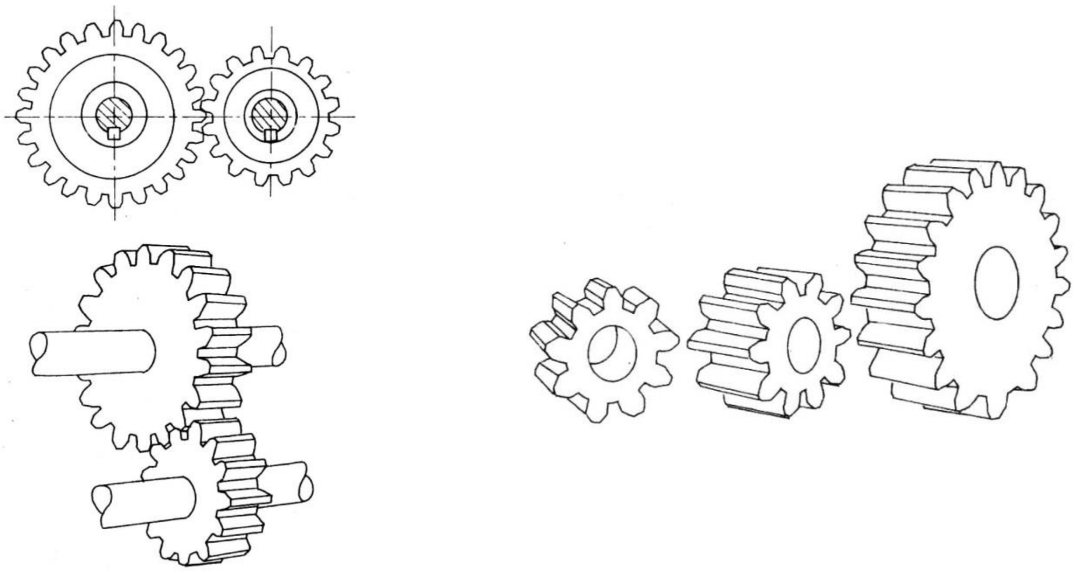


Figure 5.2 Spur gears

5.3.2 Bevel gears

Bevel gears are used to connect shafts whose axes intersect. The angle between the axes is usually 90°, but may have any value up to 180°. If two bevel gears are of the same size and dimensions, and their axes intersect at right angles, they are known as mitre wheels or mitre gears. (See **Figure 5.3 (a)** to **(c)**

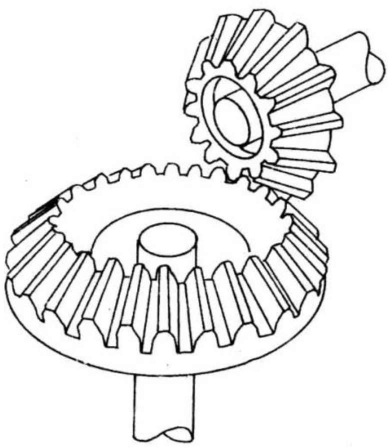


Figure 5.3 (a) Bevel gear

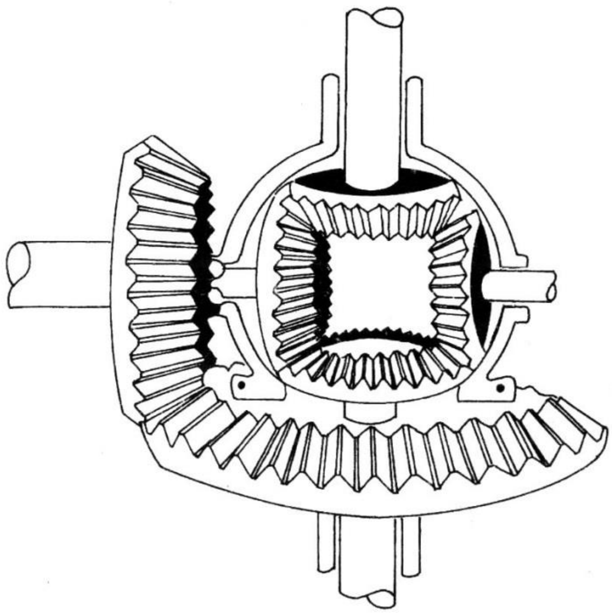


Figure 5.3 (b) System of bevel gearing

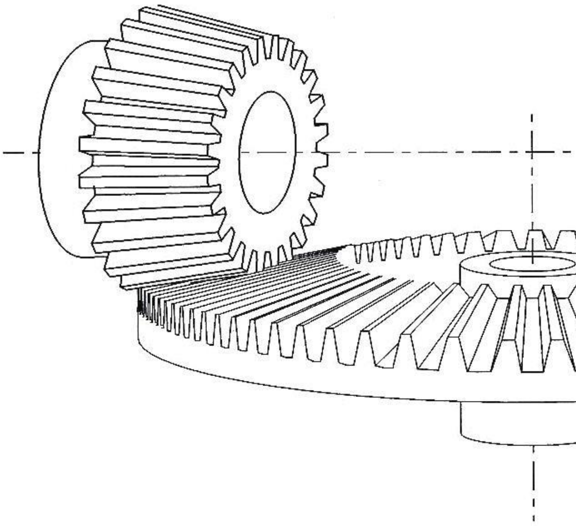


Figure 5.3 (c) Bevel gear system

5.3.3 Helical gears

Helical gearing is different to spur gearing in that the teeth are cut at an angle across the circumference of each wheel. Helical gears run more smoothly and quietly than spur gears since there is more than one tooth engaged at any one time. (See **Figure 5.4 to 5.6**) A great advantage which helical gears have over spur gears is their ability to carry heavier loads because of the increased length of the teeth.

- **Single helical gears**

A disadvantage of these gears is that side thrust is developed.

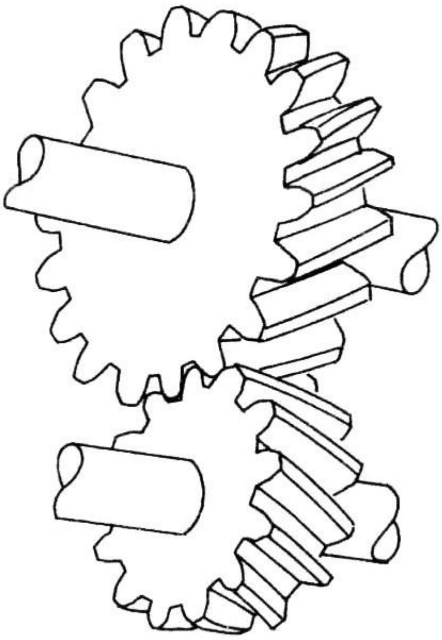


Figure 5.4 Single helical gear

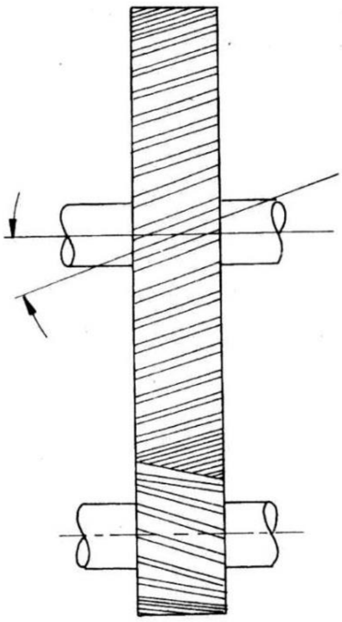


Figure 5.5 single helical gears, showing

end thrust

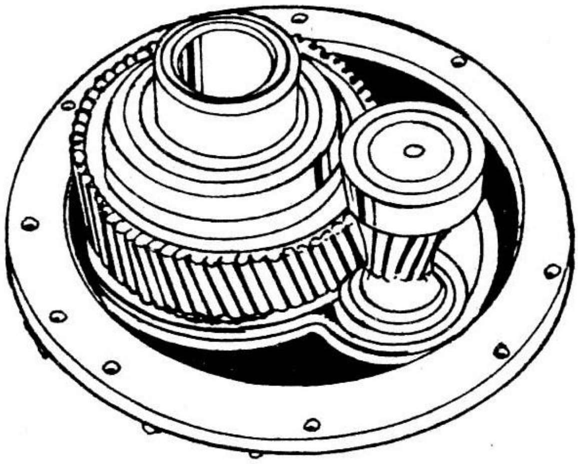


Figure 5.6 Gearbox (helical gears)

- **Double helical or herringbone gears**

This type of tooth neutralises end thrust. They are, however, difficult to cut and are therefore fairly expensive. (See **Figure 5.7 and 5.8**)

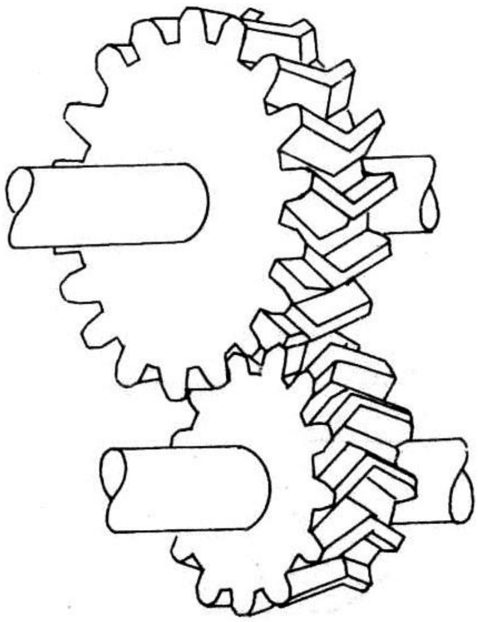


Figure 5.7 Double helical gear

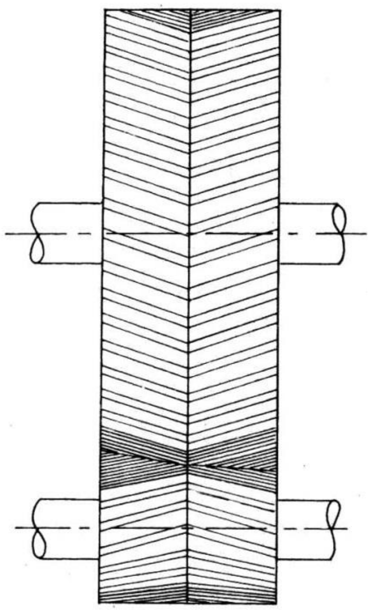


Figure 5.8 Double helical gears

- **Spiral**

These are similar to helical spur gears, except that they connect shafts which are not parallel. (See **Figure 5.9**)

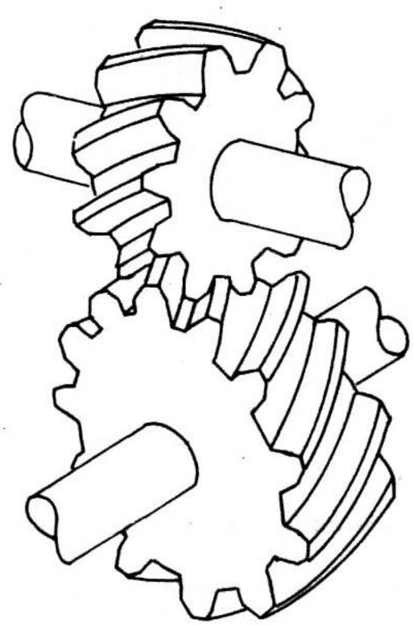


Figure 5.9 Spiral helical gears

5.3.4 Rack and pinion gears

A rack and pinion may be used when it is necessary to convert rotary motion to straight line motion. This is desirable for the table feed of milling and planning machines. (See **Figure 5.10**)

The rack may be regarded as a wheel of infinite diameter. The sides or flanks of the rack teeth are straight and inclined towards each other at an angle of 29°.

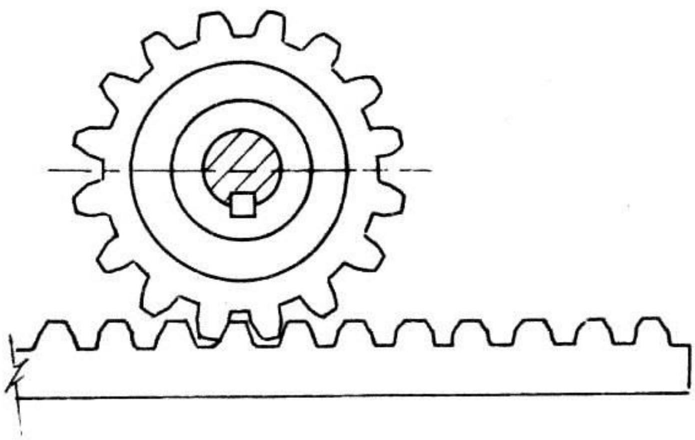


Figure 5.10 Rack and pinion gears

5.3.5 Internal gears

Internal gears may be used for transmitting motion between parallel shafts. An internal wheel and a pinion rotate in the same direction. As will be seen, internal gears are very useful for the composition of a planetary system of gear drives. (See **Figure 5.11**)

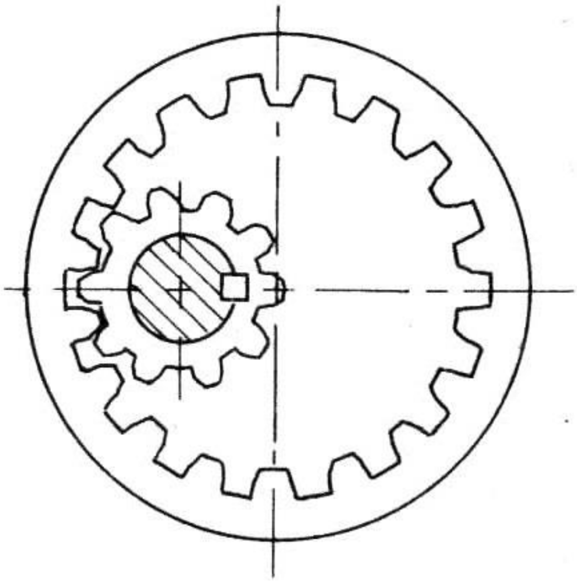


Figure 5.11 Pinion meshes with internal gear

5.3.6 Worm gears

Worm gears are used where high ratios of reduction are required. It is more or less an ordinary screw thread, whose threads engage with a specially adapted spur wheel.

The teeth on the spur wheel must be curved inwards to conform to the toothed thread on the worm. The drive shaft carrying the worm gear develops end thrust and therefore requires a thrust bearing. (See **Figure 5.12 to 5.14**)

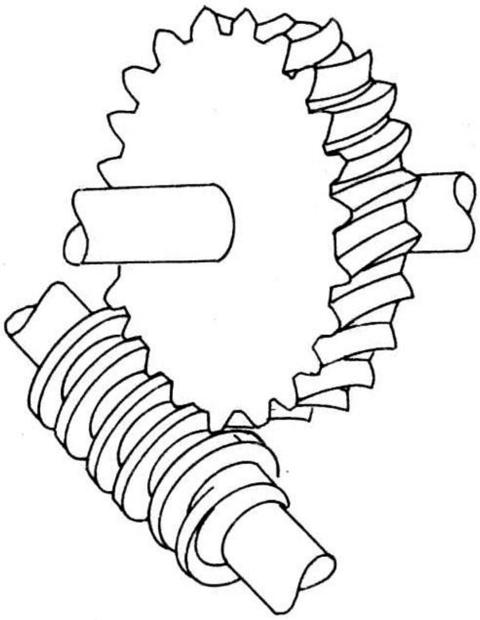


Figure 5.12 Worm gearing

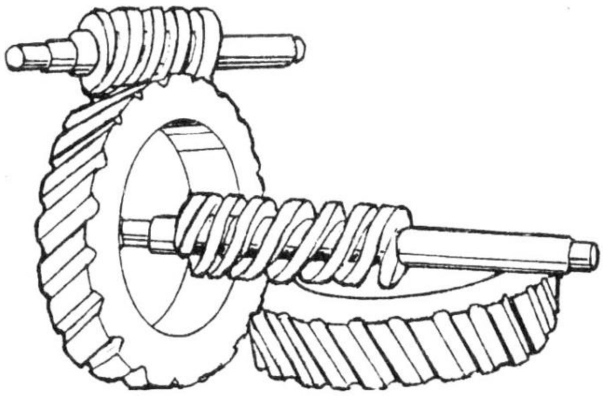


Figure 5.13 Worms and worm gears

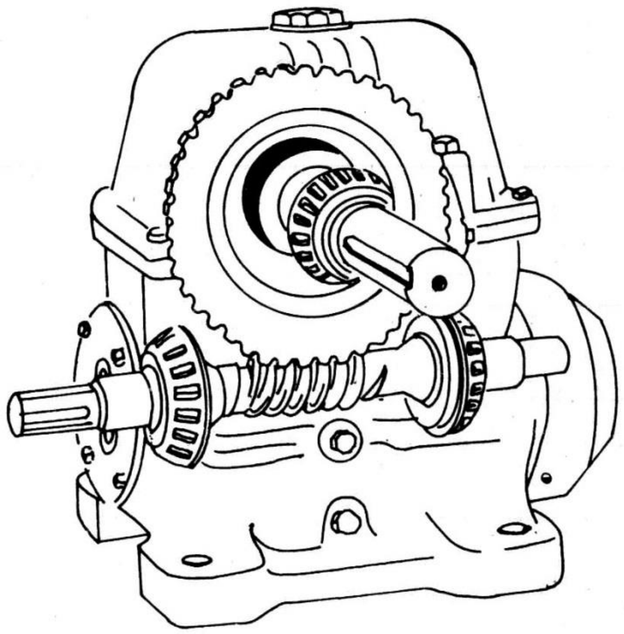


Figure 5.14 Reduction gear box

The drive is normally possible from the worm to the worm wheel and not in the reversed direction, because of friction.

5.3.7 Hypoid gears

They join shafts which are neither parallel nor intersecting. Their design allows the pinion shaft to be placed below the shaft of the gear. Hypoid gears are used in automobile drives. (See **Figure 5.15**)

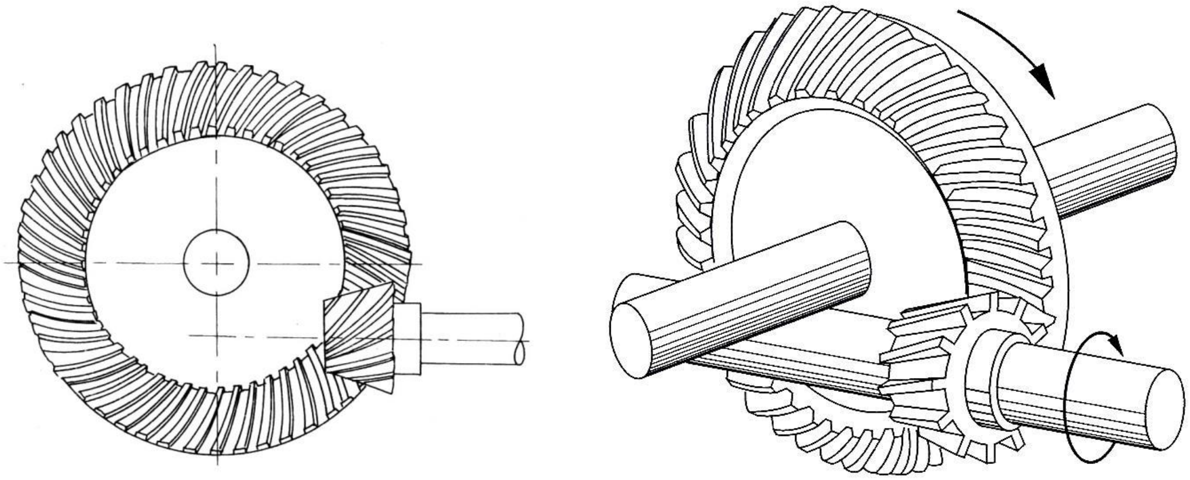


Figure 5.15 Hypoid gears

5.4 Advantages of gear drives

Compared with belt, chain or other drives, gear drives have the following advantages:

- There is a positive drive because there are no belts that can slip.
- Gear drives transmit power directly, without any additional means such as belts, chains or ropes.
- Gear-wheel systems such as the gearbox of a lathe or a motorcar are much more compact.
- Gear drives can transmit fairly large amounts of power.
- The radial loads on the bearings of the gear system are low.

5.6 Simple gear drives

Gears are used for several different purposes, one of the most important being for the increase or reduction of speed. It is a well-known fact that if two pulleys of the same diameter are connected by a belt then they will both revolve at the same speed.

All these speeds refer to the number of revolutions per minute (r.p.m.) and not to the speed of the circumference (usually given in metres per second). If, however, one pulley is twice as large as the other the ratio of the r.p.m. is 2:1, which means that the smaller pulley will revolve twice as many times as the larger pulley.

If the larger wheel B, is driving the smaller wheel A, the speed is stepped up or increased to double the original amount. However, if the smaller wheel is driving the larger wheel the speed is reduced by half. This is known as reduction or stepping down.

Exactly the same theory is applied to gearing, as the number of teeth in a gear varies according to the diameter. Thus if a 60 mm diameter gear has twenty teeth, then a 120 mm diameter gear to run with it would have forty teeth, and the speed ratio of the shafts would be 2 : 1. (See **Figure 5.16**)

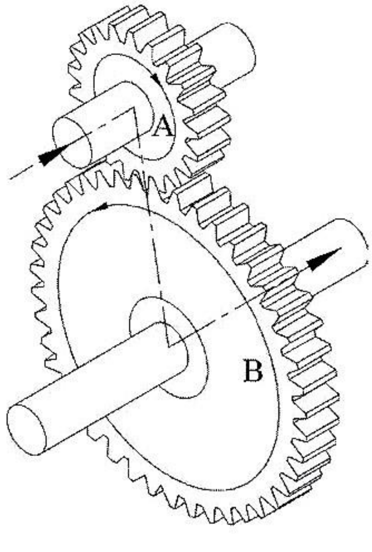


Figure 5.16 Simple gear drives

5.7 Compound gear drives

In the compound gear drive we find the difference not in the amount of gears used, but in the fact that on a shaft one may find more than one gear fitted. A single shaft may serve as a driver or as a driven gear to the system.

In the **Figure 5.17**, the velocity of gears .1 and 2 must be the same (they are in mesh). The same applies to gears 3 and 4. The rotational speed (revolutions) of gears 2 and 3 must be the same (they are attached to the same shaft). The first reduction occurs between gears 1 and 2 whilst the second reduction occurs between gears 3 and 4.

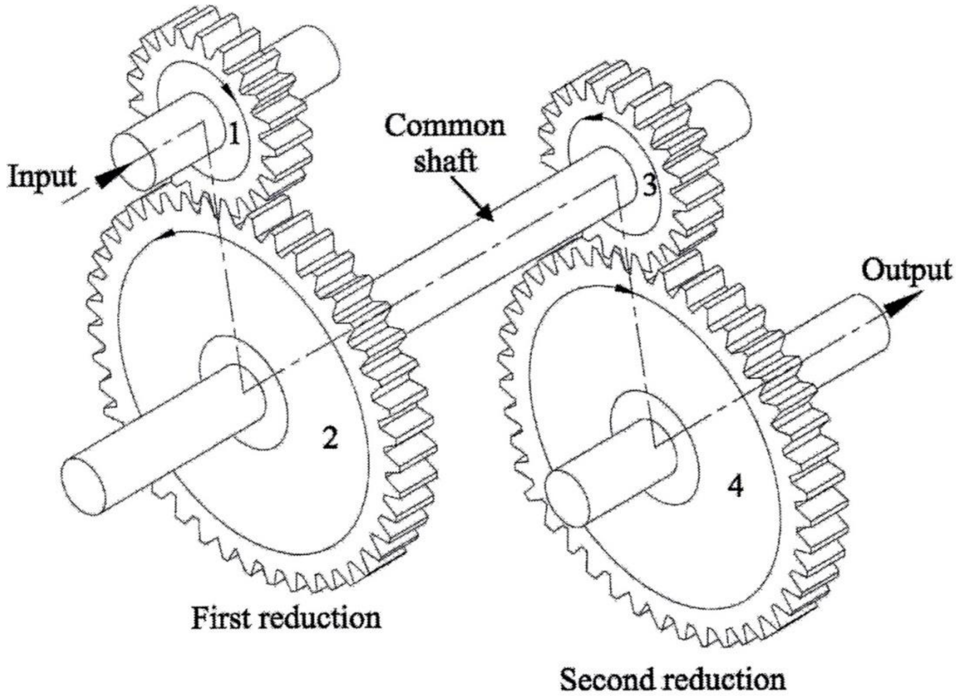


Figure 5.17 Compound gear drives

5.8 Epicyclical bevel gear assembly

In this type of gear assembly each bevel gear can rotate freely around its own shaft (see **Figure 5.18**). By fixing one gear at a time, different speeds can be obtained.

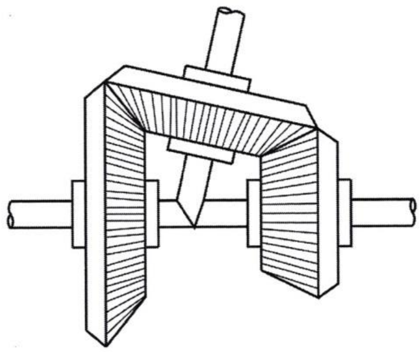


Figure 5.18 Epicyclic bevel gear assembly

5.8.1 Advantages of an epicyclic rear train

Epicyclic gear trains have the following advantages:

- A very high velocity ratio can be obtained between the input gear and the final driven gear.
- A very large number of gear combinations may be obtained.
- Epicyclic gearboxes are very compact.

Figure 5.19 illustrates the terminology applied to epicyclic gear trains.

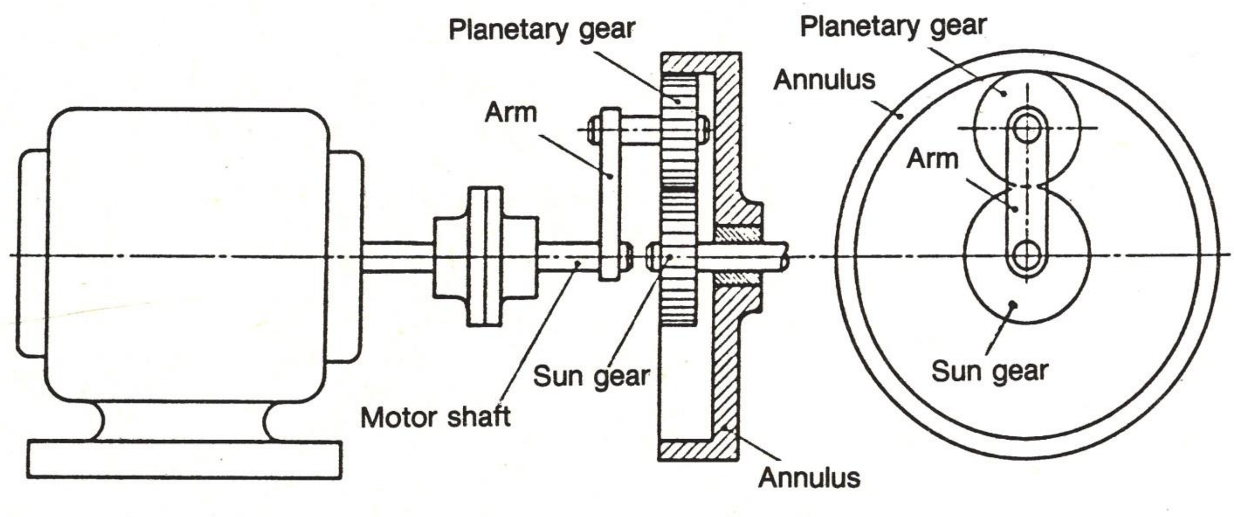


Figure 5.19 Terminology for an epicyclic gear train

5.9 Planet gear system

The sun gear is mounted in the middle of this assembly. **Figure 5.19** shows that a planet carrier supports a few planet gears. If the planet carrier rotates, it causes the planet gears to rotate in their own planetary orbits around the sun gear. The planet gears mesh with the teeth on the inside of the internal ring gear. By keeping the different parts of the assembly fixed in turn, we can obtain different speed ratios and direction of rotation.

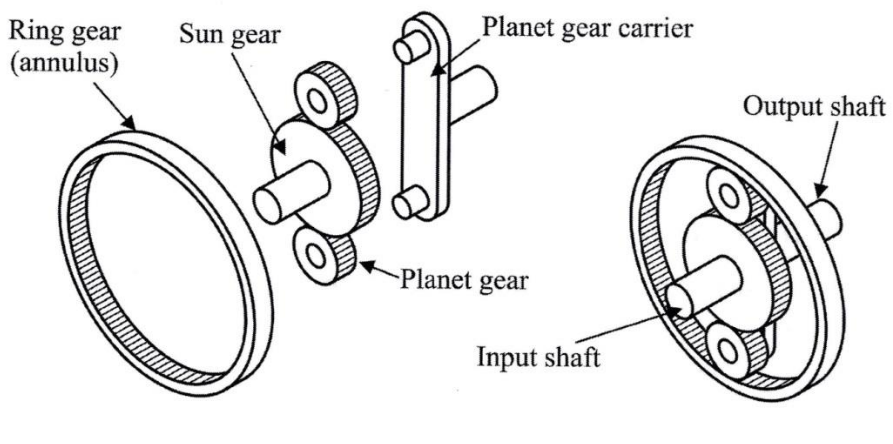


Figure 5.19 Planet gear assembly

By using a planet gear assembly, the following can be obtained:

- Direct drive by locking any two parts together.
- Speed reduction by fixing the sun gear and driving the internal ring gear by means of the planet carrier.
- Reverse gear by fixing the planet carrier.
- Neutral by connecting the sun gear, the input shaft and the planet carrier to the output shaft.

5.10 Relationship between speed reduction and torque multiplication

Reduction gearing considerably reduces the speed of power drives, but at the same time enables heavier work to be done without the load causing the motor to stop.

In fact, as the ratio of reduction increases so does the torque of the drive increases. This accounts for the extensive use of reduction gears in the design of rolling mills for rolling billets of hot steel into flat sheets. As can be seen, it would be impossible to drive the rollers direct from a motor for two reasons, firstly the speed of the motor would be too fast; and secondly, the heavy load thrown on to the motor would cause it to stop rotating. By introducing suitable reduction gearing the motor can drive the rollers with ease.

By reversing the above process the speed of a driving shaft can be 'stepped up' to a considerably higher speed, but in this case the drive is not capable of transmitting very heavy loads, as in the case of reduction gearing. This type of gearing is often used to drive blowers and fans which require high speeds but do not offer heavy loads.

These represent the simplest types of gear reduction arrangement. Only two components are involved, the driving pinion whose shaft is connected in some manner to the driving motor, and the driven gear whose shaft is usually the output shaft of the gear unit. These two gear components combine to form a single-reduction gear train.

Activity 5.1

1. Explain, in your own words, the following as related to spur gears:

   a) Circular pitch
   b) Gear wheel
   c) Base circle
   d) Centre distance
   e) Backlash
2. State ONE advantage and ONE disadvantage of double helical gears.

3. Under which circumstances will you make use of gear drives? (Reasons for using gears.)
4. Indicate, with a simple freehand drawing, where an idler will be placed so as to change direction of a spur gear system. Indicate the names and directions of each gear.
5. Give the advantage of a double helical gear as compared to a single helical gear.
6. Indicate, with a freehand sketch, where play will be found between TWO gear teeth.
7. Give THREE reasons why/when gear drives can be used.
8. Explain what you understand by the words *base circle of* a *gear.*
9. Make a neat sketch of a rack and pinion gear drive and indicate the names of all components.
10. Explain the operation of a rack and pinion gear drive
11. Give the advantages of a single helical gear system over a straight-cut gear system.
12. Explain the relationship between speed reduction and torque multiplication.
13. By means of a neat sketch explain the compound gear drive.
14.

Self-Check

I am able to:	**Yes**	**No**
1. Explain the gear terms		
2. Identity and name gear types from given drawings		
3. Distinguish between the gear drives listed above in terms of constructional features and applications		
4. Differentiate between simple, compound and planetary epicyclic gear trains		
5. Explain the relationship between speed reduction and torque multiplication		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 6

Shaft Couplings

Learning Outcomes
By the end of the module you should be able to:

- Identify from given drawings and list the categories and types of couplings
- Describe the features of couplings
- Identify and label the basic parts of the couplings

6.1 Introduction

It is obvious that it is neither possible nor desirable to have shafting too long, since it is difficult to roll it into long lengths and to keep straight. The inconvenience of handling, the weight and transport are further considerations.

Shafting is therefore made into convenient lengths and connected up to the required length.

Thus, if a long shaft is required, a number of lengths are coupled end to end by means of couplings of the following types:

- Fast, or permanent, rigid couplings
- Self-aligning couplings
- Flexible couplings.

Couplings are used to connect the shaft of a driver, such as a motor, to the shaft of a driven, such as a pump. Couplings are manufactured in many types and sizes. Some coupling types allow for slight misalignment and end play, or shaft float, between the rotating shafts.

Some couplings reduce, or dampen, or absorb vibrations or torque. Other couplings insulate the coupling halves from any electrical current transfer, which is common in some motor generator sets.

In order for equipment to operate properly and efficiently, the proper coupling must be used to connect the driver to the driven. It is also very important that the equipment be properly aligned and the coupling properly installed.

Driven: The device being driven. The driven may be a gear case, pump, or generator.
Driver: The prime mover of a system. The driver is usually a motor..

6.2 Fast, or permanent, rigid couplings

As the name implies, fast, or permanent couplings rigidly connect the driver and driven shafts. These rigid couplings do not compensate for misalignment and require precise alignment during installation. If a rigid coupling is misaligned and forced together, the drive will be damaged.

Even slight misalignment can cause vibration and operating problems. Rigid couplings are manufactured in several styles. The following are the three most common rigid couplings:

- Flanged
- Sleeved
- Ribbed (muff coupling)

6.2.1 Flanged couplings

Flanged couplings join the driver and driven shafts, using two mating flanges. One coupling flange fits on the driver shaft, and the other fits on the driven shaft. The connection between the two halves is made by bolting the flanges together. Flanged couplings require keys to prevent them from rotating on the shafts and require precise alignment. **Figure 6.1** shows a flanged coupling.

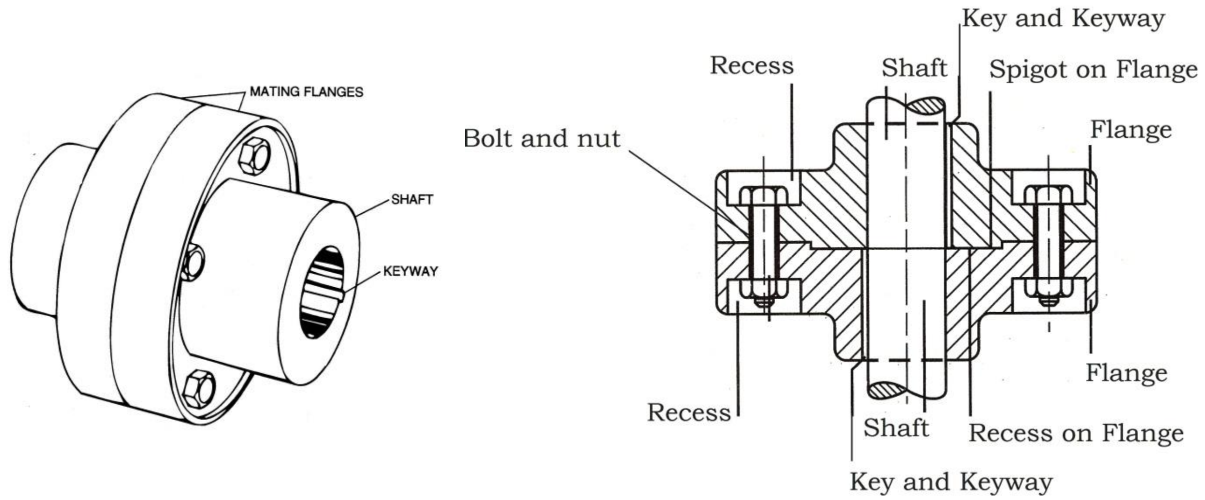


Figure 6.1 Flanged coupling

6.2.2 Sleeved couplings

Sleeved couplings, also called compression couplings, are very similar to flanged couplings, except that they are taper-bored and have tapered sleeves that fit on the shafts. The wedge principle is used to tighten the coupling on the shafts. As the two halves of the coupling are pulled together over the tapered sleeve by the flange bolts, the couplings halves are tightened on the shafts. Sleeved couplings do not require keys, are normally used on small-diameter shafts, and are not suitable for transmitting heavy loads. **Figure 6.2** shows a sleeved coupling.

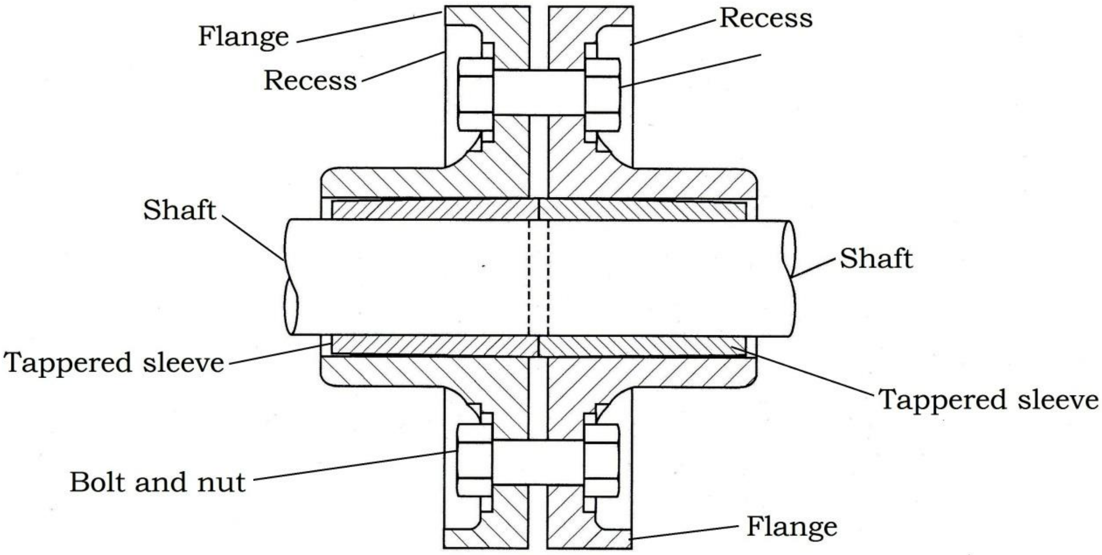


Figure 6.2 Sleeved coupling

6.2.3 Ribbed (Muff) couplings

The first and simplest design for connecting two shafts, the axes of which are in perfect alignment, is by use of the sleeve, or muff, coupling. The design consists of a cast iron cylinder fitting neatly over the end of the shafts and keyed in place by a long sunken key. In some cases the ends of the shaft are enlarged so as to allow the keyway to be cut without weakening the shaft. (See **Figure 6.3 (a)** and **(b)**

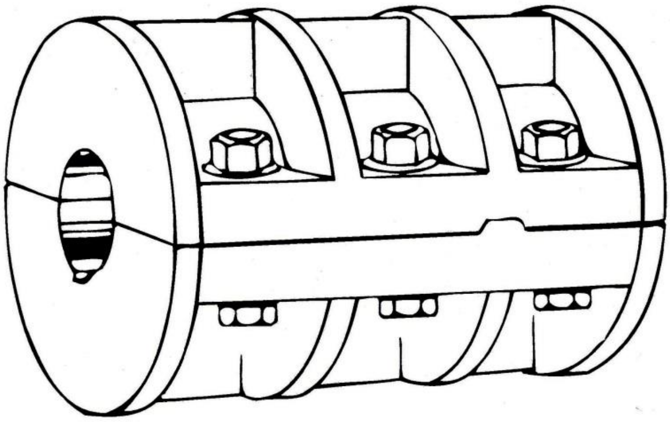


Figure 6.3 (a) Ribbed (muff) or split sleeve coupling

Ribbed (muff) couplings, also called clamp couplings, are made in two pieces. They are used when sleeved couplings are difficult to install.

The advantage of a ribbed coupling is that it can be installed on shafts that are already in place without moving one of the shafts. Ribbed couplings are used when the shafts are the same size and are also used for low-speed drives because of their unbalanced design and weight distribution.

A bearing is generally positioned relatively near to the coupling in order to steady the shaft and affect greater efficiency in the coupling design.

The coupling consists of a fixed half, which is firmly keyed to its shaft, and a sliding half, which is free to move along its feather, being moved by a fork fitting over the recess shown.

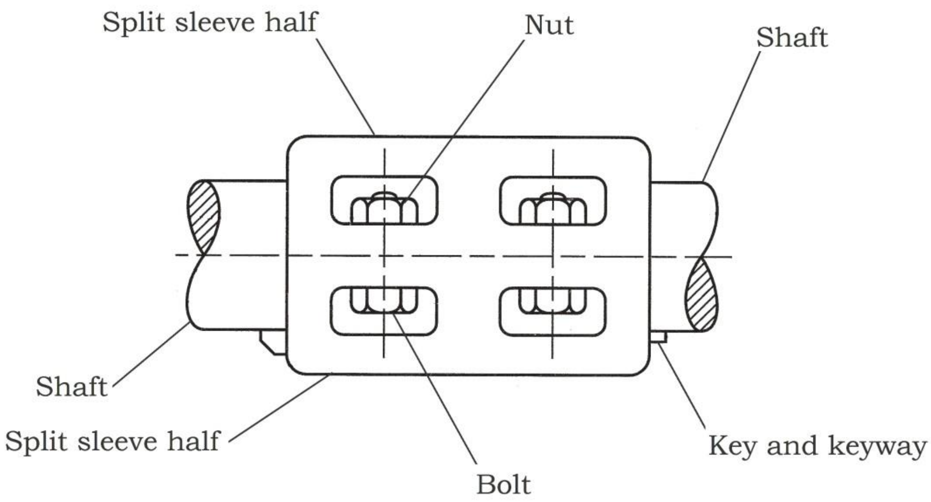


Figure 6.3 (b) Ribbed (muff) or split sleeve coupling

6.2.4 Marine couplings

These are similar to the flange couplings, except that the flange is not fitted to the shaft, but forged in one piece. Conical bolts are generally used to bolt the flanges together. The bolt holes are accurately bored and eased to the correct taper only when the flanges are together. (See **Figure 6.4**)

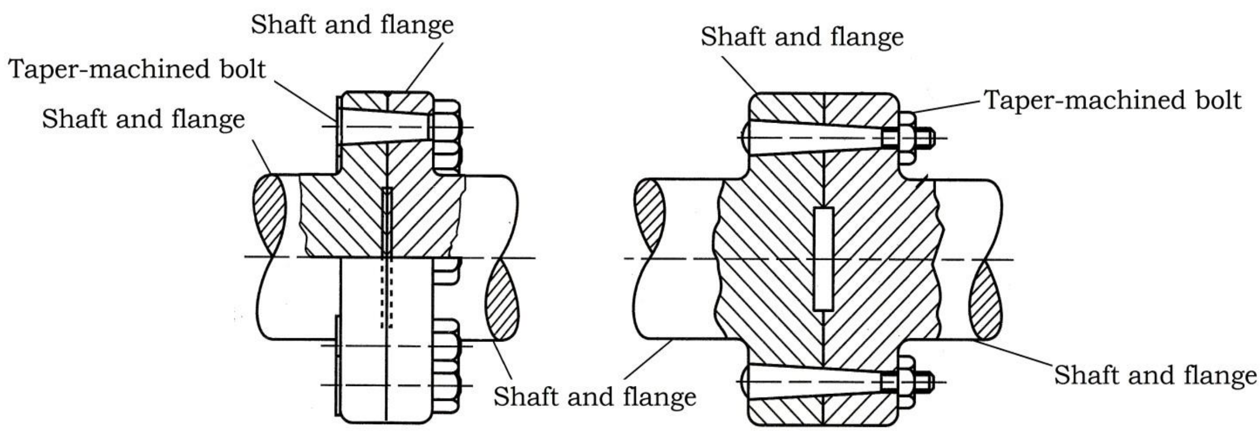


Figure 6.4 Marine couplings

Activity 6.1

1. What are the three most common types of rigid couplings?
2. Which coupling is also called a compression coupling?
3. Which coupling is also called a clamp coupling?
4. Make a neat freehand drawing of the following couplings:
   4.1 Muff (Ribbed) coupling
   4.2 Flanged coupling
   4.3 Sleeved coupling with tapered sleeves
5. Describe a marine coupling

6.3 Flexible couplings

When direct driving takes place, for example between an electric motor and machine, it is very difficult to obtain perfect alignment of the four or more bearings involved. Rigid couplings do not permit errors in alignment.

Owing to the difficulty of maintaining perfect alignment as required by rigid couplings, it is apparent that trouble and loss of power through friction is inevitable.

Flexible couplings therefore provide the solution to the connecting up of shafting that is slightly out of alignment. There are several types and forms of flexible couplings.

Flexible couplings are much more commonly used than rigid couplings because they are usually easier to install and maintain and do not require precise alignment.

Some flexible couplings allow for more severe misalignment than others. Although flexible couplings allow for some misalignment, they should be aligned as close as possible using the methods available for maximum coupling life. For instance, a coupling may have a maximum tolerance of .010, but it cannot be used at that amount of misalignment without shortening the life of the coupling.

When selecting a coupling for a particular application, it is important that it meets the necessary speed, horsepower, and other requirements. The following considerations are made when a coupling is selected:

- Will the coupling be simple to install and remove?
- Can the parts be easily replaced after normal service wear?
- Can the alignment be done using simple tools, such as a straightedge and feeler gauge, or will special tools, such as a dial indicator, be needed?

Flexible couplings should not be used when major **angular misalignment** is known to exist. Deliberate misalignment requires the use of universal joints.

Angular misalignment: The condition that occurs when two shafts are misaligned at an angle.

Flexible couplings can be divided into the following two main categories:

- Mechanical
- Material

6.3.1 Mechanical flexible couplings
Mechanical flexible couplings have metal components that may or may not need lubrication. They use the play, or clearance, in a mechanical device, such as chains or gears, to compensate for misalignment. The four major types of mechanical flexible couplings are the following:

- Slider
- Gear
- Chain
- Grid

6.3.2 Slider Couplings
Slider couplings allow for angular and parallel misalignment. They are designed for low speed and high-torque applications and are rated up to a maximum speed of 100 rpm. Slider couplings have three pieces: a slider and a two-jawed coupling half for each shaft. The slider is driven by one of the two-jawed coupling halves, which in turn drives the other coupling half. Some types have replaceable wear faces on the jaws. **Figure 6.5** shows a slider coupling.

6.3.3 Jaw couplings
- **Square jaw couplings**

They are best adapted to slow speeds and positions where slip cannot take place, and are ideal for transmitting heavy loads. The machinery should always be stopped to make engagement, otherwise broken or badly worn dogs will result. (See **Figure 6.3**)

- **Spiral jaw couplings**

This type of coupling can be driven in one direction only and immediately disengages when the direction of rotation is reversed.

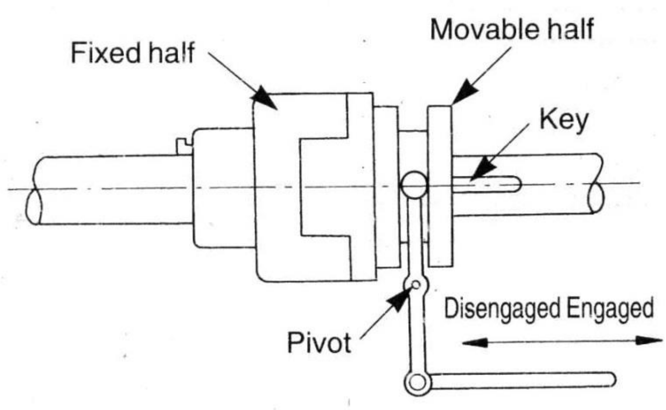


Figure 6.3 Claw coupling (square jaw)

Figure 6.4 Marine coupling

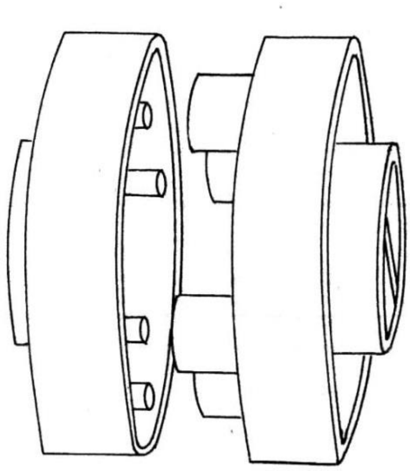


Figure 6.6 Flexible coupling

6.3.4 Pin-type couplings

The flanges A and B are provided with alternate holes tapped to accommodate bolts which hold a number of rubber or leather washers in place, while the remaining holes are enlarged to fit the washers comfortably.

When the coupling fits together, the washers not only stop any shocks and vibration that may occur, but they also act as insulators of electric current flowing from motor to machine. (See **Figure 6.7**)

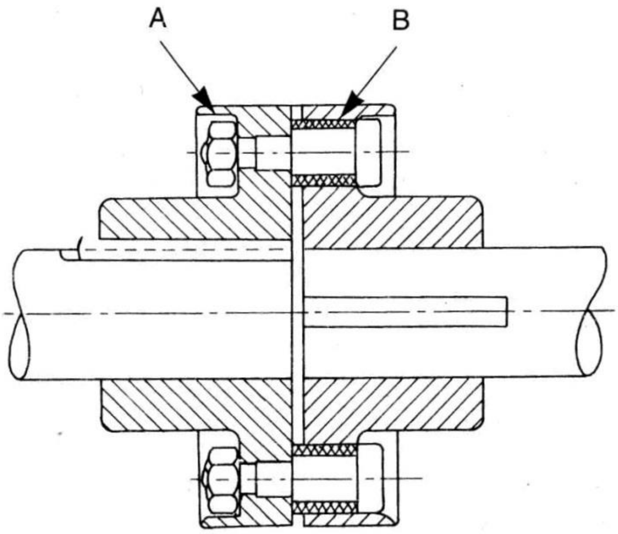


Figure 6.7 Pin-type flexible coupling.

6.3.5 Bibby couplings

In this type of coupling, two grooved discs, one on each shaft, are connected by a grid spring. The grooves are cut in the outside of the discs and when the spring is placed in then, a flexible and resilient bridge is formed. (See **Figure 6.8**)

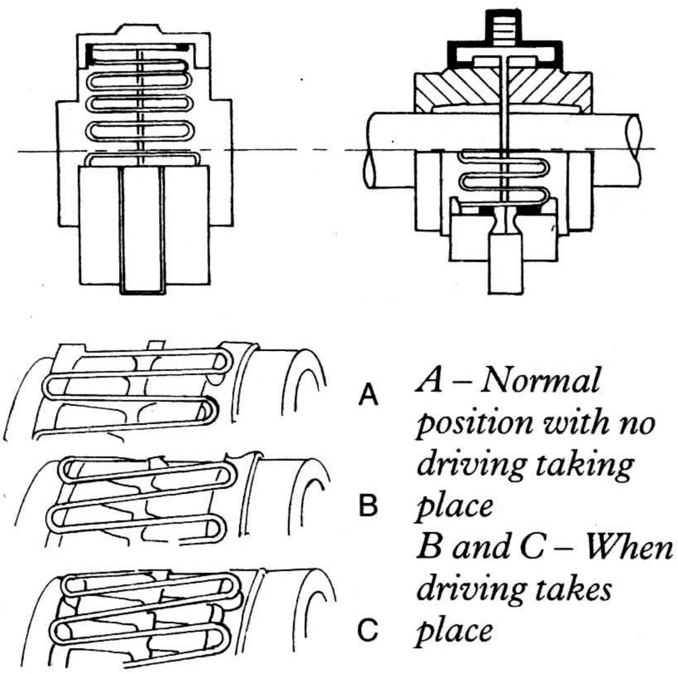


Figure 6.8 Bibby coupling

The grooves are flared in such a way that the spring members have long flexible spans at normal loads, but become supported by the sides of the grooves when overloads occur. This feature effectively prevents overstressing of the springs (See **Figure 6.9)**

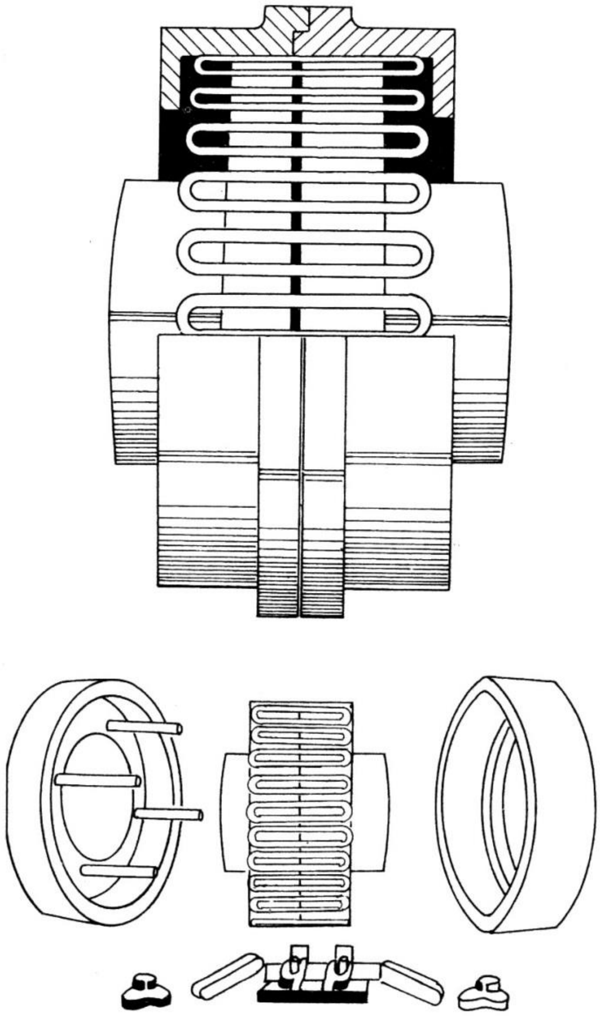


Figure 6.9 Bibby flexible coupling

6.3.6 Raffard couplings

This is a link type of coupling, which allows both axial and lateral flexibility. Leather or rubber bands are usually used for coupling each pair of pins together. The raffard coupling also insulates the motor electrically from the engine or machine. The position of the inclined band (shown by the dotted line) is adopted as soon as driving takes place (See **Figure 6.10**).

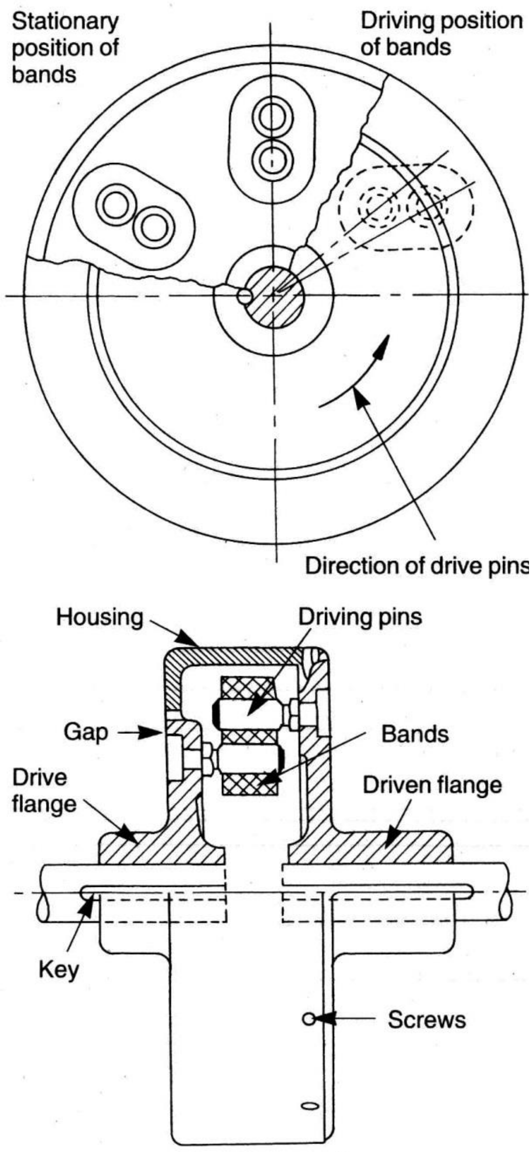


Figure 6.10 Raffard coupling

6.3.7 Laced belt couplings

The coupling consists of two flanges, A and B respectively, attached to the ends of the piece of shafting. Steel pins C project from the flanges, those on one flange being placed on a larger pitch circle than those on the other.

A leather belt D is laced through these pins and transmits the force from one set to the other. This style of coupling is very flexible and satisfactory for slow speeds and heavy loads. (See **Figure 6.11**)

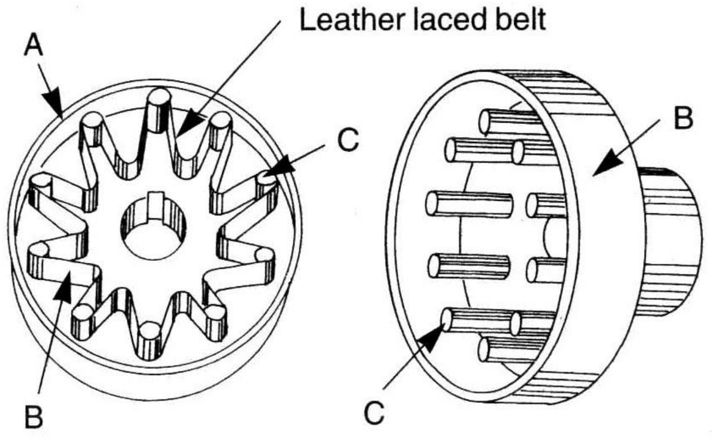
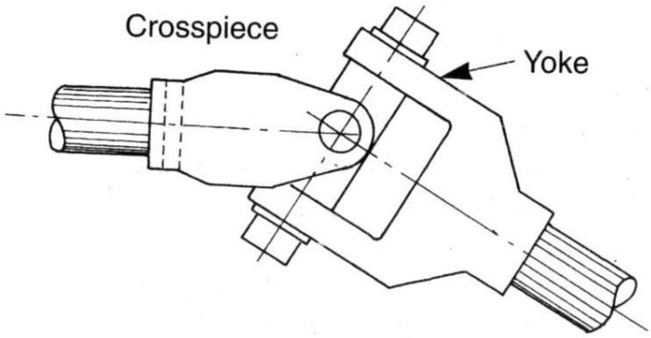


Figure 6.11 Laced belt couplings

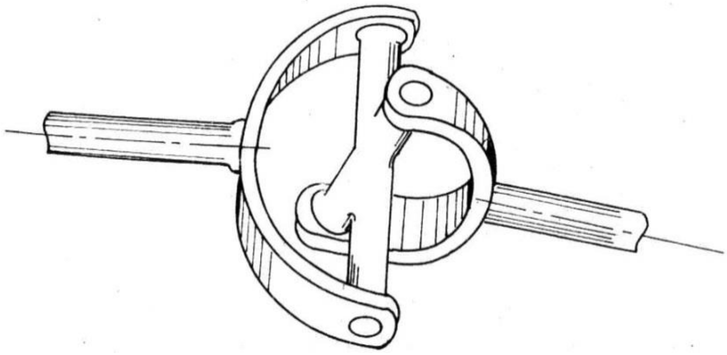
6.4 Self-aligning couplings

6.4.1 Universal coupling

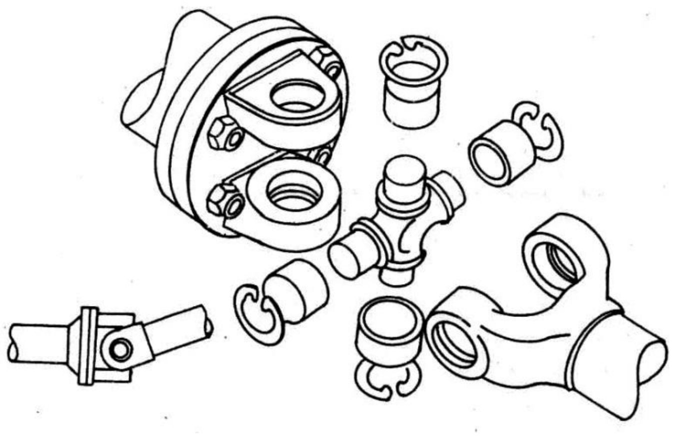
Universal coupling is also known as Hooke's coupling. The construction of this coupling is shown in **Figure 6.12 (a)**. It connects shafts whose axes are at an angle other than 180°, i.e. whose axes would intersect if produced. The angle between the shafts may be varied while the shafts are in motion.



(a)



(b)



(c)

Figure 6.12 (a) to (c) Universal shaft couplings

6.4.2 Oldham Couplings

Neither of the above-mentioned couplings can be used when the axes of the pieces of shafting to be joined are not in a straight line. Where the axes of the shafts are parallel, the Oldham coupling illustrated in **Figure 6.13** has given good results.

It consists of three pieces. Parts A and B are attached to the ends of the shafts, while part C is provided with tongues, one on each side, fitting into the corresponding grooves in the flanges of the parts attached to the shafts.

These tongues are at right angles to each other. Part C can slide in the direction of either of these tongues and so compensates for the lack of alignment between the two connected shafts.

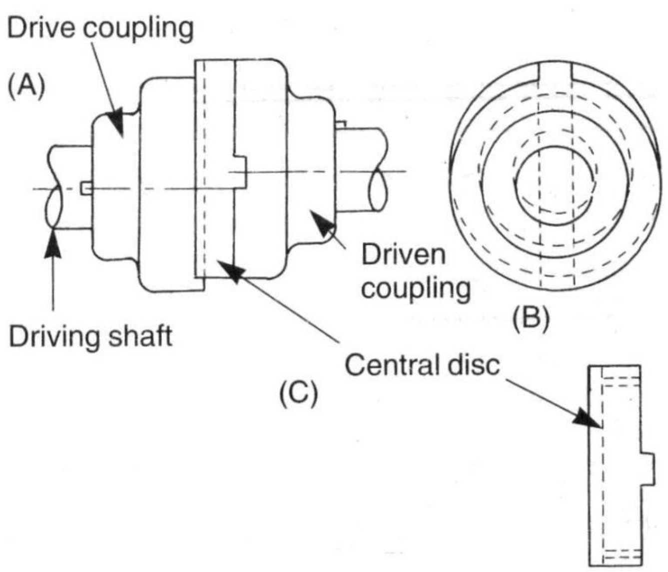


Figure 6.13 Oldham coupling

Activity 6.1

1. What does a muff coupling consist of?
2. State TWO advantages of a flexible coupling.
3. What flanges does a laced belt coupling consist of?
4. Name any THREE fixed couplings that you are familiar with. (No misalignment is allowed in these couplings.)
5. Name THREE flexible couplings.
6. Make a neat sectional drawing of a pin type flexible coupling. Do NOT name the parts.
7. Name TWO couplings that can also be employed as clutches.
8. Shaft couplings can be categorised into three groups. Specify into which groups you can place the following couplings:
   - Marine coupling
   - Hooke's coupling
   - Oldham coupling

Self-Check

I am able to:	Yes	No
• Identify from given drawings and list the categories and types of couplings		
• Describe the features of couplings		
• Identify and label the basic parts of the couplings		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 7

Clutches

Learning Outcomes
By the end of the module you should be able to:

- From given drawings, identify and name the types of clutches of the categories:
    - Positive - Friction - Centrifugal - Hydraulic
- Briefly describe the basic working principle of the categories of clutches:
    - Positive- Friction- Centrifugal- Hydraulic
- Compare the features of the two positive types of clutches mentioned above
- Compare the features of the three friction types of clutches mentioned above
- From given drawings, label the clutch parts mentioned above
- State the advantages and disadvantages of the clutches mentioned above

7.1 Introduction

A clutch is a device which permits the smooth, gradual connection of two shafts rotating at different speeds. This module describes the basic working principles of types of clutches.

7.1.1 Working principle of a clutch

When a rotating machine is started it must be accelerated from rest to the desired speed. A clutch is a device used to connect or disconnect a driven component from a prime mover such as an engine or motor.

A familiar application is the use of a clutch between the engine's crankshaft and the gearbox in automotive applications. The need for the clutch arises from the relatively high torque requirement to get a vehicle moving and the low torque output from an internal combustion engine at low levels of rotational speed.

The disconnection of the engine from the drive enables the engine to speed up unloaded to about 1000 rpm where it is generating sufficient torque to drive the transmission. The clutch can then be engaged, allowing power to be transmitted to the gearbox, transmission shafts and wheels.

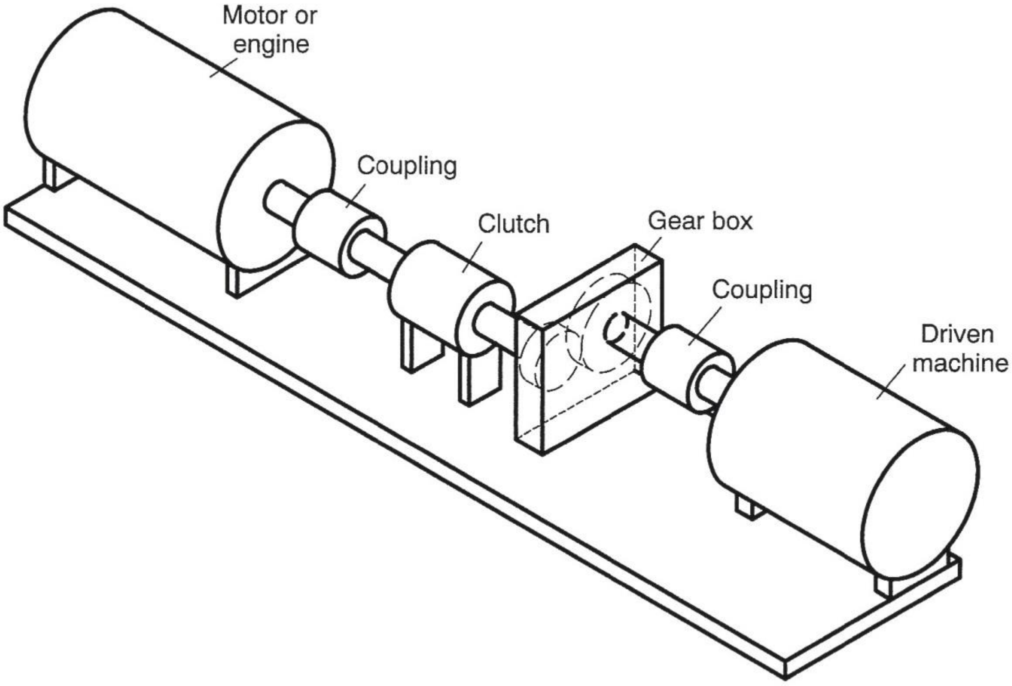


Figure 7.1 Application of clutch

	A **clutch** is a mechanical device that provides for the transmission of power (and therefore usually motion) from one component (the driving member) to another (the driven member) when engaged, but can be disengaged.

Clutches can be divided into four main groups. The four groups are:

- Positive
- Friction
- Centrifugal; and
- Hydraulic clutches.

In each category there are different types of clutches. Let's look at these different categories.

7.2 Positive clutches

There are two types of positive clutches, the square claw clutch and the spiral claw clutch.

7.2.1 Square claw clutches (square jaws)

They are best suited for slow speeds, and no slip can take place. They are ideal for transmitting heavy loads. To make engagement, the machinery must always be stopped; else broken or badly worn dogs will result.

The clutch consists of a fixed half which is firmly keyed to its shaft, and a sliding half which is free to move along its feather, being moved by a fork fitting over the recess shown.

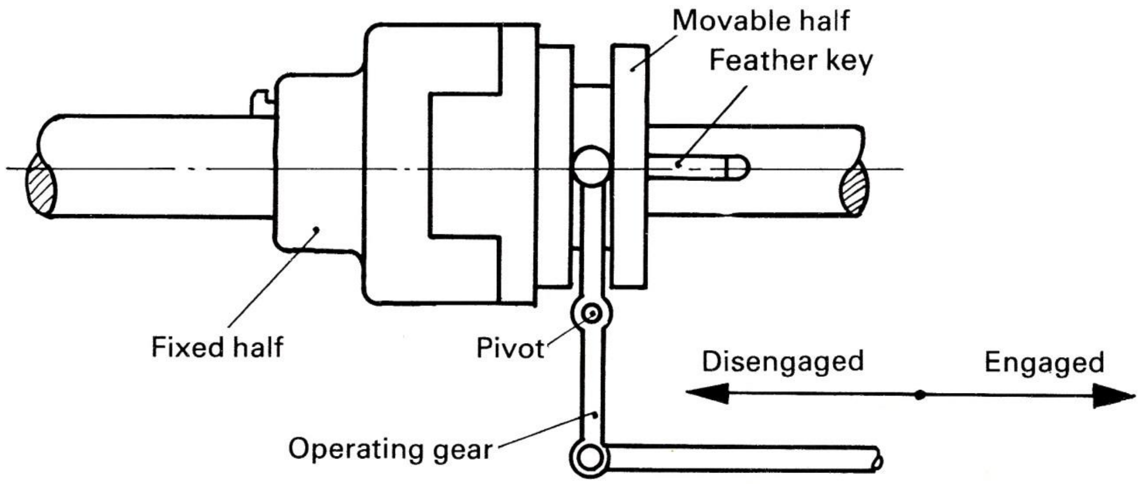


Figure 7.2 (a) Square claw clutch

Advantages and disadvantages of the square claw clutch are:

Advantages	Disadvantages
• It is designed to transmit torque without slip.	• Slippage cannot occur, which can cause great damage to the drive.
• It is very effective for slow moving shafts carrying heavy loads.	• The machine must almost stop before engagement can take place. Engagement speed is limited to approximately 10 rpm.
• It is suitable for driving in both directions.	• It is not at all suitable for fast moving loads.

7.2.2 Spiral claw clutches (spiral jaws)
This type of clutch can be driven in one direction only and it will immediately disengage when the direction of rotation is reversed.

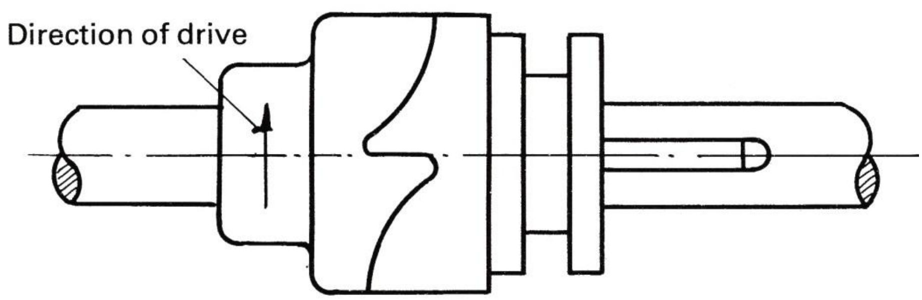


Figure 7.2 (b) Spiral claw clutch

Advantages and disadvantages of the spiral claw clutch are:

Advantages	Disadvantages
• The advantage of the spiral clutch is that it uncouples automatically when the direction of rotation is reversed to avoid damage.	• The disadvantage of the spiral clutch is that the clutch can drive in one direction only.

7.3 Friction clutches

When it is desired to connect a rotating shaft or pulley to a stationary shaft, some kind of clutch must be used, and the type of clutch depends upon the power, speed, frequency of operation and conditions under which the clutch must operate.

Many designs of friction clutches are now manufactured, each possessing some particular characteristic which should be taken into account when deciding which type to employ on any particular installation.

Before the introduction of reliable friction clutches, dog-type clutches were used to connect driving and driven shafts, but unless these were operated when both shafts were almost at rest excessive stresses were imposed on both driving and driven parts.

If properly designed and installed, a modern friction clutch is capable of connecting a stationery shaft or pulley to a revolving one and gradually accelerating to full speed, and this should be the basis upon which the clutches should be selected.

7.3.1 What factors determine the use of a friction clutch?

- The power which must be transmitted.
- The speed at which the drive must take place.
- The amount of torque to be transmitted.
- The duration of slip needed so that the drive shaft and driven shaft engage gradually.
- How often the machine will engage and disengage the clutch.
- The conditions under which the clutch is going to operate, for example dusty, oily or wet conditions and the surrounding temperatures.

7.3.2 Single-disc clutch

The disc or ring is of fibre and when brought in contact with the opposite flange causes a friction drive. These clutches, like the cone clutches, are only suitable for medium power drives.

They have the disadvantage of requiring continuous end pressure. They are most commonly employed on motor cars.

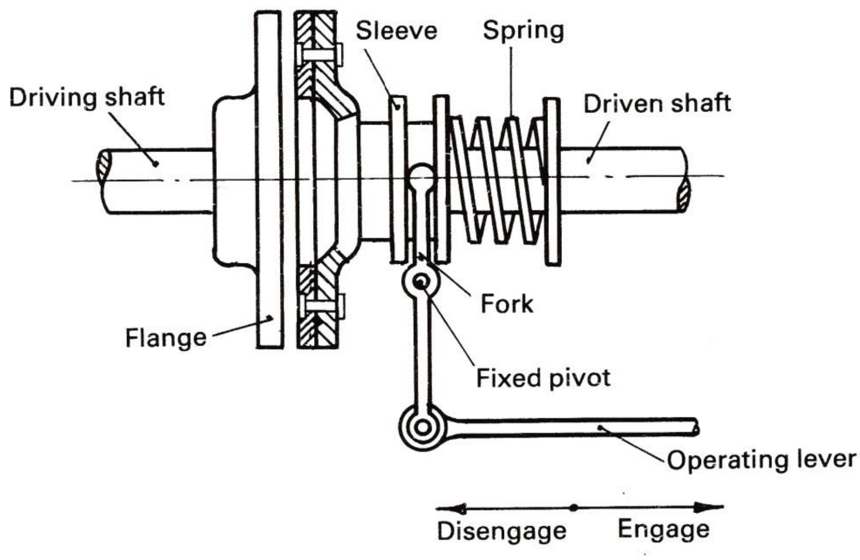


Figure 7.3 Single-disc clutch

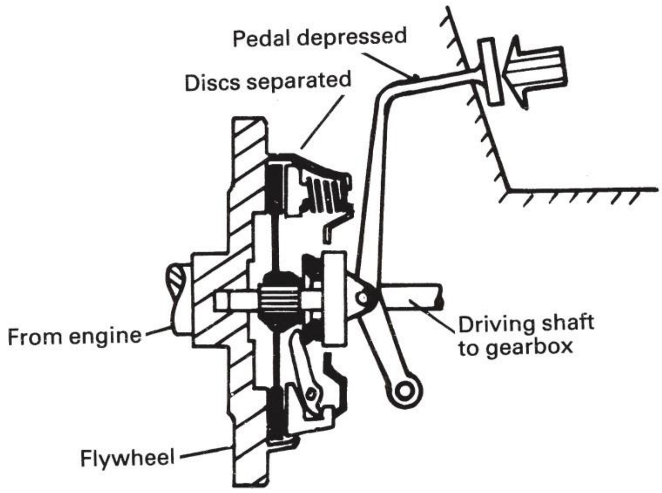


Figure 7.4 Disc clutch (free position)

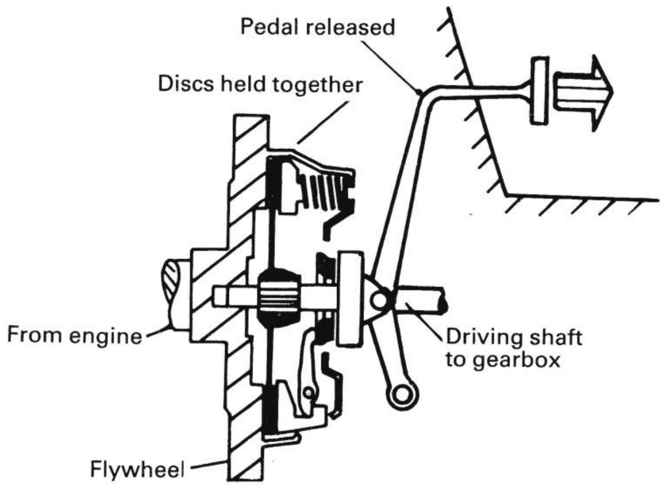


Figure 7.5 Disc clutch (engaged position)

Advantages and disadvantages of the single-disc clutch are:

Advantages	Disadvantages
• It can transmit power at high speed.	• It is not suitable for use on heavy loads.
• A single-disc clutch can be engaged when the machine is in operation.	
• It acts as a safety device in the event of overloading by slipping when the torque exceeds its maximum rating.	
• Shock engagement or disengagement is eliminated because of a certain amount of slip during engagement or disengagement. The result is therefore a gradual engagement or disengagement	

7.3.2 Multiple-disc clutch

A simple type of multiple disc friction clutch is shown in **Figure 7.6**. It consists of a series of discs keyed alternately to the driving and driven shafts. Since each pair of contact surfaces sustains the full operating force, the power which can be transmitted is directly proportional to the number of pairs of contact surfaces.

The contact surfaces are brought into or out of engagement by the system of toggle levers operated by a sliding shifter.

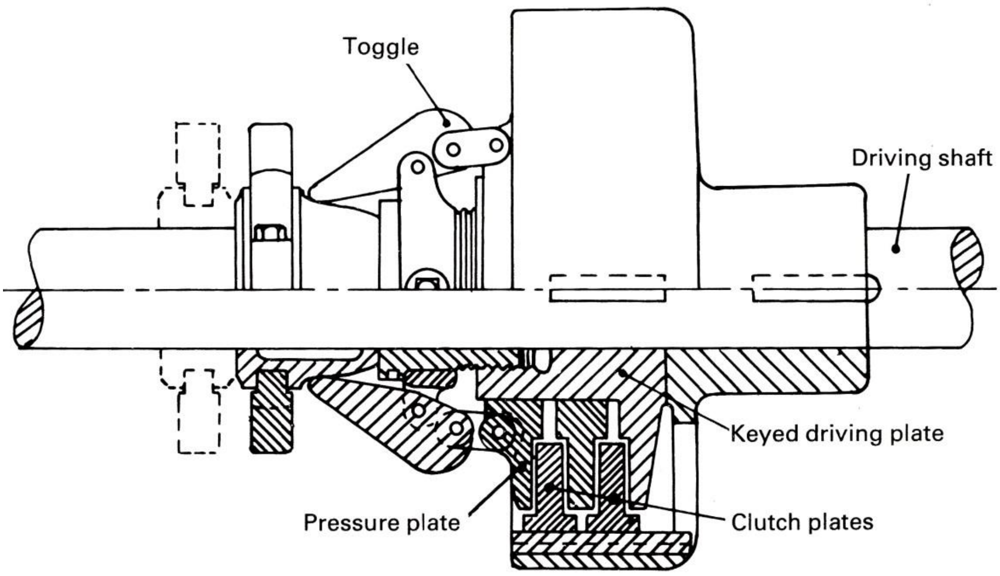


Figure 7.6 Multiple-disc clutch

Multi-disc clutches have the following advantages and disadvantages over the single-disc clutch:

Advantages	Disadvantages
• The diameter of the clutch is smaller, so the unit is more compact.	• The number of surfaces on which slip can take place is increased.
• If one of the discs fails, the clutch can still function to a limited extent using the remaining discs.	• The initial cost of this clutch is high.
• Less slippage takes place, which gives the clutch a longer working life.	
• Greater power can be transmitted, as the power that is transmitted is directly related to the number of pairs of contact surfaces.	

7.3.3 Cone clutch

This is a type of friction clutch consisting of two iron castings A and B. Of these, A is keyed to a driven shaft and bears against a solid collar, while B is secured to its shaft by means of a feather, along which it can slide so as to make frictional contact with the inside of casting A. Engagement is possible while the machine is in motion.

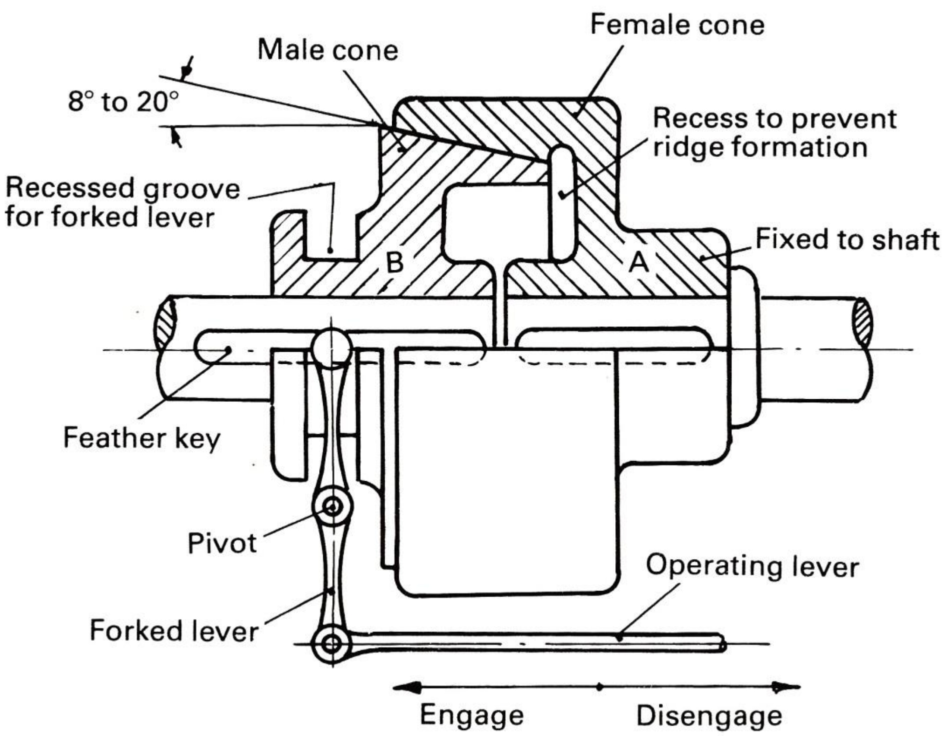


Figure 7.7 Cone clutch

Cone clutches have the following disadvantages:

Disadvantages
• Compared with other types, considerable axial force is necessary to keep the halves in working engagement. This force sets up an end thrust.
• The axial force, which is needed to keep the two halves of the clutch engaged, results in too much end thrust on the driven shaft.
• Slippage often occurs between the two halves when the cone clutch is in operation.

Causes of slip and remedies to fix

1. Glazed frictional surfaces due to constant slipping, overheating, etc. This can be remedied by roughening both contact faces with coarse sandpaper, etc.
2. Oil and grease on friction faces. This can be overcome by scraping and removing undesirable matter leaving the surfaces clean and dry.
3. Faulty adjustment of links, levers, etc. The remedy is to check the wear on pins, bushes, etc., and make the necessary adjustment on operating rods.

7.4 Centrifugal clutches

This type of clutch is used where motors are required to start against heavy loads. Overloads are taken care of by this clutch, as the engagement is gradual and thus does away with any sudden starting shocks. They enable smaller motors and less expensive switch gear to be employed.

7.4.1 Construction

Centrifugal clutches consist of three main components:

1. Body slippers: They are faced with asbestos friction lining, which comes into contact with the clutch shell when the clutch is engaged.
2. Body: This is keyed to the driving shaft of the motor, and has a number of pockets into which the slippers are fitted.
3. Clutch shell: This is the driven member and is either fixed to the driven shaft or carries the pulley or gearwheel.

7.4.2 Working principle of the centrifugal clutch

As the body rotates, the slippers are thrown outwards by centrifugal force, and the fibre impregnated material facings press on the inside of the clutch shell with increasing pressure as the speed increases until full speed is reached.

The weight of the slippers is sufficient to transmit up to the maximum horsepower stipulated. Centrifugal clutches are designed for loads with a start-up period of 30 seconds; with longer periods heat is rapidly generated, and damage can result.

7.4.3 Loose-weight type of centrifugal clutch

Figure 7.8 illustrates how the 6 fibre impregnated –lined loose slippers are accommodated in the spider pockets. As the motor speed increases, centrifugal force is so controlled that the pressure on the friction lining is sufficient to start in motion and accelerate the driven portion without overloading the motor.

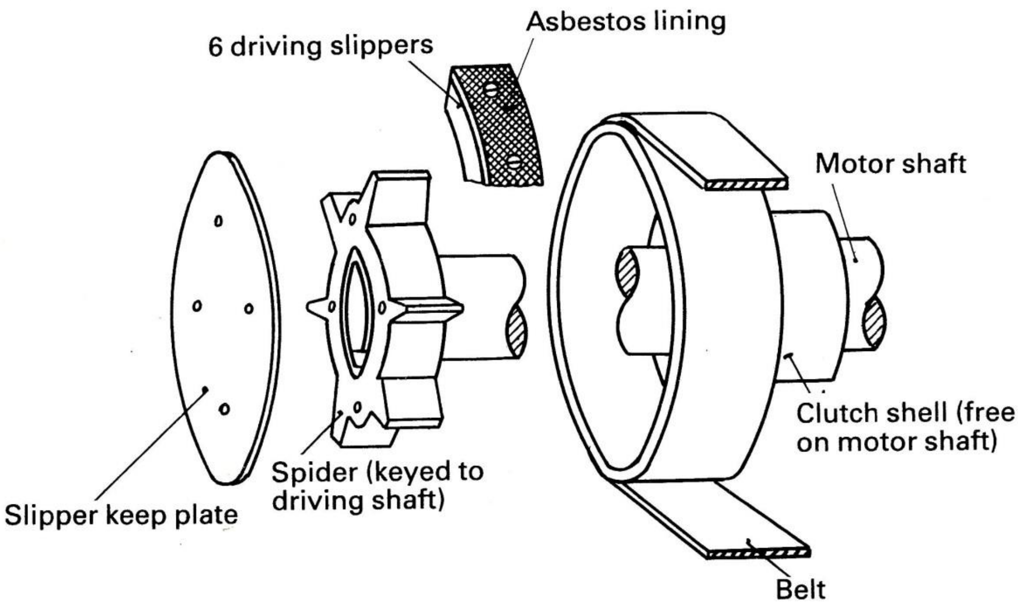


Figure 7.8 Loose-weight type of centrifugal clutch (exploded view)

This design prevents serious overload on the motor when driving, as the clutch is arranged to slip at slightly less torque than the motor can exert at any speed.

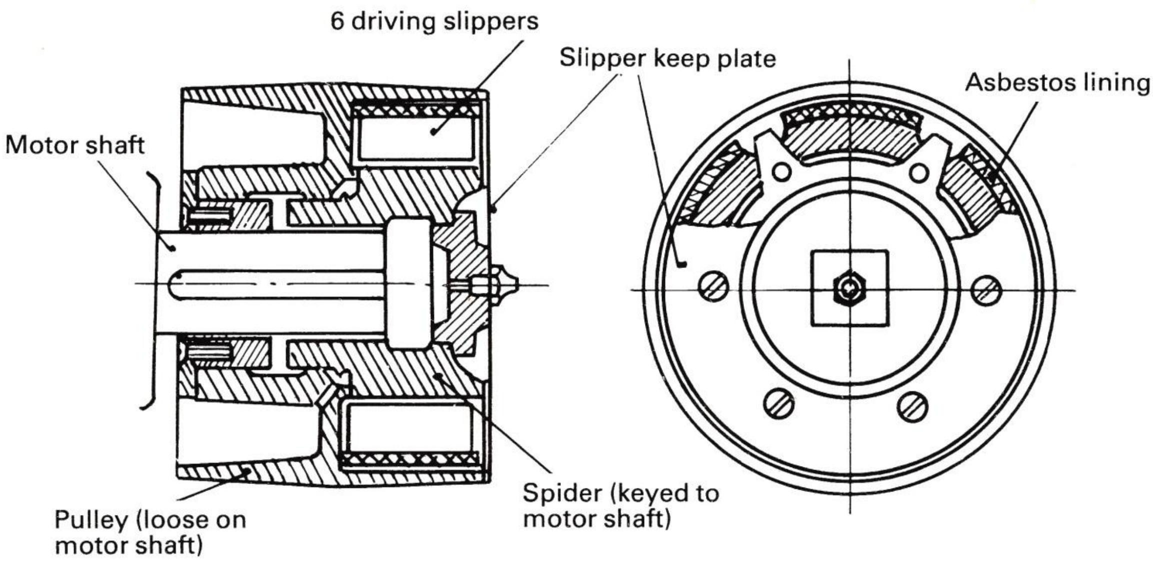


Figure 7.9 Loose-weight type of centrifugal clutch (assembled view)

Loos-weight centrifugal clutches have the following advantages and disadvantages:

Advantages	Disadvantages
• It releases and engages automatically according to the speed of the driving shaft. • It is ideal for applications where smooth pick-up is required. • It is particularly useful with engines which cannot be started under load.	• One of the disadvantages of the loose-weight centrifugal clutch is that the slippers are in contact with the drum long before the drive shaft rotates fast enough for them to drive the drum. This causes slippage and there is a lot of wear on the linings. Slippage occurs from the time the slippers begin to touch the drum until the drum rotates at the same speed as the drive shaft. The wear caused by the slippage is worse if the work load on the drum is heavy. We can overcome the problem of too much slippage in the centrifugal clutch by using a fixed-weight centrifugal clutch.

7.4.4 Spring-controlled centrifugal clutch

When starting loads are heavy, it is very important to provide some arrangement to prevent dragging and possible burn-out of the clutch faces during the picking-up period of the load.

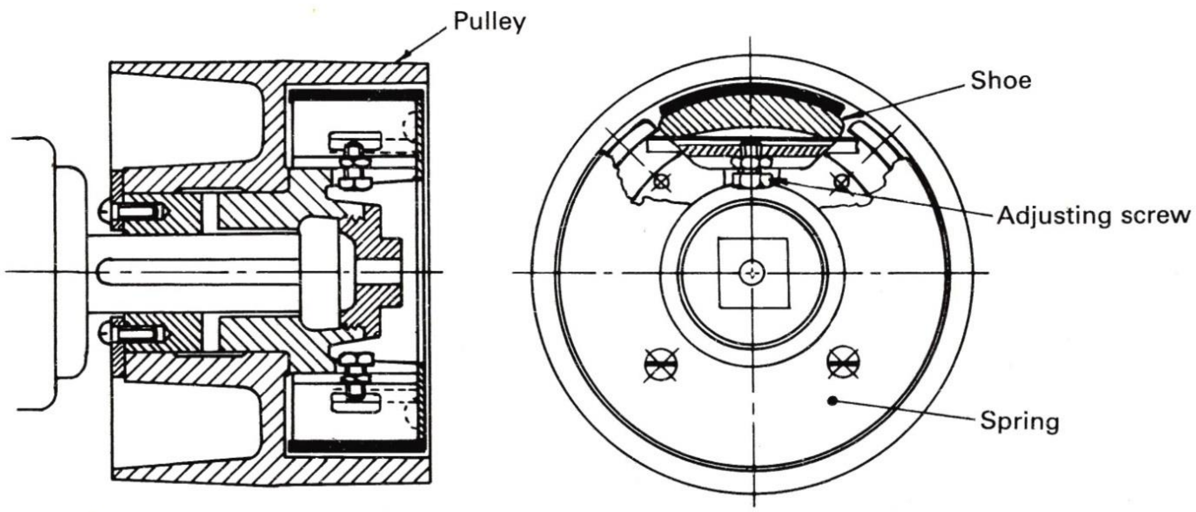


Figure 7.10 Centrifugal clutch with spring-loaded shoes

This problem can be solved by fitting springs to prevent the loose slippers from being thrown outwards by centrifugal force too soon. The slippers will thus only make friction contact when the motor attains a speed of say 75% of its normal running speed.

7.5 Hydraulic clutches

The working principle of a hydraulic or fluid clutch can best be explained as follows:

1. Take two fans and arrange them facing each other about 50 mm apart.
2. Plug the one fan in so that it r uns.
3. The current of air from the running fan will now cause the blades of the other fan to turn (as shown in **Figure 7.11**).
4. To make an efficient hydraulic clutch, oil is used as the fluid and the two halves of the clutch are mounted very close together and enclosed in a housing. **Figure 7.12** shows the two members of a hydraulic clutch.

   Note: that they resemble a hollowed-out doughnut sliced in half, with blades or vanes set radially into the halves.

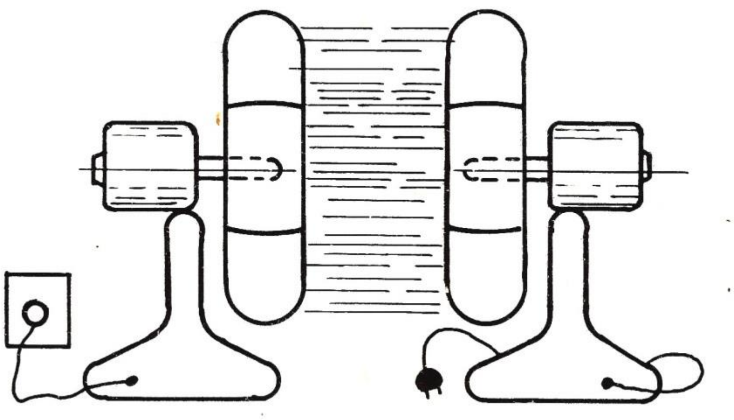


Figure 7.11 Two fans facing each other

5. The mechanism consists of only three parts:

   (a)the driver unit, (b) the driven unit, and (c)the housing.

6. Power is transmitted from the driver to the driven unit through the circulation oil. The driver must rotate faster than the driven unit. The percentage difference in the rotation speed between the two units is known as slip.
7. The faster the driving member turns, the harder the oil strikes the vanes of the driven member, and the greater is this turning effort imparted to the driven member.

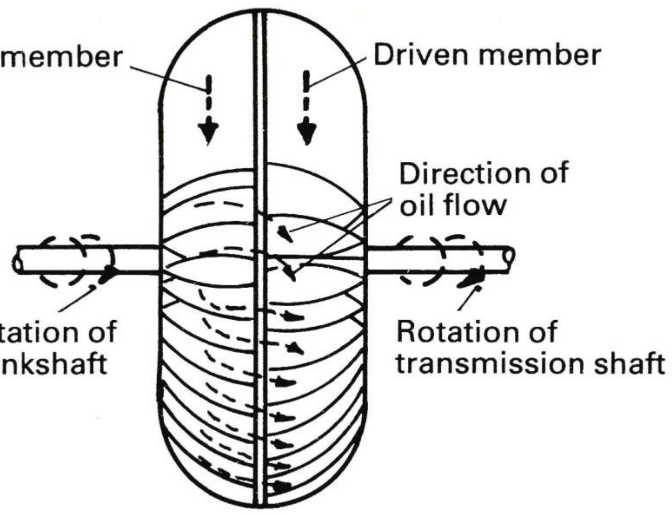


Figure 7.12 Hydraulic clutch

Advantages and disadvantages of the hydraulic clutch are:

Advantages	Disadvantages
• The design of the hydraulic clutch is simple. It consists mainly of the impeller, follower and the hydraulic fluid.	• Precision parts and seals can be damaged if exposed to bad weather and dirty atmosphere.
• A wide range of speed variations is possible without bringing the motor to a stop.	• Corrosion, dirt and the deterioration of the hydraulic fluid can have an adverse effect on the function of the clutch.
• A hydraulic clutch has a smooth and quiet operation.	
• It is effectively protected against overloads.	
• The operating costs are low, because the moving parts are constantly lubricated by the hydraulic fluid.	

7.5.1 Type of fluid used

The fluid used is a mineral oil of low viscosity. It should flow easily even at low temperatures. Any kind of oil should not be used for this purpose, as it can cause a great deal of trouble.

7.5.2 Operating features of hydraulic clutch

1. It operates at maximum efficiency when the driven member approaches the speed of the driving member.

2. If the two members turn at the same speed, then the oil will not pass from one to the other.
3. The driving member always has to be turning a little faster than the driven member for engine power to be transmitted through the fluid coupling to the motor car wheel.

Activity 7.1

1. Briefly describe the purpose of a clutch.
2. List the FOUR main groups of clutches.
3. Make simple drawings of these clutches and label them to show the different basic parts.
4. Briefly describe the operation of a friction clutch.
5. Certain factors determine the choice of a friction clutch. List SIX of these factors.
6. Briefly describe the operation of the cone clutch.
7. What are the advantages gained by employing a multi-plate disc clutch in preference to a single-plate disc clutch?
8. Make a neat sketch of a cone clutch and explain how it operates.
9. Explain with the aid of a simple sketch the operation of a centrifugal clutch.
10. The shoes of centrifugal clutches are sometimes fitted with springs. Explain the main reasons for this practice.
11. Explain with the aid of a simple sketch the working principle of a hydraulic clutch.
12. Explain the advantages gained by using a friction type of clutch instead of a dog type of clutch.
13. Make a neat sketch of a centrifugal clutch. Indicate the main parts on the sketch.
14. What is the disadvantage of a cone clutch when compared to other types of clutches?
15. Explain under what conditions a centrifugal clutch would be used.
16. Centrifugal clutches consist of three main parts. Mention these three parts.
17. Make a neat sketch of a cone clutch. Also indicate the angle of the taper of the friction faces.
18. State three causes of slip on a cone clutch.
19. What is the disadvantage of a cone clutch when compared to other types of clutches?
20. Make a neat half-sectional sketch of a centrifugal clutch and give one application of the clutch.
21. Make a neat half-sectional sketch of a cone clutch. What are the maximum and minimum angles of the cones?

Self-Check

I am able to:	**Yes**	**No**
• From given drawings, identify and name the types of clutches of the categories:		
o Positive - Friction - Centrifugal - Hydraulic		
• Briefly describe the basic working principle of the categories of clutches:		
o Positive- Friction- Centrifugal- Hydraulic		
• Compare the features of the two positive types of clutches mentioned above		
• Compare the features of the three friction types of clutches mentioned above		
• From given drawings, label the clutch parts mentioned above		
• State the advantages and disadvantages of the clutches mentioned above		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 8

Brake Systems

Learning Outcomes
By the end of the module you should be able to:

- Describe the purpose of brakes
- Describe the activating and the de-activating action of the following brake operating principles:
  - Electromagnetic – Hydraulic - Air (spring) Mechanical
- Describe the advantages and disadvantages of each of the braking systems
- Compare the advantages disadvantages of the following braking units:
  - Disc brake - Internal drum and shoe brake - External drum and band brake - Cone brake
- Discuss and compare the factors that will be taken into consideration in the application of the transmission concept dealt with in Modules 4 to 8

8.1 Introduction

A brake is a mechanical device which inhibits motion. It is a device for decreasing the speed of a body or stopping its motion. Most brakes act on rotating mechanical elements and absorb kinetic energy mechanically, hydrodynamically, or electrically.

Mechanical brakes are the most common; they dissipate the kinetic energy as heat generated by mechanical friction between a rotating drum or disk and a stationary friction element.

Kinetic energy of an object is the energy which it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity.
Having gained this energy during its acceleration, the body maintains this kinetic energy unless its speed changes. The same amount of work is done by the body in decelerating from its current speed to a state of rest.

A hydrodynamic (fluid) brake has a rotor (rotating element) and a stator (stationary element). Resistance to rotation is created by fluid friction and circulation of the liquid (usually water) from a series of pockets in the rotor to a series of complementary pockets in the stator.

A hydrodynamic (fluid) brake has a rotor (rotating element) and a stator (stationary element) that resemble the impeller and runner in a hydraulic coupling. Resistance to rotation is created by fluid friction and circulation of the liquid (usually water) from a series of pockets in the rotor to a series of complementary pockets in the stator.

8.2 Purpose of braking systems

Brakes are used for:

1. Controlling the speed of the load
2. Holding the suspended load at rest
3. Controlling the speed of the moving masses.
4. Stop the machine within a determined time and speed
5. Slowing down the speed of the machine
6. Stop the machine in emergencies for safety precautions

Most commonly brakes use friction to convert kinetic energy into heat, though other methods of energy conversion may be employed. For example regenerative braking converts much of the energy to electrical energy, which may be stored for later use.

DIFINITION:
Brakes: a device for slowing or stopping a vehicle or other moving mechanism by the absorption or transfer of the energy of momentum, usually by means of friction.

Other methods convert kinetic energy into potential energy in such stored forms as pressurized air or pressurized oil. Eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, fin, or rail, which is converted into heat.

Still other braking methods even transform kinetic energy into different forms, for example by transferring the energy to a rotating flywheel.

TAKE NOTE:
The main purpose of a braking system on a machine or motor vehicle is to apply friction to a moving surface.

Brakes are generally applied to rotating axles or wheels, but may also take other forms such as the surface of a moving fluid (flaps deployed into water or air).

Some vehicles use a combination of braking mechanisms, such as drag racing cars with both wheel brakes and a parachute, or airplanes with both wheel brakes and drag flaps raised into the air during landing.

8.3 Friction with respect to brakes

8.3.1 Kinetic friction

If the brakes are applied excessively the wheels lock, and the friction between the tyres and the road while the tyres are sliding is called kinetic friction (moving friction).

8.3.2 Static friction

If the brakes arc applied gradually so that the wheels continue to rotate then static friction is brought into play between the tyres and the road.

8.4 Types of braking systems

Braking systems may be broadly described as using friction, pumping, or electromagnetics. One brake may use several principles: for example, a pump may pass fluid through an orifice to create friction:

a) **Frictional brakes** are most common and can be divided broadly into "shoe" or "pad" brakes, using an explicit wear surface, and hydrodynamic brakes, such as parachutes, which use friction in a working fluid and do not explicitly wear. Typically the term "friction brake" is used to mean pad/shoe brakes and excludes hydrodynamic brakes, even though hydrodynamic brakes use friction.

b) **Friction (pad/shoe) brakes** are often rotating devices with a stationary pad and a rotating wear surface. Common configurations include shoes that contract to rub on the outside of a rotating drum, such as a band brake; a rotating drum with shoes that expand to rub the inside of a drum, commonly called a "drum brake", although other drum configurations are possible; and pads that pinch a rotating disc, commonly called a "disc brake".

c) Other brake configurations are used, but less often. For example, PCC trolley brakes include a flat shoe which is clamped to the rail with an electromagnet; the Murphy brake pinches a rotating drum, and the Ausco Lambert disc brake uses a hollow disc (two parallel discs with a structural bridge) with shoes that sit between the disc surfaces and expand laterally.

d) **Pumping brakes** are often used where a pump is already part of the machinery. For example, an internal-combustion piston motor can have the fuel supply stopped, and then internal pumping losses of the engine create some braking. Some engines use a valve override called a Jake brake to greatly increase pumping losses. Pumping brakes can dump energy as heat, or can be regenerative brakes that recharge a pressure reservoir called a hydraulic accumulator.

e) **Electromagnetic brakes** are likewise often used where an electric motor is already part of the machinery. For example, many hybrid gasoline/electric vehicles use the electric motor as a generator to charge electric batteries and also as a regenerative brake. Some diesel/electric railroad locomotives use the electric motors to generate electricity which is then sent to a resistor bank and dumped as heat.

Some vehicles, such as some transit buses, do not already have an electric motor but use a secondary "retarder" brake that is effectively a generator with an internal short-circuit. Related types of such a brake are eddy current brakes, and electro-mechanical brakes (which actually are magnetically driven friction brakes, but nowadays are often just called "electromagnetic brakes" as well).

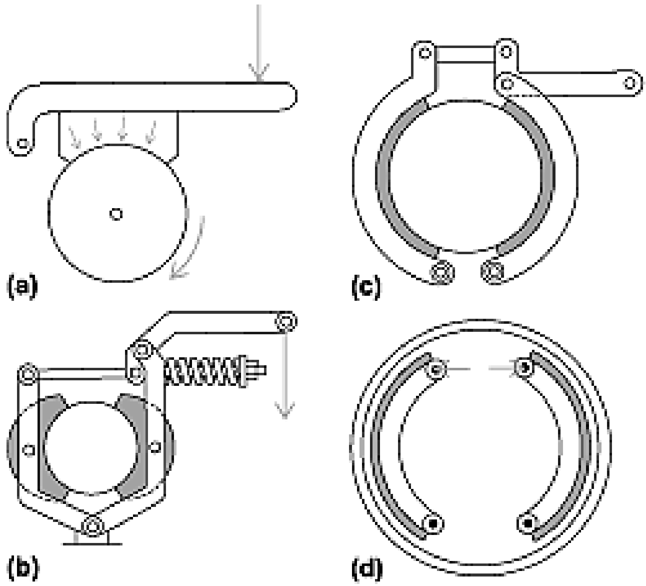


Figure 8.1 Types of band brakes

8.5 Characteristics of brakes

Brakes are often described according to several characteristics including:

- **Peak force** – The peak force is the maximum decelerating effect that can be obtained. The peak force is often greater than the traction limit of the tires, in which case the brake can cause a wheel skid.
- **Continuous power dissipation** – Brakes typically get hot in use, and fail when the temperature gets too high. The greatest amount of power (energy per unit time) that can be dissipated through the brake without failure is the continuous power dissipation. Continuous power dissipation often depends on e.g., the temperature and speed of ambient cooling air.

- **Fade** – As a brake heats, it may become less effective, called brake fade. Some designs are inherently prone to fade, while other designs are relatively immune. Further, use considerations, such as cooling, often have a big effect on fade.
- **Smoothness** – A brake that is grabby, pulses, has chatter, or otherwise exerts varying brake force may lead to skids. For example, railroad wheels have little traction, and friction brakes without an anti-skid mechanism often lead to skids, which increases maintenance costs and leads to a "thump thump" feeling for riders inside.
- **Power** – Brakes are often described as "powerful" when a small human application force leads to a braking force that is higher than typical for other brakes in the same class. This notion of "powerful" does not relate to continuous power dissipation, and may be confusing in that a brake may be "powerful" and brake strongly with a gentle brake application, yet have lower (worse) peak force than a less "powerful" brake.
- **Pedal feel** – Brake pedal feel encompasses subjective perception of brake power output as a function of pedal travel. Pedal travel is influenced by the fluid displacement of the brake and other factors.
- **Drag** – Brakes have varied amount of drag in the off-brake condition depending on design of the system to accommodate total system compliance and deformation that exists under braking with ability to retract friction material from the rubbing surface in the off-brake condition.
- **Durability** – Friction brakes have wear surfaces that must be renewed periodically. Wear surfaces include the brake shoes or pads, and also the brake disc or drum. There may be trade-offs, for example a wear surface that generates high peak force may also wear quickly.
- **Weight** – Brakes are often "added weight" in that they serve no other function. Further, brakes are often mounted on wheels, and un-sprung weight can significantly hurt traction in some circumstances. "Weight" may mean the brake itself, or may include additional support structure.
- **Noise** – Brakes usually create some minor noise when applied, but often create squeal or grinding noises that are quite loud.

8.6 Terminology associated with brakes

- **Types of brakes**: apparatuses used to slow or stop a moving vehicle.
- **Drum brake**: mechanism that slows and stops a car by fiction, by pression brake shoes against a drum.
- **Drum**: cylindrical part attached to the wheel, against which the brake shoes are pressed to stop the car.
- **Brake lining**: frictional part on the outside edges of the brake shoes.
- **Return spring**: part of the brake mechanism that returns the brake shoes to their initial position.
- **Piston**: cylindrical part that transmits the pressure to and receives pressure from the brake shoes.
- **Wheel cylinder**: type of roller that applies a uniform pressure to the wheel then the brake is activated.
- **Brake shoe**: part on which the brake lining is mounted.

- Brake pads: part activated by the piston.
- **Wheel hub**: central part crossed by the axel.
- **Stud**: metal pin.
- **Disk**: round, flat, piece of metal, pressed against the wheel to slow or stop the car.
- **Brake line**: system liquid-transporting tubes.
- **Splash shield**: protector that prevents dirt from fouling the braking system.
- **Disk brake**: mechanism that slows and stops a car by friction, by pressing a disk against the wheel axel.

Figure 8.2 Illustrates the terminology associated with brakes.

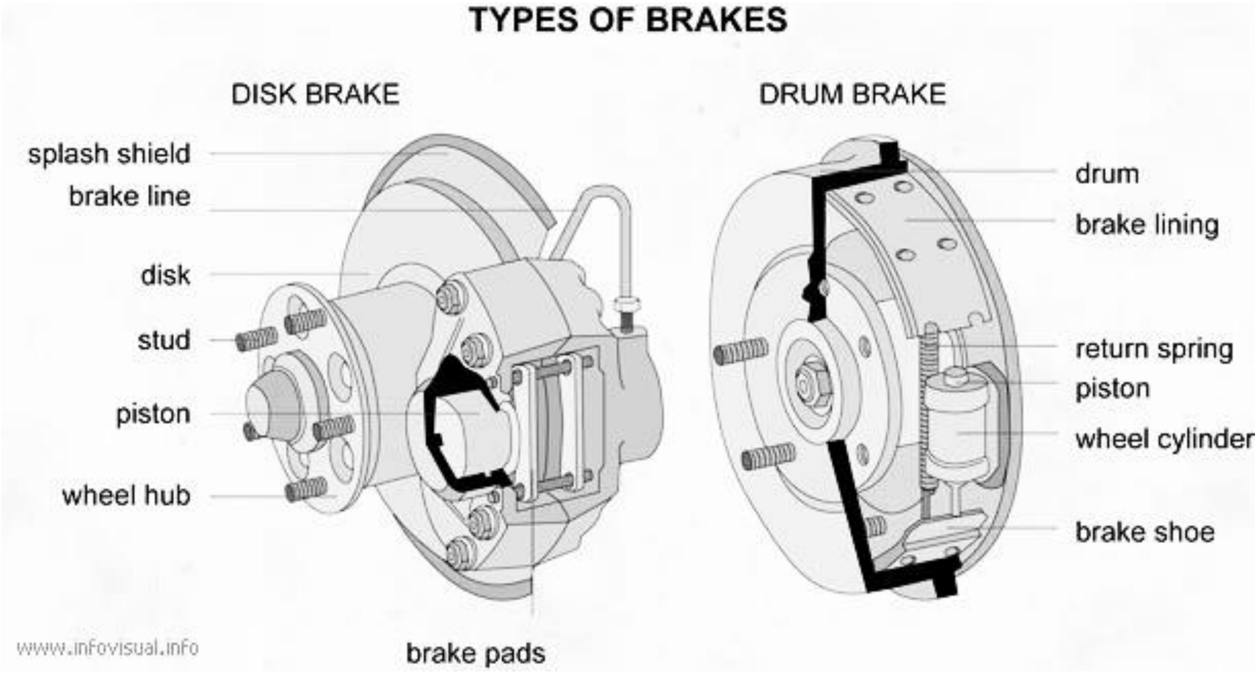


Figure 8.2 Terminology associated with brakes

8.7 Activating and the de-activating action

Stopping safely is one of the most important functions a machine or motor vehicle can perform. Failure of the brake system will almost invariably result in property damage, personal injury, or even death. So then the operating principle of a braking system must activate or deactivate the system.

A manually operated brake pedal or handle is used to activate a brake. With low-power machinery or vehicles the operator can usually apply sufficient force through a simple mechanical linkage from the pedal or handle to the stationary part of the brake.

In many cases, however, this force must be multiplied by using an elaborate braking system. In many modern braking systems there no longer is a direct connection between the pedal and the brake; a sensor is used register the

force applied to the pedal, and that information is used to determine the pressure to apply to the brake.
Automobile braking systems may also include an override that disables the accelerator when the brake is activated.

An antilock braking system (ABS) uses sensors to identify when a wheel is locking and then applies and releases the brake automatically several times per second to prevent lockup. ABS can prevent skids, permitting controlled stops, and decreases the amount of time and distance needed to stop a car.

We will look at the following braking systems:

- Air braking system
- Hydraulic braking system
- Vacuum braking system
- Mechanical braking system
- Electromagnetic braking system

8.8 The Air Braking System

An early system for multiplying the braking force, called the air brake system, or air brake, was invented by American manufacturer George Westinghouse and was first used on passenger trains in 1868.

It is now widely used on railroad trains. The fundamental principle involved is the use of compressed air acting through a piston in a cylinder to set block brakes on the wheels. The action is simultaneous on the wheels of all the cars in the train.

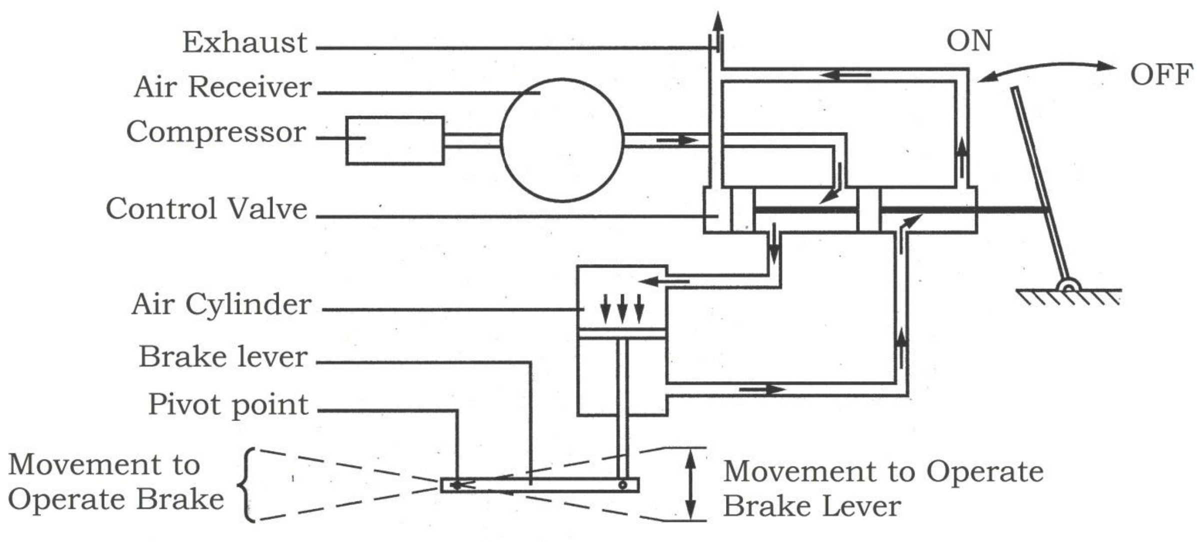


Figure 8.3 Schematic layout of an Air brake system

The compressed air is carried through a strong hose from car to car with couplings between cars; its release to all the separate block brake units, at the same time, is controlled by the engineer.

An automatic feature provides for the setting of all the block brakes in the event of damage to the brake hose, leakage, or damage to individual brake units. The air brake is used also on subway trains, trolley cars, buses, and trucks.

8.8.1 Advantages of Air Braking Systems

1. Unlimited force obtained from the compressed air
2. Relatively inexpensive as it has air as a medium to the operation
3. Can be used on trailers and large trucks
4. As long as there is air in the reservoir the air brake will function unlimitedly
5. Free resource so no refilling or changing requirement
6. Air pressure is quick to act and hence air brakes are immediate
7. The pressure of brakes applied is directly proportional to the air pressure
8. A little feather touch on the brakes would apply

8.8.2 Disadvantages of Air Braking Systems

1. The pressure must build up before the air brakes are fully operational
2. Connection pipes and hoses could leak or burst allowing the system without air to operate
3. Lower breaking force than other systems due to compressed air

8.9 The Hydraulic Braking System

The hydraulic brake system, or hydraulic brake, is used on almost all automobiles as well as a hydraulic machine. The hydraulic machine derives its power from the motion or pressure of water or some other liquid.

In a hydraulic brake system, when the brake pedal is pressed, a pushrod exerts force on the piston(s) in the master cylinder, causing fluid from the brake fluid reservoir to flow into a pressure chamber through a compensating port.

This results in an increase in the pressure of the entire hydraulic system. This forces fluid through the hydraulic lines toward one or more callipers where it acts upon one or two calliper pistons sealed by one or more seated O-rings which prevent the escape of any fluid from around the piston.

The brake calliper pistons then apply force to the brake pads, which pushes them against the spinning rotor, and the friction between the pads and the rotor causes a braking torque to be generated, slowing the vehicle.

Heat generated by this friction is either dissipated through vents and channels in the rotor or conducted through the pads, which are made of specialized heat-tolerant materials such as kevlar or sintered glass.

Subsequent release of the brake pedal/lever allows spring(s) to return the master piston(s) back into position. This relieves the hydraulic pressure on the calliper, allowing the brake piston in the calliper assembly to slide back into its housing and the brake pads to release the rotor.
The hydraulic braking system is designed as a closed system: unless there is a leak in the system, none of the brake fluid enters or leaves it, nor does the fluid get consumed through use.

8.9.1 Advantages of the hydraulic Braking Systems

1. Highly reliable and is safe. It has two master cylinders and if one fails the other can still operate as a braking system to stop the vehicle.
2. Provides a powerful braking action because of a fluid is incompressible
3. No breakage or stretch to cables or rods
4. Parts for the braking system are easily obtainable and can be maintained efficiently

8.9.2 Disadvantages of hydraulic Braking Systems

1. Will need to bleed the brakes if air is trapped in the system
2. Loss of fluid due to leaks can cause the braking system to fail.

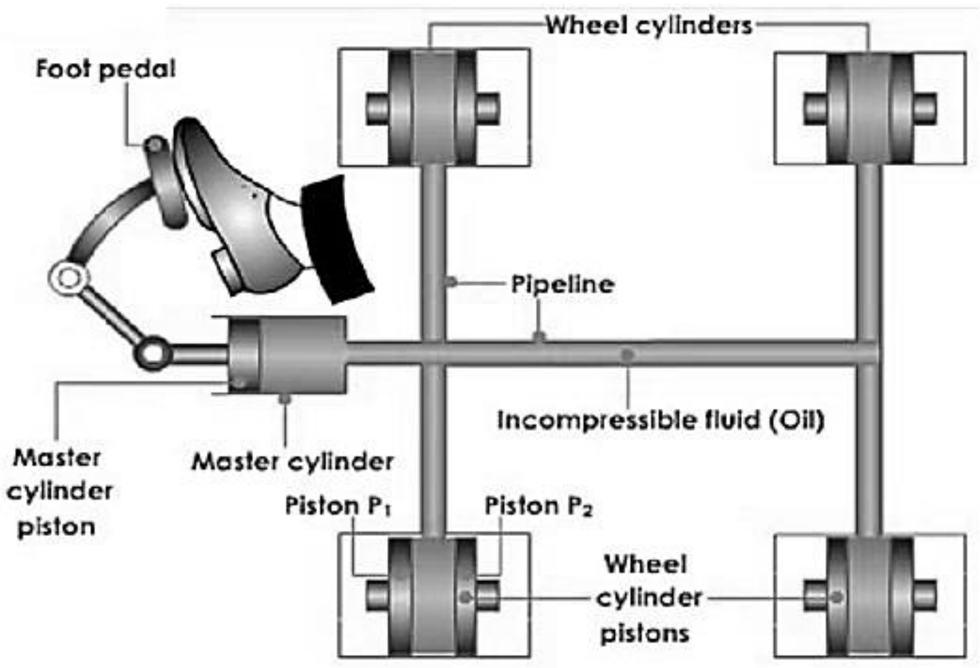


Figure 8.3 Hydraulic braking system

When the brake pedal of an automobile is depressed, a force is applied to a piston in a master cylinder. The piston forces hydraulic fluid through metal tubing into a cylinder in each wheel where the fluid's pressure moves two pistons that press the brake shoes against the drum.

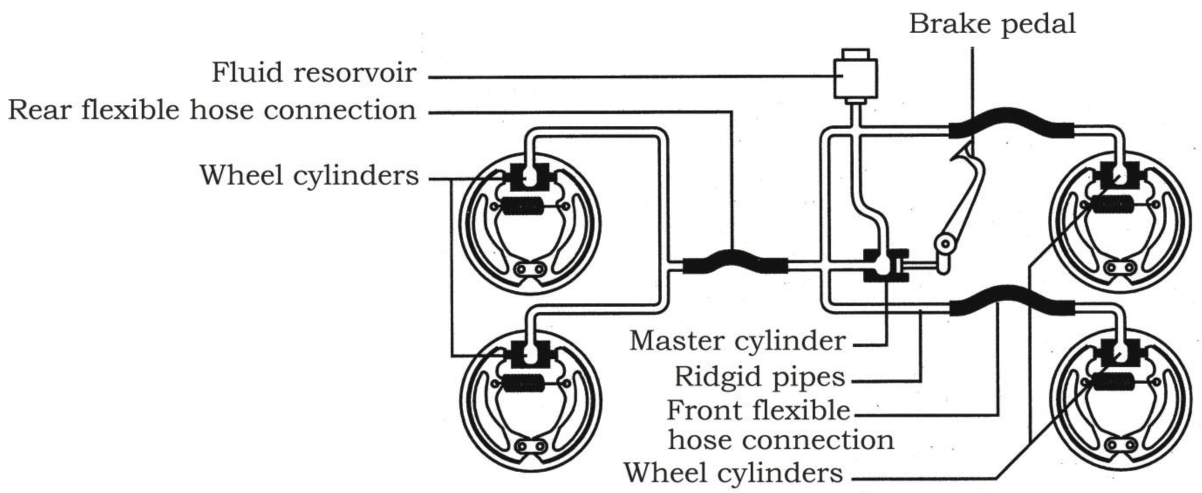


Figure 8.4 Schematic layout of a hydraulic brake system

8.9.3 Hydraulic band brakes

The master cylinder as well as the hydraulic cylinder on the brake is provided with pistons.

Both pistons are equipped with special cup seals which prevent fluid leakage and permit pressure to be built up. The piston of the master cylinder is controlled by a braking pedal.

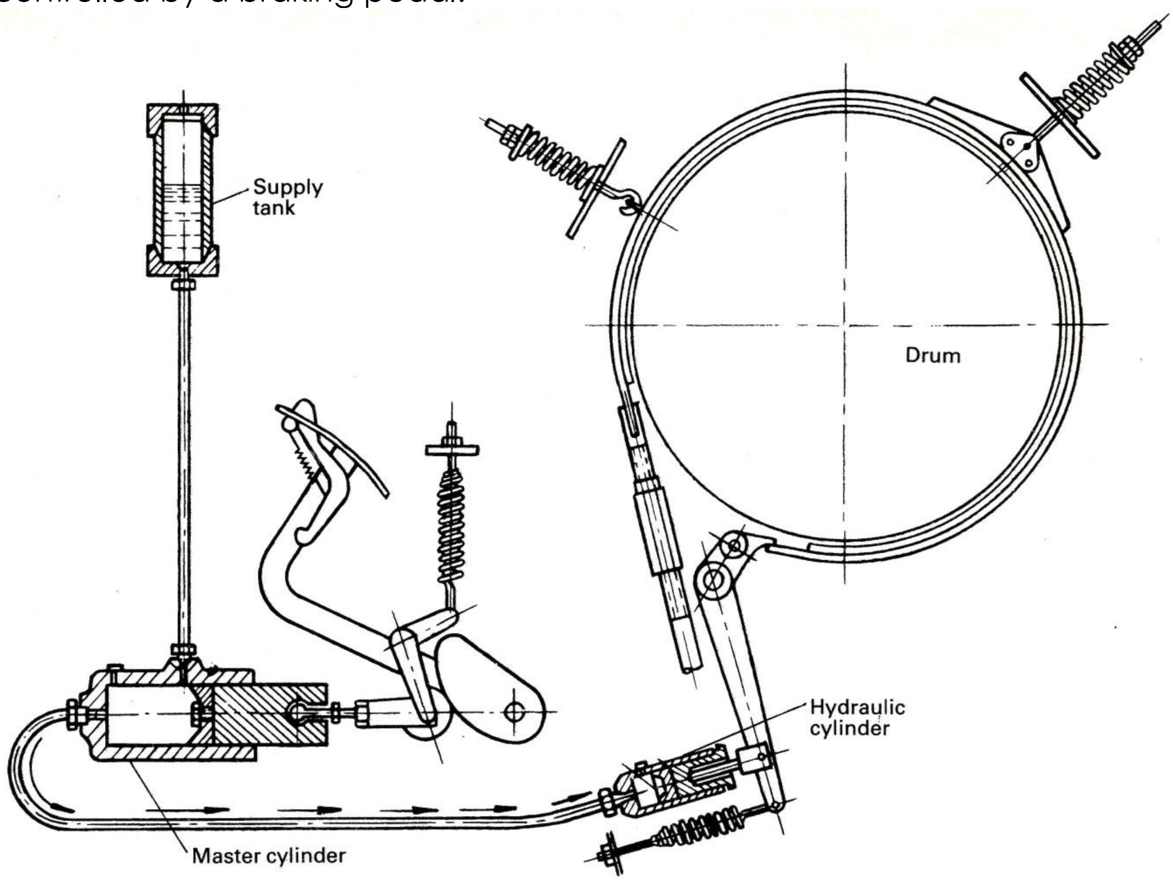


Figure 8.5 Hydraulic band braking system

The fluid forced from the master cylinder by the moving piston is directed along the tubing into the hydraulic cylinder, presses against its piston and, acting on the lever system, produces the braking effect. Increased pressure on the pedal of the master cylinder correspondingly increases pressure on the brake shoes.

When no force is exerted on the pedal the brake band is released by means of a spring which also acts on the piston of the hydraulic cylinder, forcing out the fluid and returning it along the tubing to the master cylinder. The brake pedal is pushed back by a return spring.

These brakes can be used on pulling winches.

8.10 The Vacuum Braking System

The vacuum brake system, or vacuum brake, depends upon the use of a vacuum to force a piston in a cylinder to hold a brake shoe off a drum; when the vacuum is destroyed, the shoe is released and presses on the drum. In an automotive power brake system, extra pressure can be exerted on the hydraulic master cylinder piston by a vacuum brake's piston.

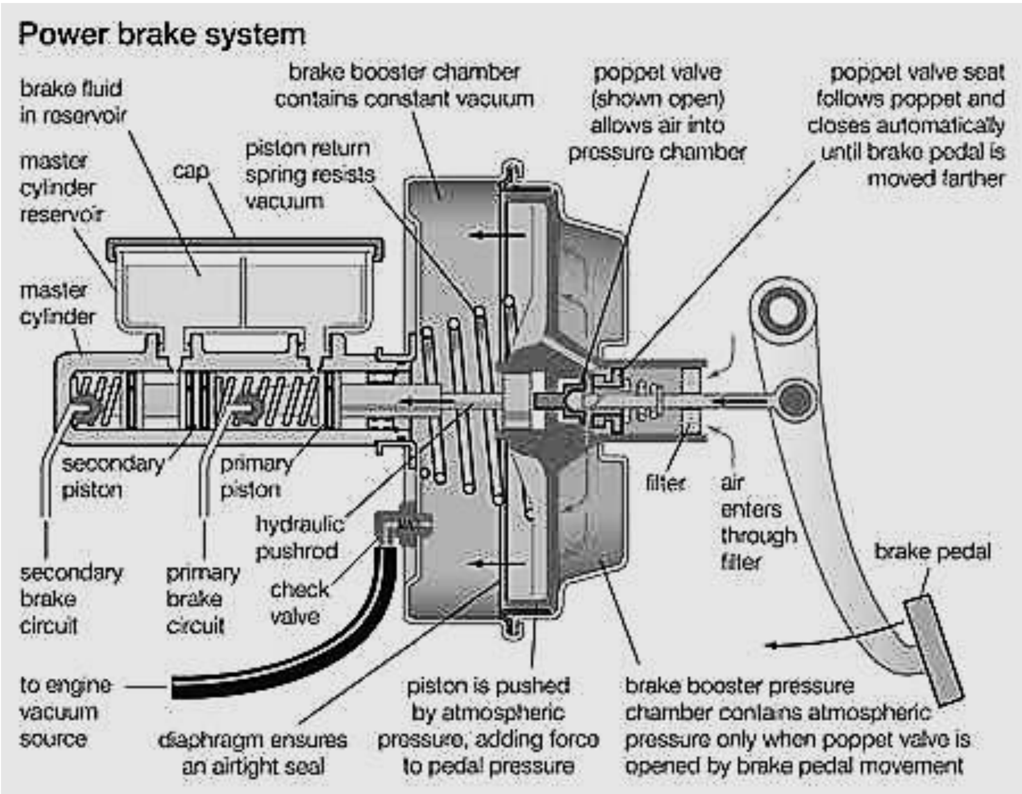


Figure 8.5 Power Braking system

8.11 Mechanical Braking System

In the mechanical brake system all the movements from the point of applied force (foot or hand on the brake) to the action of the brake shoes are purely mechanical.

Figure 8.6 illustrates a schematic layout of the mechanical braking system. This system incorporates rods, with a combination of cables can be used by linking the brake lever with the brake shoe operating device.

The turn buckle adjuster is used to adjust the length of the rods and cables. This is usually there for adjustment to ware on the levers and pivot points.

> The term **mechanical** means that all movements from the point of applied force to the action of the brake shoes are purely mechanical.

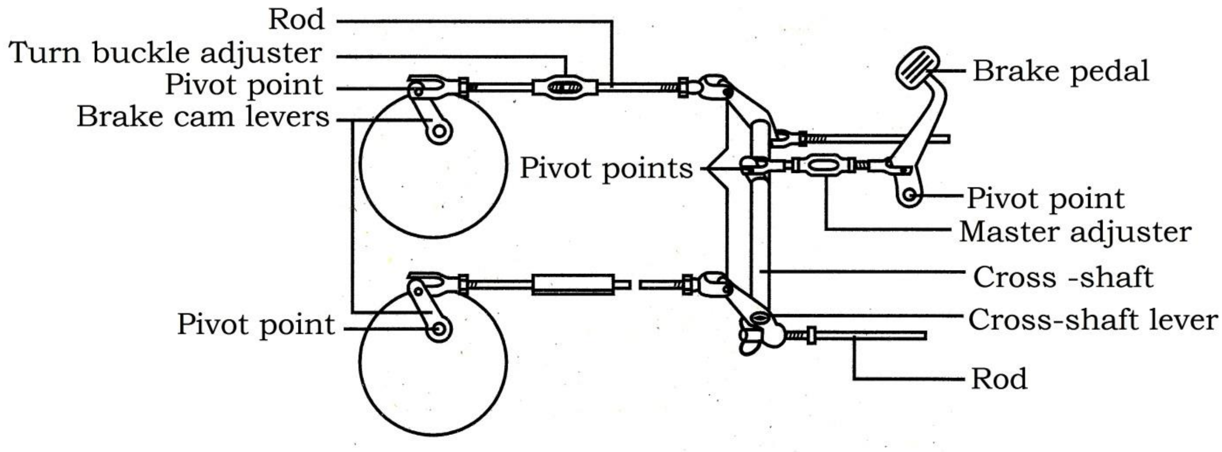


Figure 8.6 Schematic layout of a mechanical braking system

8.11.1 Advantages of the Mechanical Braking Systems

1. Brakes are always functioning (power failure has no effect)
2. Mechanical braking system is easily maintained (simple system and not complicated)
3. All wheels are coupled separately, in the event of a cable or rod breakage the remainder of the braking system will not be affected.

8.11.2 Disadvantages of Mechanical Braking Systems

1. On-going maintenance and attention needed due to large number of components in the braking system
2. Adjustments needed frequently due to on-going wear
3. Water and dust can contaminate the system and can have a damaging effect on the system
4. Rods and cable have the tendency to stretch and this will lead to loss of breaking effectiveness
5. Slow braking response

8.12 Electromagnetic braking system

The most common form of lift brake is constructed on the electro-magnetic principle and is situated between the motor and the gearbox (see **Figure 8.7**).

The brake shoes are lined with Ferodo or some similar material so that the brake can maintain its adjustment for long periods without attention. When the elevator car approaches the required floor, the hoisting motor is automatically switched off and the brake is gently applied to bring the car to a smooth stop.

The brake is also automatically applied in the case of:

- Safety gear being brought into operation.
- A power failure

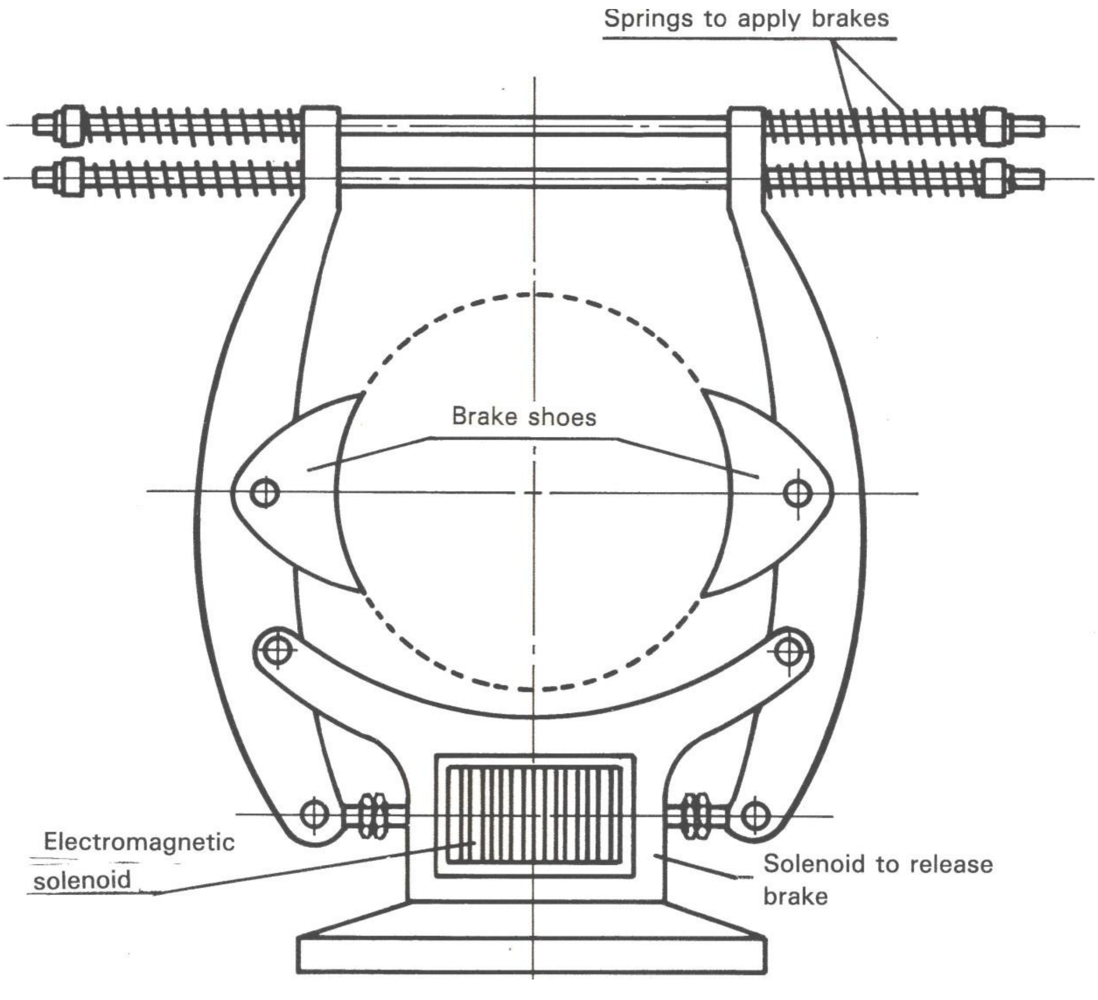


Figure 8.7 Electromagnetic brake

8.12.1 Advantages of the Electromagnetic Braking Systems

1. Electromagnetic braking system is extremely safe and provides safe working conditions
2. Fast and efficient braking system
3. Easily maintained and cost effect

8.12.2 Disadvantages of Electromagnetic Braking Systems
1. Cannot operate without electric current
2. Not effective in areas where there is no electric current
3. If there is a power outage the electromagnetic braking system will be ineffective

8.13 Disc brakes
The disc brake was developed to overcome the many disadvantages of the brake drum system on motor vehicles. The brake shoes are pads which, when the brake is applied, are pushed onto both sides of the disc, thus clamping the disc between them and slowing down or stopping the wheel.

The disc can be cooled much more effectively by the air flow and distortion is eliminated. One disadvantage of the disc brake is that there is no self-servo or "wrapping" action as with a drum brake, consequently a heavier pressure is required at the pedal and power assistance is therefore desirable.

8.13.1 Advantages of disc-type brakes
1. The surface on which heat is generated is directly exposed to the air, therefore easier dissipation of heat is obtained to prevent brake fade.
2. Disc brakes are self-adjusting.
3. Disc pads are easily replaced.
4. Heat does not affect the pedal travel as in the case of drum brakes.
5. Disc brakes are independent of self-energising action and a more progressive braking action is obtained, i.e. braking is proportional to the applied force.

8.13.2 Disadvantages of disc-type brakes
1. A booster is necessary to increase the applied force.
2. Braking area is smaller and lining material wears faster.
3. Brake noise is sometimes a problem.

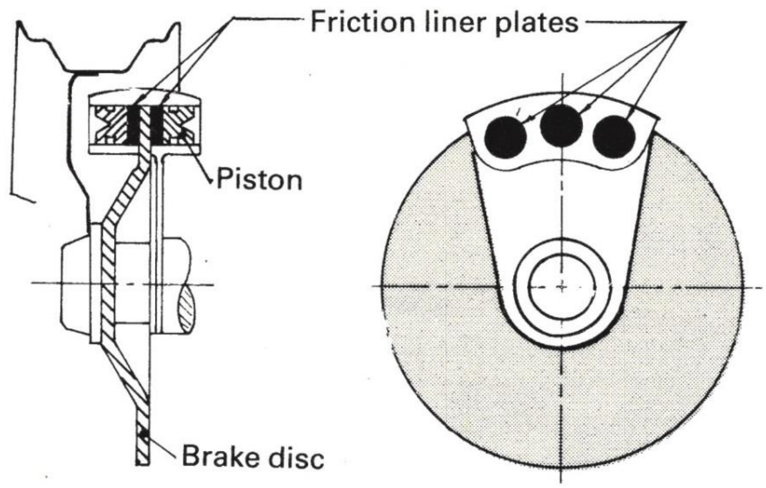


Figure 8.8 (a) Disc brakes

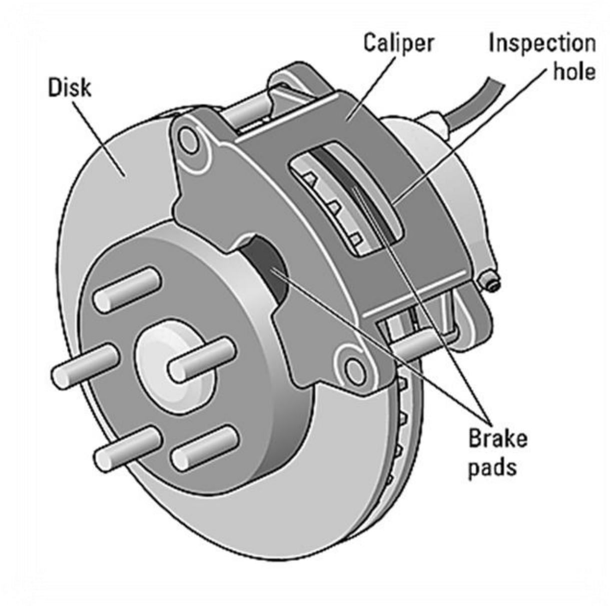


Figure 8.8 (b) Disc brake components

8.13.3 Disc brakes on mine hoists

Until recently all mine hoists were equipped with drum brakes. A radical change has now taken place with the introduction of disc brakes. The braking effort required for a large hoist could well be more than a hundred times as great as that for a motor car.

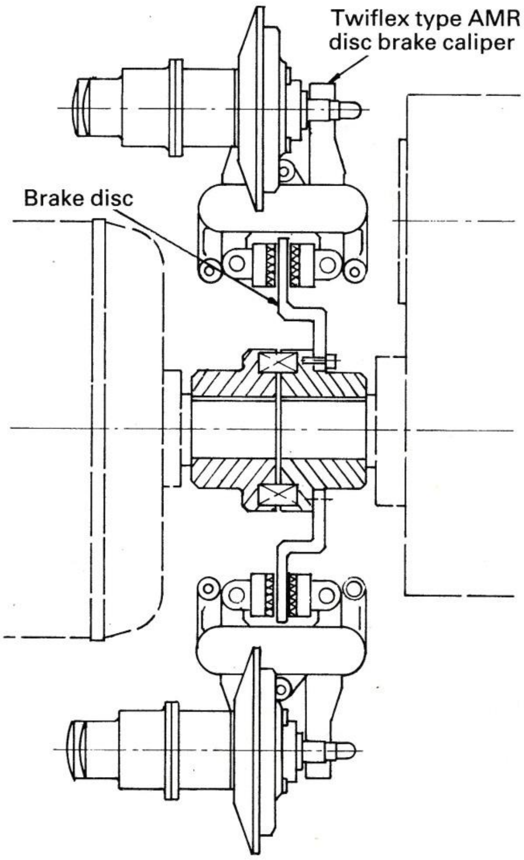


Figure 8.9 Typical installation disc brake on electric motor drive

Apart from providing a more efficient braking system the design of disc brakes is more compact and requires smaller underground excavations.

The disc brake pads operate in pairs on either side of the flat surfaces of a solid steel disc and the braking effort is continually exerted by a system of springs while the control is used to release the brakes, thus maintaining a safety condition.

8.14 Internal drum and shoe brakes

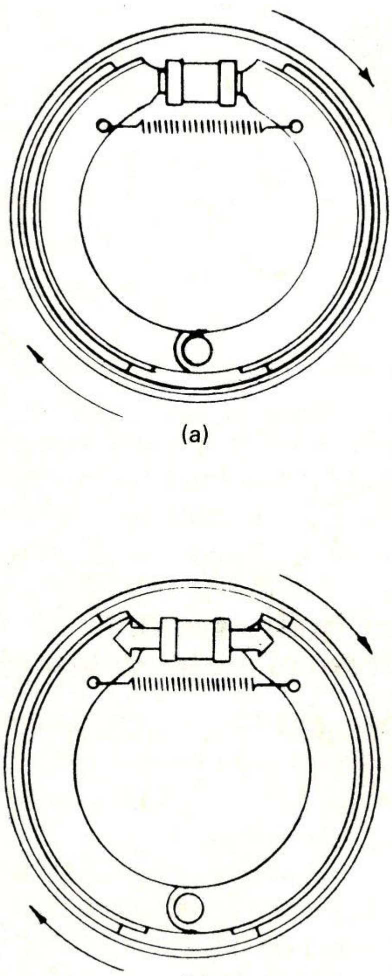
Figure 8.10 (a) and **(b)** show how a hydraulic system relies on fluid pressure to force the brake shoes against the wheel drums of a motor vehicle.

The principle of operation of hydraulic brake systems is that when the brake pedal is depressed it pushes a piston along a cylinder (called a master cylinder) filled with brake fluid. This cylinder feeds a pipeline to each wheel.

At the brake end of each pipeline is another cylinder in which a piston is moved by the incoming fluid.

This piston operates the brake shoes and brings them into contact with the brake drum. It will be seen that the operation of such a system depends on the fact that the brake fluid, like all liquids, is almost incompressible and acts as a fluid column inside the pipeline.

When the brake pedal is released the brake shoes return springs pull the shoes back to their original position and push the column of brake fluid back towards the master cylinder.



(a)

(b)

Figure 8.11 Action of hydraulic brake shoes (a) Leading and trailing shoes in "off' position (both brake shoes hinge on the same pivot), (b) the same brake "on" (leading shoe, on right, exerts more force than/railing shoe, on left

TAKE NOTE:
Internal drum and shoe brake system the force is applied in a radial direction up-against the drum friction surface which is parallel to the rotational centre line of the wheel.

8.14.1 Hydraulic brake fluid

To provide positive brake action under all conditions, brake fluid must meet many requirements.

1. It must not swell or soften the rubber parts.
2. It must prevent corrosion of the different parts.
3. It must not vaporise at the highest temperature encountered in actual service.
4. It must have a low freezing point.
5. It must act as a lubricant to the moving parts of the system.
6. It must mix satisfactorily with other makes of hydraulic brake fluid.

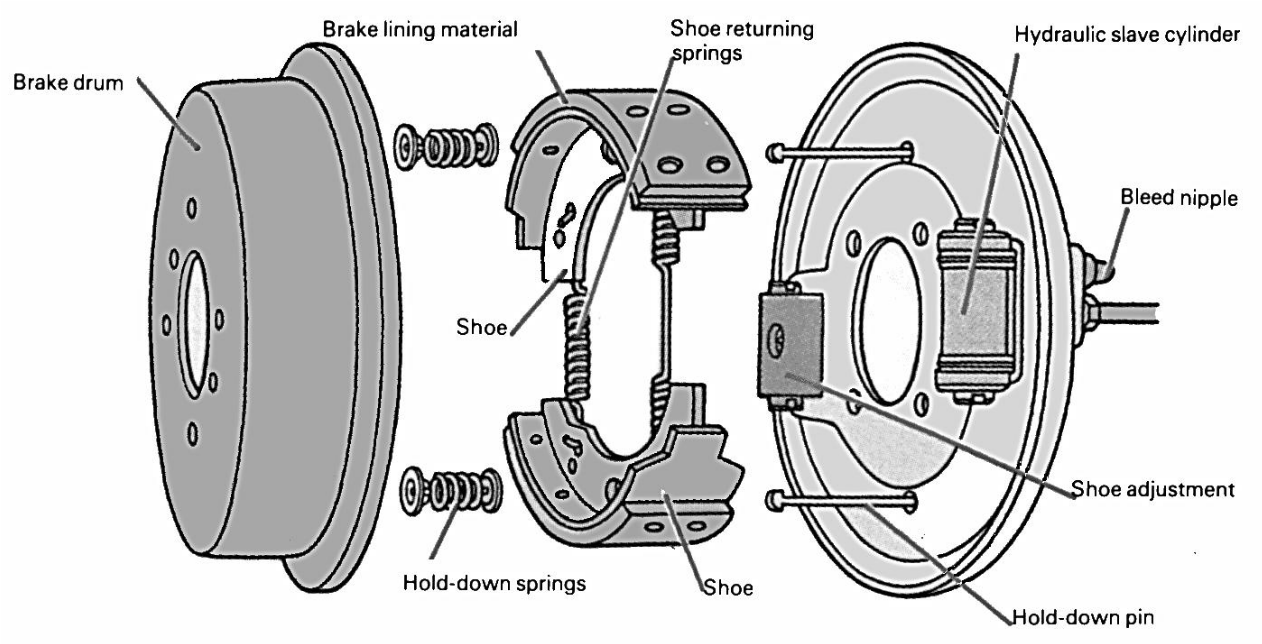


Figure 8.12 Internal drum and shoe brakes

⚠	**TAKE NOTE:** A drum brake is a brake that uses friction caused by a set of shoes or pads that press against a rotating drum-shaped part called a brake drum.

8.14.2 Advantages of internal drum and shoe brakes

1. No adjustment is needed for brake lining wear as this is affected automatically.
2. A drum brake can provide more braking force than an equal diameter disc brake.
3. Drum brake shoes last longer than disc brake pads used in a brake system of similar dimensions and braking force.
4. Drum brakes retain heat and are more complex than disc brakes.
5. A drum brake has long life wear characteristics.
6. Drum brake return springs give more positive action and, adjusted correctly, often have less drag when released.

8.14.3 Disadvantages of internal drum and shoe brakes

1. When the drums are heated by hard braking, the diameter of the drum increases slightly due to thermal expansion, so the shoes must move farther and the driver must press the brake pedal farther.
2. The properties of the friction material can change if heated, resulting in less friction. This can be a much larger problem with drum brakes than disc brakes, since the shoes are inside the drum and not exposed to cooling ambient air.
3. Excessive brake drum heating can cause the brake fluid to vaporize, which reduces the hydraulic pressure applied to the brake shoes.
4. Drum brakes collect water and dust and does not drop off easily.
5. No cooling system built in to reduce overheating.
6. Overheating reduces the frictional force developed.

8.15 Development of brake systems of motor vehicles

Manufacturers of motor vehicles are at present concentrating greatly on the comfort, convenience and safety of the motorist. To bring a powerful car to a stop within reasonable limits at a speed of say 120 km/hour, use is being made of the servo brake action to boost the power exerted on the brake pedal.

Modern vehicles arc thus equipped with some form of servo system for efficiency and the convenience of the motorist. Even in powerful diesel motor trucks fitted with pneumatic brakes the servo brake system with drums is installed to bring them to a standstill fast when heavily loaded.

Disc brakes require much more pressure on the brake shoes to obtain efficient brake action than drum brakes. For this reason manufacturers use the vacuum servo brake assembly in conjunction with disc brakes in order to obtain the extra power required for the efficient application of the disc brakes.

If, when the bonnet is lifted, you observe a vacuum servo assembly in the engine-block next to the main brake cylinder, it is clear that the vehicle is equipped with disc brakes on the front wheels.

8.15.1 Self-energisation

The amount of pressure applied to the brake shoe is considered the most important point in the effectiveness of brakes. Apart from the force on the brake shoe by the brake fluid force, self-energisation greatly multiplies the force pressing the shoe against the brake drums.

Self-energisation is obtained by the tendency of the rotating drum to drag the lining along with it. When self-energisation includes both shoes it is called servo action.

8.15.2 Full servo brake assembly

To accomplish the full servo action, the shoes are linked together at the bottom by means of a floating pivot pin. The anchor pin at the top acts as a stop for the brake shoes. When the brakes are applied, both the shoes will move with the rotation of the drum until the secondary shoe is stopped by the pivot or anchor pin and the primary shoe is also stopped as the two shoes are linked at the bottom. Servo action is thus obtained on both shoes.

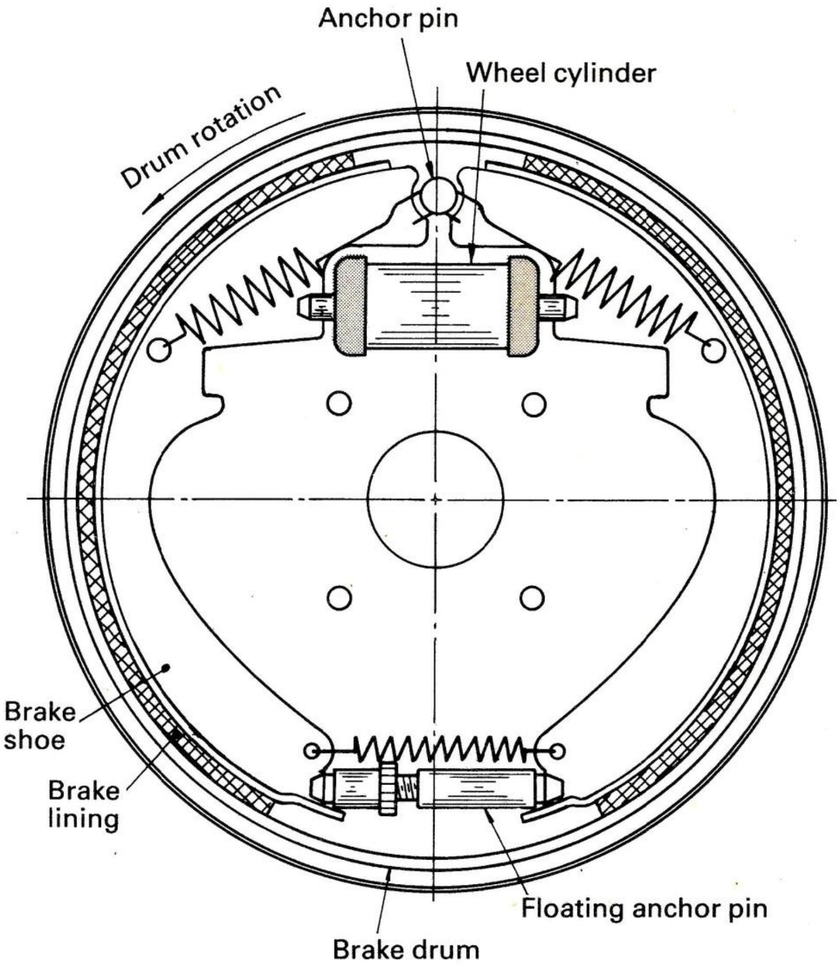


Figure 8.13 Servo action of brake shoe

8.15.3 Double leading brake-shoe arrangements
Two fixed wheel cylinders act as shoe anchors and the rubber-sealed pistons force each shoe tip outwards.

The hydraulic cylinders are linked by means of a pipe. When the brakes are applied, the shoes are forced against the drum and self-energisation is obtained at both shoes.

With this arrangement a more powerful and stable brake is obtained and the linings will wear more evenly. It is commonly used on front brakes.

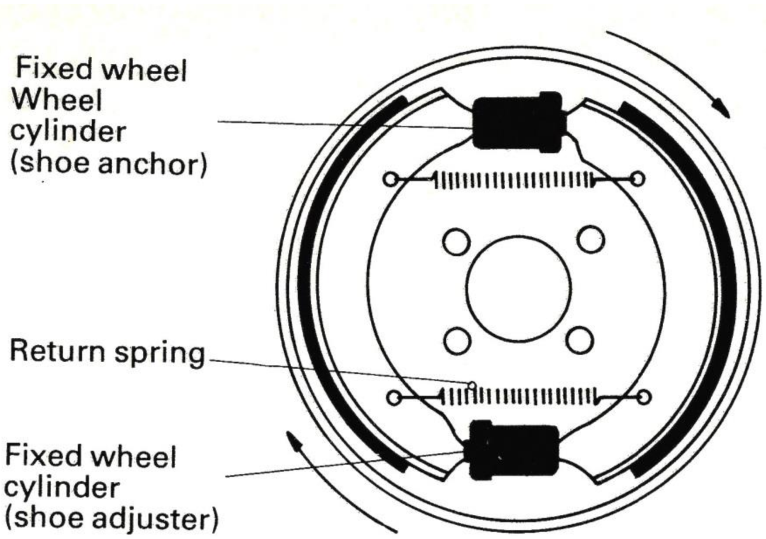


Figure 8.14 Double brake shoe arrangement

8.15.4 Semi-energising brake

In this arrangement the brake shoes are anchored at one end to the backing plate. In some cases both shoes are anchored to one pivot pin.

In other designs each shoe is anchored individually to its own pivot pin. The shoes of this type are not free to float inside the drum. The front shoe tends to move outwards with the drum but is held back by the anchor.

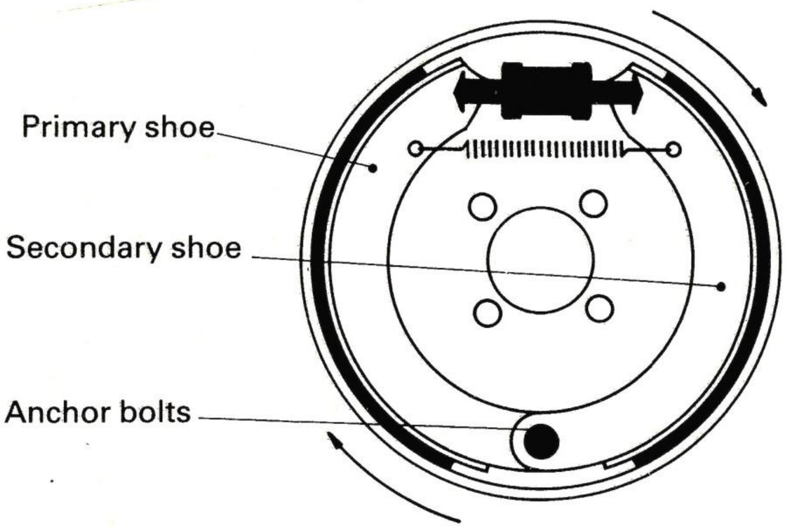


Figure 8.15 Semi-energising brake

The rotating drum tends to force the rear shoe inwards away from the drum. The front shoe exerts a greater braking force than the rear shoe, causing the primary lining to wear quicker than the secondary lining.

8.15.5 Vacuum servo brakes

In the vacuum servo brake system a conventional master cylinder is joined by brake lines to a vacuum cylinder and master cylinder assembly.

This system multiplies the pressure produced by the conventional master cylinder. When the brakes are applied while the engine is running, the pressure developed in the fluid from the conventional master cylinder forces the brake shoes against the drums.

Further pressure actuates the vacuum cylinder control valve, closes the vacuum port and opens the port to the atmosphere. As air is admitted, the forces acting on the piston of the vacuum power cylinder are transmitted directly to the hydraulic piston through the push rod.

The total hydraulic pressure created and transmitted to the wheel cylinders is therefore the sum of the pressure developed as a result of the thrust on the vacuum power cylinder push rod and the pressure received from the master cylinder.

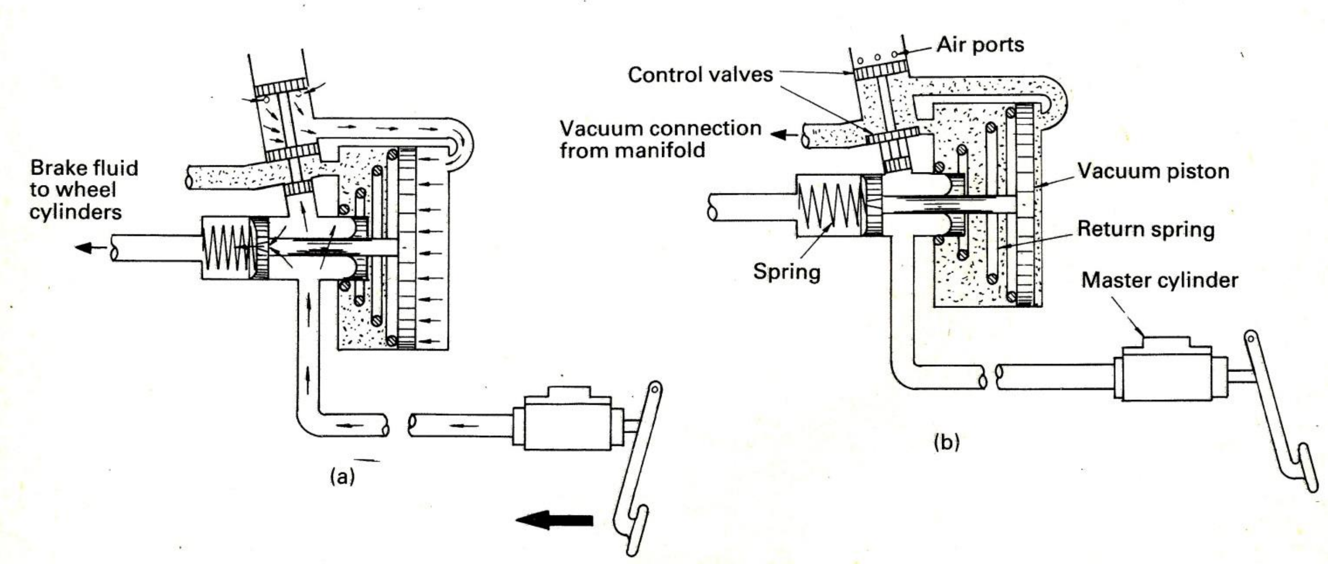


Figure 8.16 Vacuum servo system (a) Brakes applied, (b) brakes not applied

8.15.6 Function of vacuum servo unit

The function of the vacuum servo unit is to assist the driver of the vehicle to provide a large force at the brake shoe. Vacuum is obtained by connecting the device to the inlet manifold or, in the case of a compression-ignition engine, to an exhauster driven by the engine. This is an eccentric vane air pump with the inlet side producing the vacuum.

Every servo system must continue to function if the vacuum fails. It must also operate progressively; that is, the assistance given by the servo should be proportional to the force applied by the driver. There are two types of power brakes:

1. The air-suspended type and the vacuum-suspended type.
2. The vacuum-suspended type is used almost exclusively because removing the air from the air-suspended type takes time which may be precious when stopping a vehicle in an emergency.

8.15.7 Advantages of the vacuum servo brake

1. Less effort is necessary to apply brakes.
2. A much greater braking force can be applied.
3. Less brake pedal movement is necessary for an equal braking force.

8.16 External drums and band brakes

This braking system is opposite to the internal drum and shoe brake system. The braking system is applied on the outside of a drum.

TAKE NOTE:
External drum and band brake system the force is applied on the outside of the brake drum.

Figure 8.17 shoes typical application of these. This system is applied to brakes on overhead cranes, hoists, driving gear haulages and winding drums.

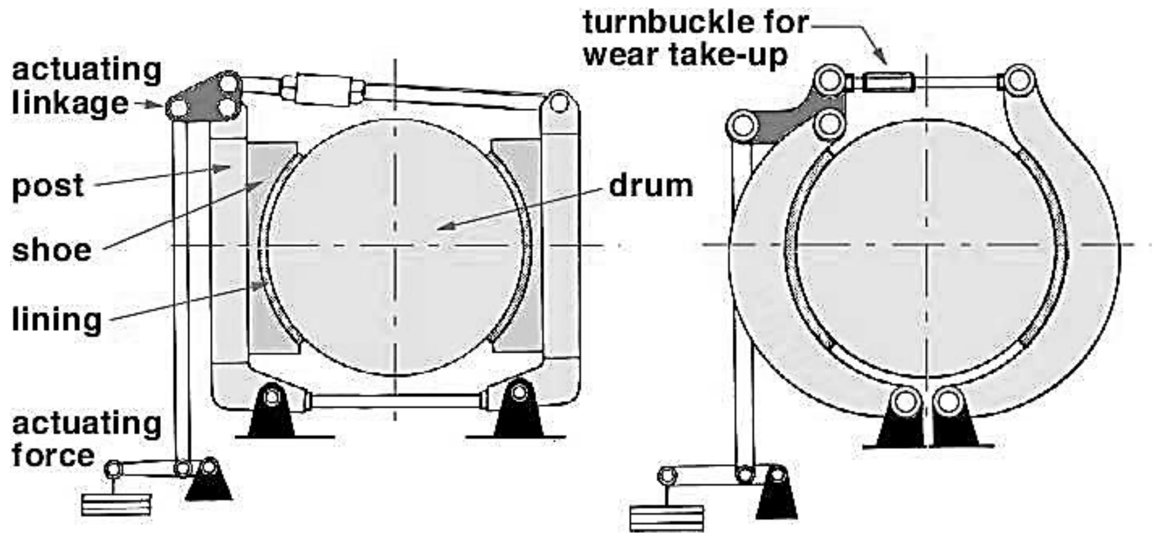


Figure 8.17 Typical external drums and band brakes

8.16.1 Brakes on overhead cranes

Previously most overhead crane hoists were fitted with solenoid-operated brakes. These were in effect a positive brake system which was either on or off, depending on whether the solenoid was "energised" or not.

A more recent innovation is what the British Thomson-Hauston Co. term the “Sta-creep" brake system, which is a pair of brake shoes, springloaded, adjusted to finer clearances than the solenoid type, and operated by a "thruster".

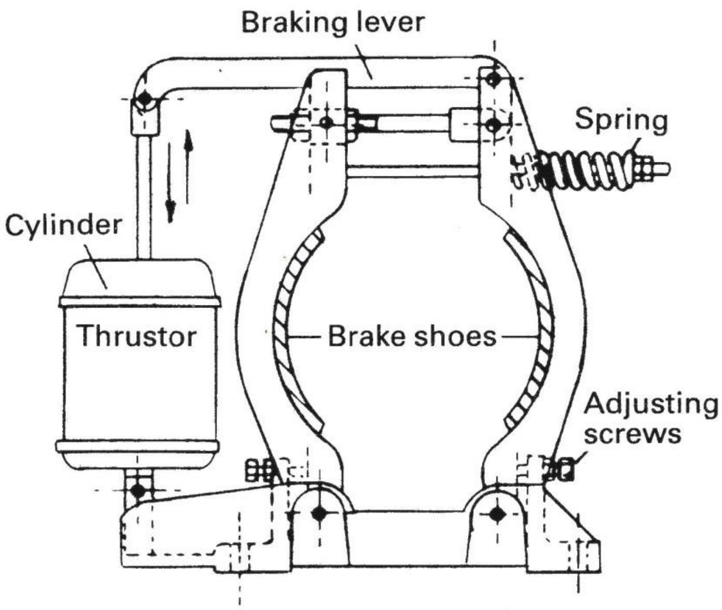


Figure 8.18 (a) Automatic brake

The brake on the drum shaft operates automatically and is applied when the electric current or hydraulic pressure to the motor fails.

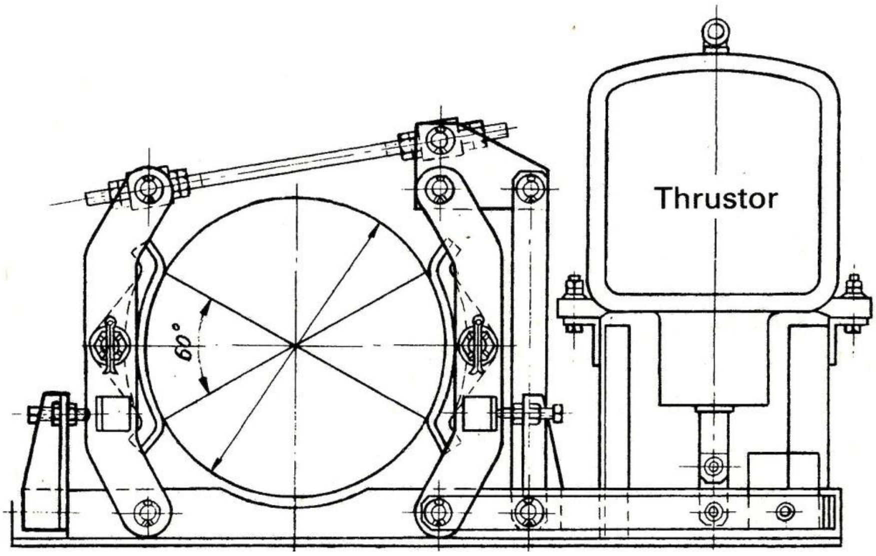


Figure 8.18 (b) Automatic brake

8.16.2 Advantages of external drum and band brakes

1. Inspection and maintenance is no complicated and can be done efficiently.
2. Adjust can be made without dismantling the drum.
3. Dust, dirt and water is dropped off and can be cleaned easily.
4. Friction surface is on the outside therefore easy cooling to the drum.

8.16.3 Disadvantages of external drum and band brakes

1. Unsafe because the band is not guarded and protected and can damage other equipment or hurt persons.
2. The braking system does not adjust automatically; adjustment must be carried out regularly.
3. Wear and tear on both brake lining and drums due to friction.
4. Maintenance is on-going and difficult due to large brake drums.

8.17 Cone brakes

Cone brakes are employed either as independent systems with electro-magnetic control or in combination with ratchet gearing. **Figure 8.19** shows a sectional view of a cone brake and how it operates.

TAKE NOTE:
Cone brakes are friction brakes with cone-shaped rubbing components (male and female).

These brakes are frequently used for lowering loads. In raising the load the ratchet runs free, but when the load tends to lower the ratchet engages, bringing the cone surfaces together.

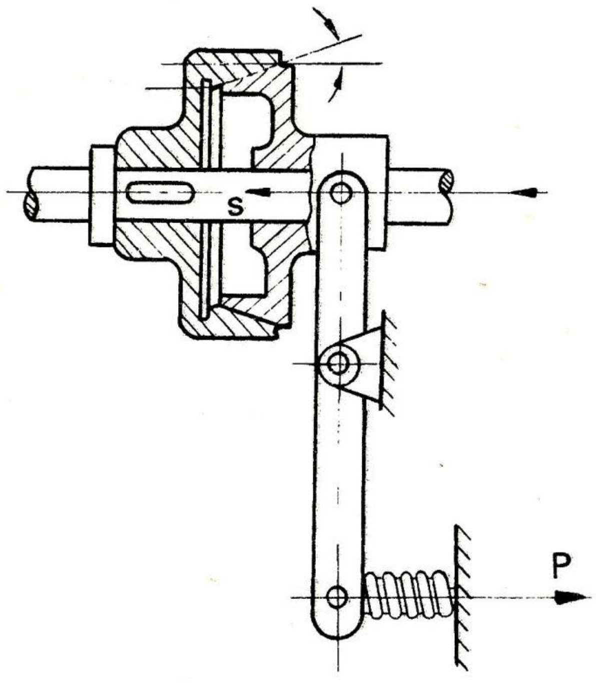


Figure 8.19 Cone brake

8.17.1 Advantages of the cone brakes

1. Less axial force needed for baking power due to the wedge shape contact between surfaces.
2. Small angle between the surfaces resulting in smaller axial force needed to operate the braking system.

8.17.2 Disadvantages of the cone brakes

1. Other components such as bearings and drive shaft can break down due to the large amount of end thrust applied when braking.
2. Wear and tear on pins, links, bushes which leads to poor operation of the braking system.
3. Any oil or grease on the surfaces will cause slippage and failure to the braking system.

Activity 8.1

1. Explain the function and purpose of brakes.
2. Define the activating and de-activating action of braking systems.
3. Name FOUR types of braking systems.
4. Make a neat schematic diagram of:
   4.1 Air brake system
   4.2 Mechanical braking system
   4.3 Hydraulic brake system
5. Discuss the advantages and disadvantages of the above question.
6. Hydraulic brake fluid must comply with certain requirements to ensure efficient working operation of braking system. Name FIVE such requirements.
7. Discuss advantages and disadvantages of:
   7.1 Disc brakes
   7.2 Internal drum and shoes brakes
   7.3 Cone brakes
   7.4 External drum and band brakes

Self-Check

I am able to:	**Yes**	**No**
• Describe the purpose of brakes		
• Describe the activating and the de-activating action of the following brake operating principles:		
o Electromagnetic – Hydraulic - Air (spring) Mechanical		
• Describe the advantages and disadvantages of each of the braking systems		
• Compare the advantages disadvantages of the following braking units:		
o Disc brake - Internal drum and shoe brake - External drum and band brake - Cone brake		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 9

Bearings

Learning Outcomes
On completion of this module, the student should be able to:

- Explain the difference between friction bearings (bush type) and anti-friction bearings (rolling bearings)
- Identify and name the following anti-friction bearings from a given drawing:
    - Single and double row radial ball, and cylindrical roller bearings
    - Thrust ball and thrust roller bearing (single and double direction)
    - Single row angular contact bearing
    - Tapered roller bearing
    - Needle roller bearing
    - Spherical roller bearing
- Name three main types of loads and those relative to the above bearings
- Describe bearing failures, and failure prevention methods
- State factors that have a detrimental effect on the bearings mentioned above
- Select the correct type and size bearing using a manufacturer's catalogue (calculations are not necessary).

9.1 Introduction

In this module we will discuss bearings. Bearings are used to reduce friction. There are various types of bearing and we will explain the difference of these as well as how to select the correct bearing for the particular application.

Energy is used, the surfaces wear, and this reduces component life and product efficiency. Friction may be reduced by lubrication which keeps the surfaces apart. At the same time, lubricants dissipate heat and maintain clean contact surfaces.

Materials are carefully selected with appropriate mechanical and physical properties for bearings and their housings, to minimize the effects of friction, and particular care is taken with the accuracy of machining, surface finish and maintenance of all component parts associated with bearings.

IMPORTANT TO NOTE:

Bearings are important in power transmission. A bearing is a device especially designed to reduce friction between two parts of a mechanism, one of which is moving, the other stationary. A bearing is a support for a rotating shaft. It reduces the friction between moving surfaces. Thus, it provides smooth movement and reduces wear.

Bearings are available in many types and styles. We can divide bearings into two categories, friction and anti-friction bearings. A bearing arrangement does also include components associated with bearings.

The shaft and the housing as shown in **Figures 9.1(a)** and **9.1 (b)** are examples of these components.

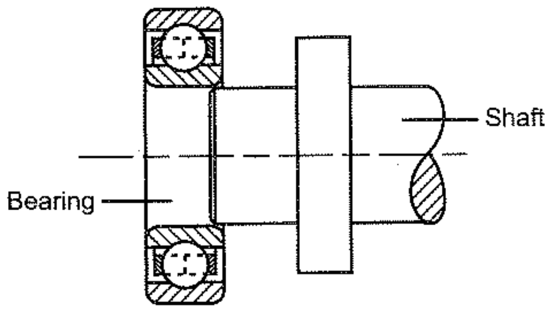


Figure 9.1 (a) Bearing fitted on a shaft

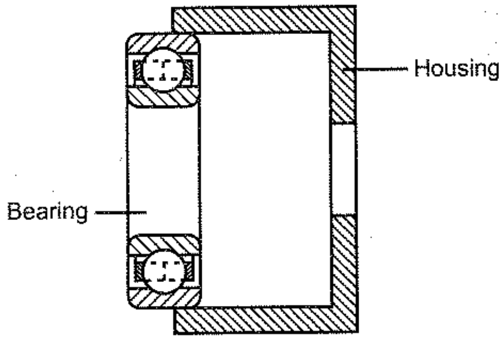


Figure 9.1 (b) Bearing fitted in a housing

To design a bearing arrangement it is necessary to select a suitable type and size of bearing. It is also important to consider the type and quantity of lubricant, appropriate fits and bearing clearance.

9.2 Plain bearings and bushes

Plain bearings or bushes are also known as friction bearings. Friction bearings operate on the principle of sliding friction. This means that there is a relative sliding movement between the shaft and the bearing.

Because of the friction between the two surfaces, we use a lubricant to separate the surfaces and to overcome friction. Separating the surfaces in this way by using a film of lubrication, results in a longer bearing life.

The bearing metal should have a low coefficient of sliding friction, be able to conduct heat generated away from the bearing surfaces, resist wear in use and be tough enough to withstand shock loading in service.

In the event of breakdown due to lack of lubrication, it may be desirable when overheating occurs for the bearing material to run, preventing seizure and possible severe damage to associated mechanical parts.

9.2.1 Classification of plain bearings

Plain bearings may be classified as follows (see **Figure 9.2**):

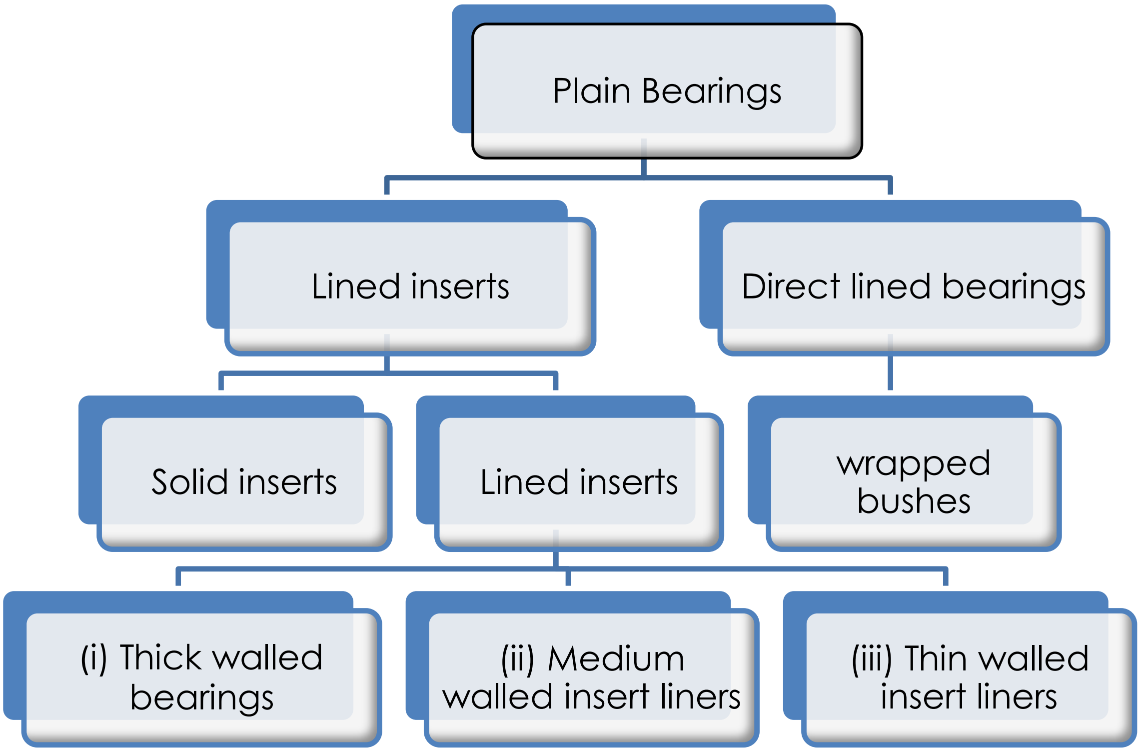


Figure 9.2 Classification of plain bearings

9.2.2 Direct lined housings

These housings are lined directly with bearing materials and the choice of material is limited by the practicality of keying or bonding the bearing material to the housing surface.

The dimensions of the housings, casting temperatures and bonding characteristics of the bearing materials will determine whether metallurgical bonding is possible without unacceptable distortion of the housing.

Generally this technique is limited to ferrous housings with low melting point white-metal bearing surfaces. Light alloy and zinc base housings are difficult to line directly with white-metal.

9.2.3 Insert liners

These are bearing elements which consist of a liner inserted into a previously machined housing and they can be divided into separate classes:

(a) Solid insert liners.

(b) Lined inserts.
(c) Wrapped bushes.

- **Solid insert liners:** Manufactured wholly from suitable bearing materials such as aluminium alloy, copper alloy or white-metal, these liners consist of machined bushes, half bearings and thrust washers.

  The housings are machined to relatively close tolerances. An insert may be finished machined after assembly or a prefinished standard precision liner added as a final operation and this has the added advantage of spares replacement.

  Typical applications of insert liners are to be found in diesel engine small bores, crank shaft main bearings, bushes for gearboxes, steering gear and vehicle suspensions.

- **Lined inserts:** These consist of a backing material such as cast iron, steel or a copper alloy which has been lined with a suitable bearing surface of aluminium or copper alloy, or of white-metal. This type can also be supplied as a solid insert, a split bush, half bearing or thrust washer.

Insert bearing half liners are manufactured as;

1. Rigid or thick walled bearings.
2. Medium walled bearings.
3. Thin walled bearings.

o **Thick walled bearings:** These are backing shells of cast iron, steel pressings and copper base alloys generally lined with white-metal and copper alloys are used to produce bearings which are manufactured as pairs and used in turbines, large diesel engines and heavy plant machinery. Usually more economic than direct lined housings, these bearings may be provided with a finishing allowance for the bore and length which is adjusted during assembly.

o **Medium walled insert liners:** Normally a steel backing is used with a wide range of lining materials. Bearings are prefinished in bore and length and manufactured as interchangeable halves.

o **Thin walled insert liners:** These are high precision components with steel backing and white-metal or copper and aluminium base alloy surfaces, and are suitable for universal application in large production products such as high speed diesel engines and compressors.

9.2.4 Wrapped bushes
These are pressed from flat strip of rolled bronze, or steel lined with white-metal, lead bronze, copper-lead, or aluminium alloys. They are supplied as a standard

range of prefinished bushes or with a bore allowance for finishing in situ by fine boring, reaming, broaching or burnishing.

These are suitable for all bushing applications in which the tolerable wear will not exceed the thickness of the lining material.

9.3 Types of plain bearings

If you have a look at **Figures 9.3 (a)** and **9.3 (b)** you will see the difference between a radial load and an axial load.

If the forces acting on the shaft have a line of action in line with the shaft's radius, we call it a radial load.

If the forces acting on the shaft have a line of action in the same line as the axis of the shaft, we call it an axial load.

We also use friction bearings to guide a sliding movement in a specific direction. *We* will discuss sliding movement later in this module.

Here are some examples shown in **Figure 9.3 (a)** and **(b)** below.

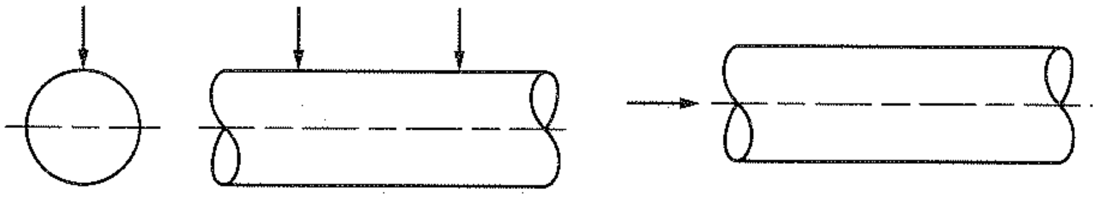


Figure 9.3 (a) Radial Load

Figure 9.3 (b) Axial Load

9.3.1 Solid bearings

Solid bearings are also known as bushes or journals. Solid bearings cannot be repaired but can easily be replaced. **Figure 9.4** shows how these bearings support radial loads. They are typically found in generators, starter motors and idler pulley. These are also known as pedestal bearings.

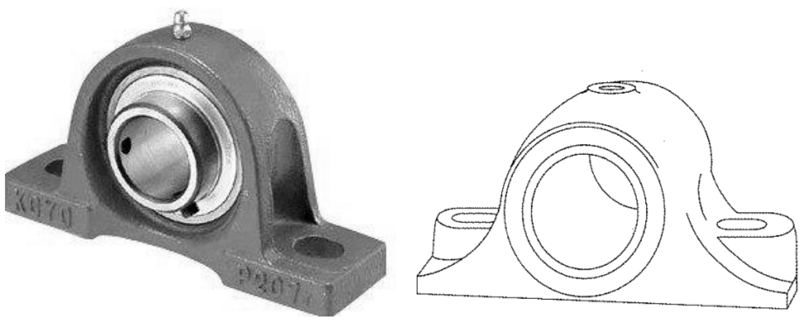


Figure 9.4 Solid bearing or bush in housing

The solid bearing is used when speed and pressure are moderate and little wear is anticipated. The hole is parallel-bored and the class of fit determined by the nature of the work the machine is required to do. Provision is made for a thin film of oil to separate the shaft from the bearing.

Furthermore, as holes will eventually wear oval, they are lined with thin replaceable gun metal bushes, so that the bearing itself may thus be corrected to its original condition. Bushes should be kept in place by means of screws or dowels to prevent them turning with the moving journal.

9.3.2 Slit bearings

In many cases solid bearings are undesirable, and in others, it would be impossible to use them.

Bearings are therefore divided or split. This is a more satisfactory design for coping with wear besides permitting shafts to be fitted in place even though permanent collars are at each end.

The drawing in **Figure 9.5(a)** illustrates a type of split bearing which is made up of the base and cap together with fastening bolts. The holes are provided for the foundation bolts.

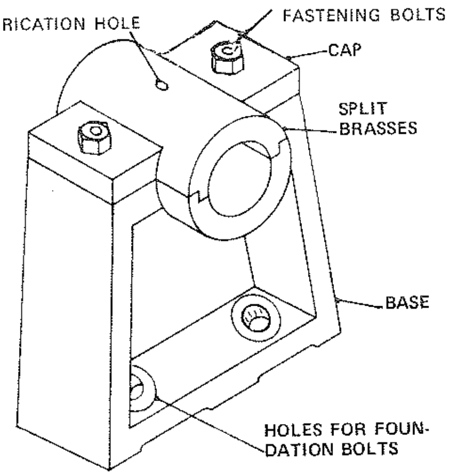


Figure 9.5(a) Plain spilt bearing

Figure 9.5(b) shows a bearing that is divided or split. These bearings have the appearance of a solid bearing cut axially in half to form a top and bottom section. This allows the shaft to be removed easily. These bearings can be adjusted to minimise wear by taking out the shim which are thin pieces of metal plate inserted between the two bearing halves.

Split bearings can also be re-metalled and used again. These bearings support radial loads. They are typically used on big end bearings in reciprocating engines and pinion gear shafts.

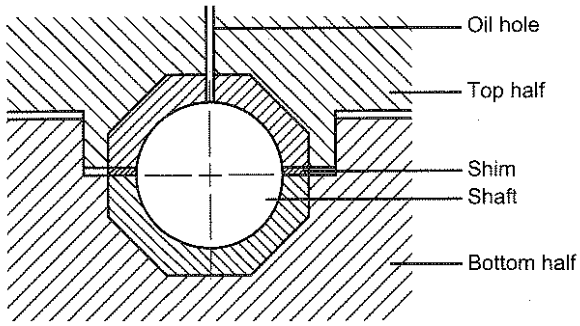


Figure 9.5 (b) Cross-section of a split bearing

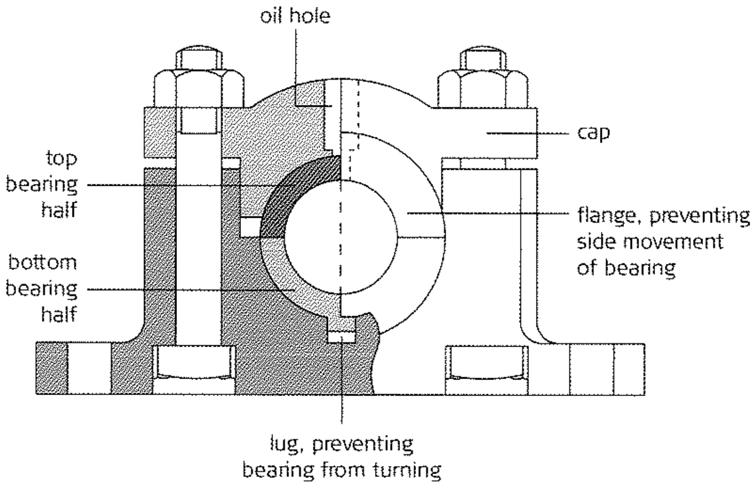


Figure 9.5 (c) Split plumber-block bearing

An example is shown in **Figure 9.5 (c)** of a split plummer-block bearing. Split bearings are used in places where it is impossible to use solid bearings such as:

- Connecting rod big end bearings;
- Crank shaft main bearings;
- Line shaft bearings.

9.3.3 Part bearings

A part bearing looks like a curved piece of metal that has been cut from a solid bearing. It is placed on the part of the shaft that carries the heaviest load. A part bearing is used in heavy industrial mining equipment, to shorten the amount of maintenance time. You can replace a part bearing easily and cheaply due to its size.

If you have a look at **Figure 9.6 (a)** you will see that the part bearing is positioned on that part of the shaft on which the main load is concentrated.

Figure 9.6 (b) shows that these bearings can be used in housing in the position of that part of the housing on which the main load is concentrated.

Part bearings are low cost bearings because their size is small in relation to solid bearings. These bearings can be replaced easily. Part bearings support radial loads only.

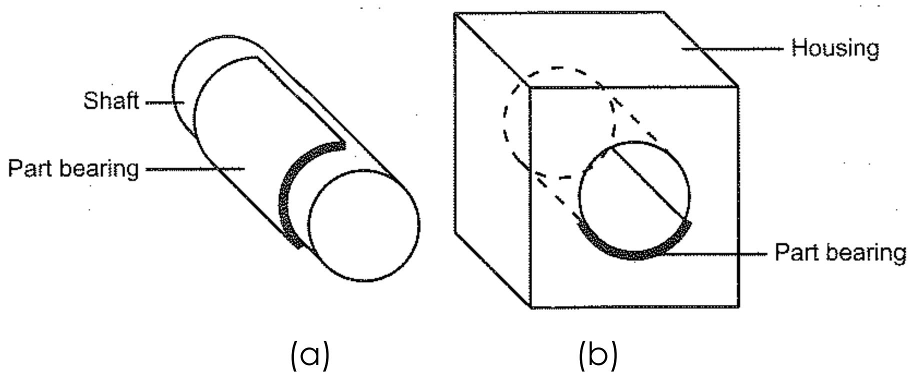


Figure 9.6(a) and (b) Part bearings

9.3.4 Thrust bearings

Thrust bearings are used to support axial loads, also called thrust loads. If you look at **Figure 9.7 (a)** you will see that the thrust bearing can only allow a thrust load in one direction.

A pressure pad positioned in housing allows the thrust collar to push against it to take up the friction and wear between the pressure pad and the thrust collar.

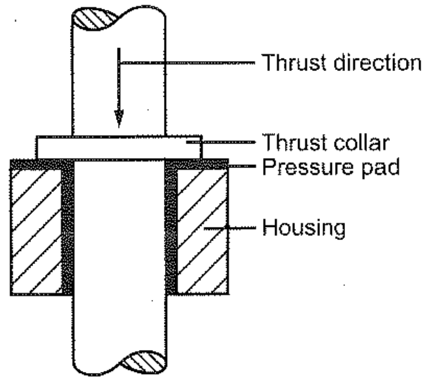


Figure 9.7 (a) Thrust bearing

Figure 9.7 (b) and **(c)** shows examples of a single collar and a multi-collar thrust bearing.

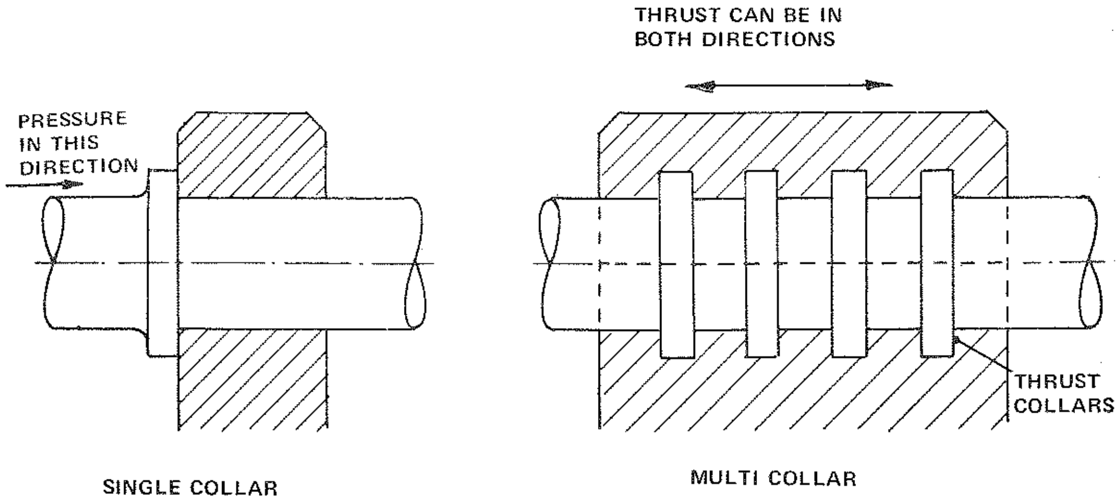


Figure 9.7 (b) and (c) Examples of thrust bearings

Footstep bearings are often called pivot or vertical thrust bearings which support shafting operating in a vertical position. The sketch in **Figure 9.7 (d)** shows a sectional view of the shaft on the wearing disc.

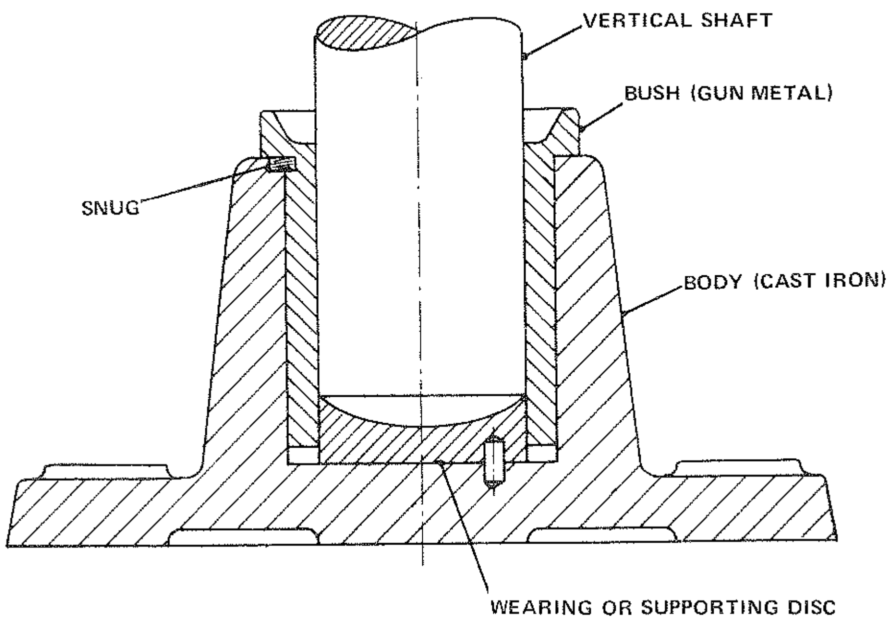
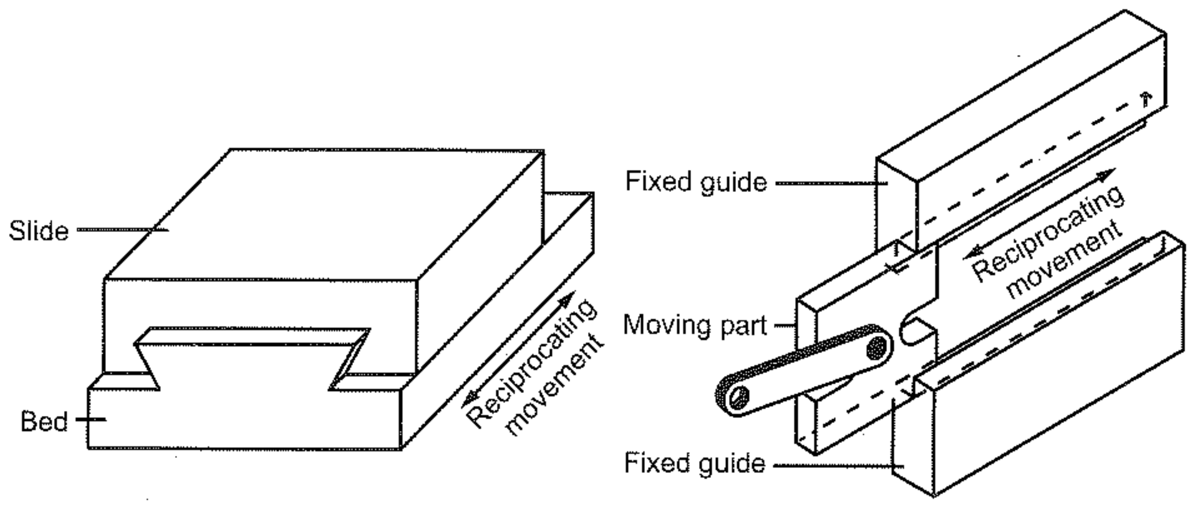


Figure 9.7 (d) Footstep bearing

9.3.5 Guide bearings

Guide bearings are used to support and to align machine parts that have sliding or reciprocating movement. **Figure 9.8 (a)** and **(b)** shows examples of sliding motion as it is found on the cross-slide of a centre lathe and the reciprocating movement of the cross-head of a pump assembly.

These bearings guide relative movement while carrying the load. The load usually consists of the components or parts of the machine itself or the work piece attached to a machine tool component.



(a) Lathe cross-slide

(b) Cross-head assembly

Figure 9.8 Guide bearings

Features of the friction bearings mentioned above are that they are quiet in operation, low in cost and that they have great rigidity. We can repair these bearings when they are worn and they are not limited by fatigue.

However, we must lubricate friction bearings according to very strict requirements as they are easily damaged if the lubrication supply is irregular or insufficient.

9.3.6 Taper bearings

Various types of' taper bearings are used, particularly on American and Continental lathes, but they are all subject to the general problem of correct adjustment of the two tapers.

The sketches in **Figure 9.9** illustrate a design for a front and rear journal taper in the same direction, with separate longitudinal adjustment on each bearing.

The finely threaded lock nuts provide for easy and sensitive adjustment. The different types of bearings have already been discussed.

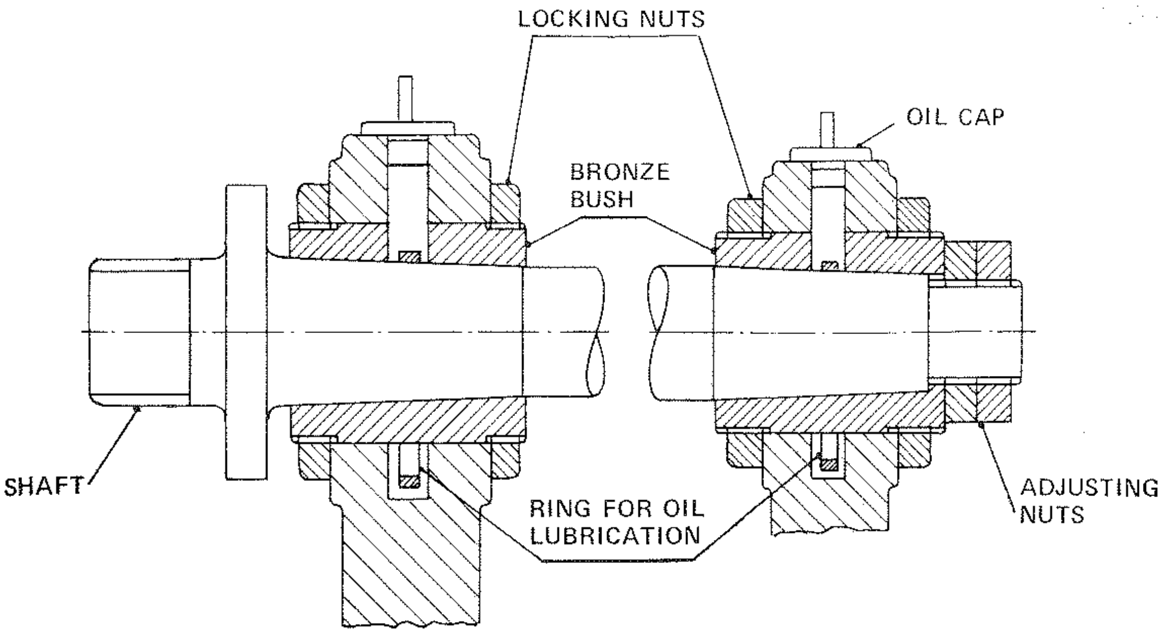


Figure 9.9 Taper bearings

9.3.7 Hanger bearings

We use hanger bearings to support line shafts in factories and workshops, also used on the underside of some overhead cranes. **Figure 9.10** shows a typical adjustable hanger bearing.

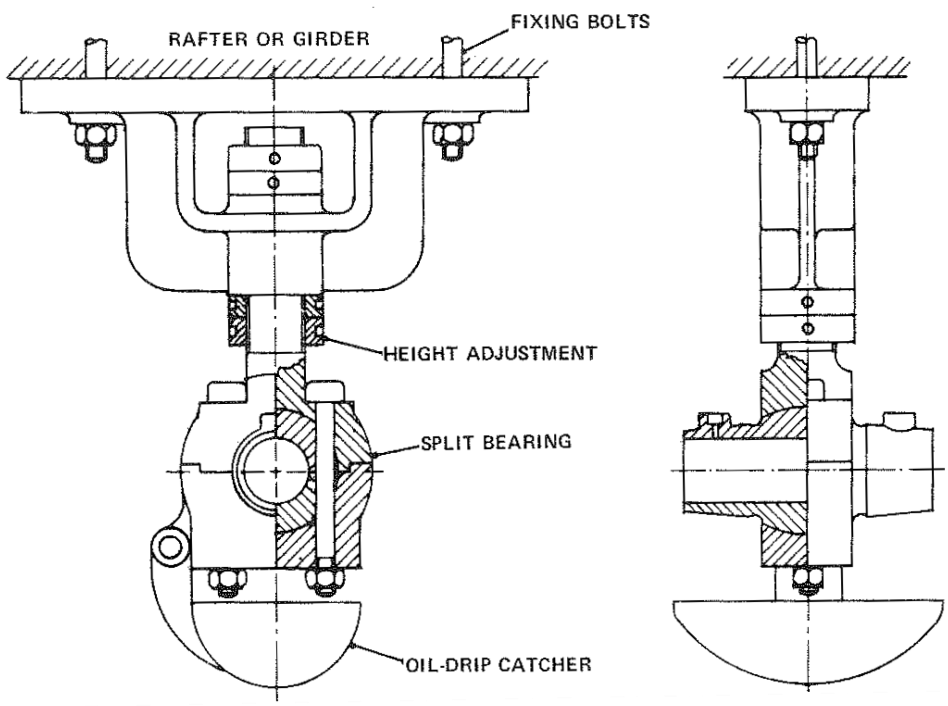
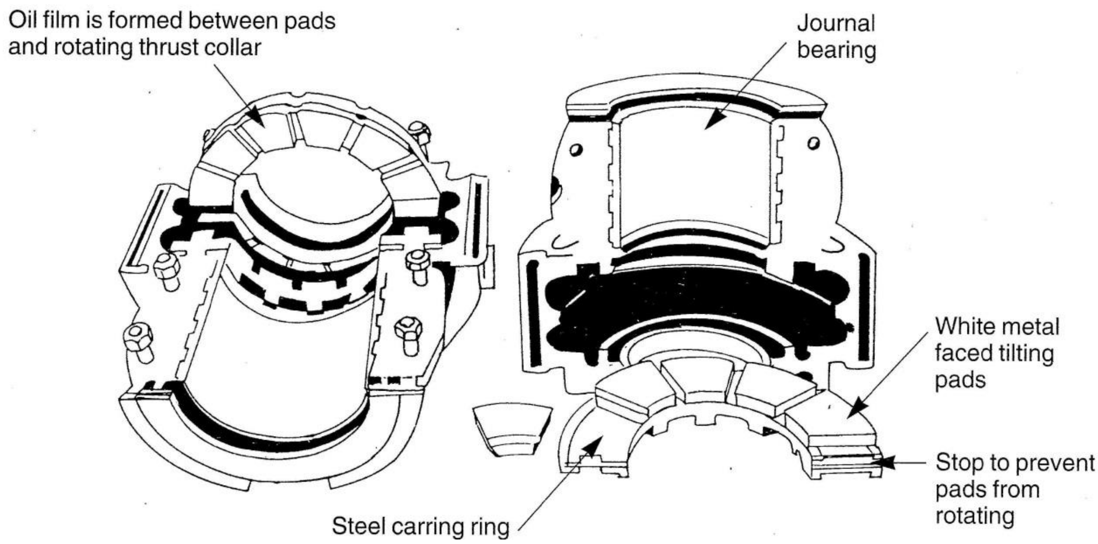


Figure 9.10 Adjustable hanger bearing

9.3.8 Mitchell thrust bearings

The Mitchell thrust bearing is designed to take axial thrust as is found in turbine rotor shafts. The turbine shaft is equipped with a thrust collar. Mitchell thrust bearings are used to eliminate end thrust, also known as axial thrust, which develops in turbine shafts.

The white-metal faced, gun-metal tilting pads, mounted in steel carrier rings, are shown in the sketches in **Figure 9.11(a)**



9.11(a) Mitchell thrust bearing

Each pad is an easy fit in the carrier ring and is prevented from rotating in the thrust collar.

The action of the bearing is as follows:

- Each pad is free to take up a slight angle to the plane of rotation.
- The lubricant is drawn into the wedge-shaped space so formed and the high-pressure oil film generated between the surfaces eliminates all metallic contact, thus enabling the thrust to take place entirely on the oil.

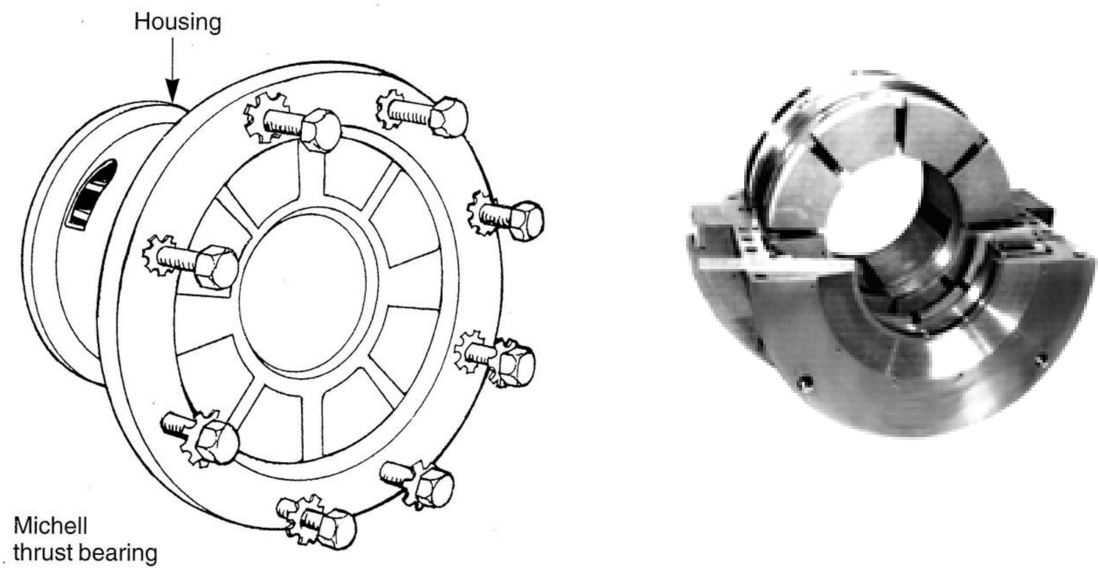


Figure 9.11(b) Typical thrust block with the Mitchell thrust bearing in position

A thrust collar is fitted on the shafts. This collar holds gun-metal pads on its circumference by means of a steel carrier ring. **Figure 9.11 (b)** shows a Mitchell Thrust bearing in position.

The pads do not rotate with thrust collar. Oil is drawn into the wedge-shaped space between the pads during rotation. End thrust is taken up by the high pressure oil cushion created in this space.

9.4 Advantages and disadvantages of plain bearings

9.4.1 Advantages of plain bearings

The advantages of plain bearings are:

- Quiet operation.
- Low cost.
- Great rigidity.
- Can be repaired when worn.
- Life is not limited by fatigue.

9.4.2 Disadvantages of plain bearings

The disadvantages of plain bearings are:

- Higher frictional properties.
- Increased power consumption.
- Easily damaged by foreign material in lubricant.
- Stringent lubrication requirements.
- Easily damaged by interruption of the fabrication supply.

9.5 Plain bearing lubrication

The requirements of a lubricant can be summarized as follows:

1) To support the bearing when static and under all speed and load conditions.
2) To have a low coefficient of friction.
3) To be non-corrosive to the materials used in the bearings.
4) To maintain viscosity over the operating range of temperature.
5) Able to provide an effective bearing seal.
6) Have the ability to adhere as a film to the bearing.
7) Be able to conduct heat rapidly.

No single lubricant can satisfy all of these properties and the design of the equipment will determine which aspect needs priority before a choice from available types can be made.

9.6 Material properties

The material used for plain bearings must possess the following specific properties:

- ***Fatigue resistant***: to withstand repeated stresses and strains without cracking or flaking.
- ***Embedability***: to absorb or embed dirt particles present in the lubricating medium.
- ***Compatibility (anti-scoring):*** to permit the shaft and bearing to resist galling or seizing under conditions of metal-to-metal contact, such as when starting up.
- ***Conformability:*** to flow slightly under load, as in the initial stages of running in, permitting the shaft and bearing contours to conform to each other.
- ***Thermal conductivity***: to absorb and carry away the heat generated by the bearing.
- ***Corrosion resistant:*** to resist attack by organic acids which sometimes form in oil.
- ***Load capacity:*** to withstand hydrodynamic pressures during operation.

9.7 Plain bearing materials

The application of the bearing, the bearing material and the lubricant used are all interdependent, but four basic requirements are necessary for the material:

1) Strong enough to resist failure by fatigue or overheating.
2) Good wear resistance and running properties.
3) Good lubricant retention.
4) High corrosion resistance which may arise due to temperature, the environment and lubricants used.

A wide range of materials consists of metallic, metallic backings with various bearing surfaces, reinforced synthetic resin, graphitic and sintered metallic. Various surface treatments are also available to improve wear resistance and reduce friction.

9.7.1 White-metals

These are a large range of either lead base or tin base alloys and are covered by British Standards. Antimony is used as a hardening agent since tin and lead are soft.

White-metal is a low melting point alloy which is compatible with virtually any type of mating surface.

Bearing materials should not be subject to corrosion due to water or the products of oil oxidation and the resistance of tin base white-metals is high but lead base alloys are susceptible to acidic corrosion from oil oxidation products.

White-metals are nearly always lubricated under pressure. Loss of lubricant for a short period may cause the bearing to soften and 'wipe'. It loses its compressive strength at elevated temperatures.

9.7.2 Other bearing materials

Other materials for plain bearings include copper lead alloys, lead bronzes, tin bronzes (phosphor bronze), gun metals and aluminium base alloys.

Before concluding this section it should be stated that metallic porous metal bearings are widely used which are manufactured by powder metallurgy where very fine metal powders are mixed and compressed in moulds to the correct form and sintered at high temperature in a reducing atmosphere.

The product is in effect a metal sponge which can be impregnated with lubricating oil. The porosity depends on the initial compression and these products are designed for suitable applications where high volume is required. Self- lubricating materials are also available in tube and bar form for individual manufacture.

Figure 9.12 shows a selection of different types of bearings.

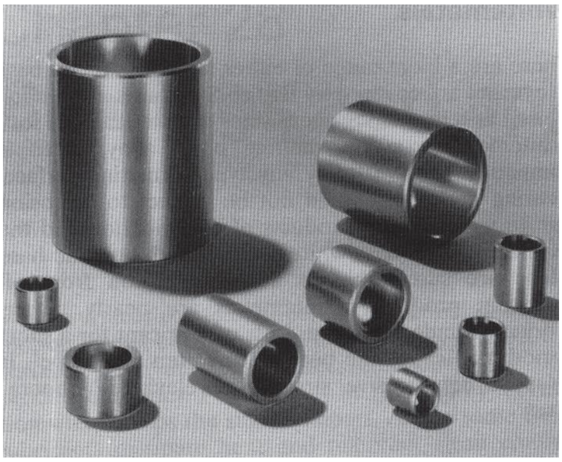


Figure 9.12 Different types of plain bearings

9.8 Bearing maintenance

Although machine designers and manufacturers supply good quality bearings with their equipment there are instances where bearings may be improperly designed, manufactured, or installed. It is difficult to determine the exact cause of bearing failure, but usually the problem can be traced to one or more of the following areas:

- *Unsuitable material for shaft and/or bearing.* With soft bearing materials like white metal, soft steel journals may be used, but with harder bearing materials the shaft or journal must be of sufficient hardness to operate satisfactorily.
- *Unsuitable surface finish.* Rough surfaces usually cause scoring, overheating and bearing failure. The smoother the finish the closer the shaft can approach the bearing without metal contact. Surface finish is important in any plain bearing but may become critical when a harder material such as bronze is used.
- *Insufficient clearance.* An oil film may be prevented from forming between bearing and journal, resulting in bearing failure.
- *Incorrect grooving.* Incorrectly made or located grooves will result in bearing failure.
- *High operating temperatures.* The life of plain bearings is affected by high operating temperatures. High temperatures reduce oil viscosity, affecting oil film thickness, which in turn affects the load carrying capacity of the bearing. Also, most lubricants oxidize more rapidly at high temperatures resulting in unsatisfactory performance.
- *Oil contamination.* When the lubricant is exposed to abrasives, soft materials such as babbitt are used. Babbitt has the ability to embed hard particles completely, so protecting the shaft against abrasion. Hard bearing materials are scored by abrasives caught between bearing and shaft.

- *Improper relining.* Many bearing failures can be traced to faulty relining. This is particularly true of babbitt bearings. The following are reasons for faulty relining:

    - Improper preparation of bonding surface.
    - Wrong pouring technique.
    - Contamination of babbitt.
    - Overheating of babbitt.
    - Bearing poured to size with journal in place.

9.8.1 Plain bearing failures
The following elements of neglect, or abnormal operating conditions, may result in bearing failure:

- Excessive speed.
- Overloading.
- Excessive operating temperature.
- Foreign material in oil supply.
- Corrosion of bearing material.
- Fatigue of bearing material.
- Unsuitable lubricants.
- Lack of lubricant.
- Design faults.
- Oil deterioration.
- Water contamination.
- Incorrect assembly and maintenance.

9.8.2 Overheating of plain bearings
A bearing that runs hot may be caused by one or more of the following:

- No lubricating oil, or an inadequate supply.
- Dirty oil, causing undue friction.
- Wrong grade of oil, causing film to collapse.
- Bearing and shaft out of line.
- Shaft out of roundness.
- Bearing halves pulled up too tight.
- Excessive load on bearing.
- Bearing surfaces uneven.
- Bearing shell not seating properly.

To treat an overheated bearing the following steps can be taken:

- Flood the bearing with lubricating oil.
- Examine oil; if gritty, keep on flooding with oil to wash out grit.
- Pour oil on shaft, close to bearing, to carry away some of the heat from the bearing.

- o If bearing remains hot, slacken set-screws or bearing cap nuts, or ease load on bearing.
- o Flood with heavy cylinder oil.
- o When temperature is normal slowly tighten nuts. If temperature remains normal the load can be put back on.

TAKE NOTE: Caution
Never pour cold water on an overheated bearing and shaft. The bearing will contract and seize, or may even crack.

9.9 Lubrication of plain bearings

There is little purpose in supplying oil to a bearing if there is no distribution within the bearing. The point of oil introduction and the distribution around the bearing are important.

- Oil holes and grooves should be placed away from the loaded area, in the area of low pressure.
- Oil should be supplied along the entire length of the bearing before being allowed to the load or high pressure zone.
- Oil should not be allowed to escape from the bearing before accepting its share of the load.
- Oil from the supply should flow into the groove to within 12 mm from the bearing ends.

9.9.1 Lubrication holes

In horizontal journal bearings, the oil hole is nearly always situated at a point opposite the load bearing area. In vertical bearings, the oil is fed in from the top.

In multi-collar thrust a bearing, oil is fed in between the collars where centrifugal force aids correct distribution.

9.9.2 Lubrication grooves

Oil grooves have the function of distributing the oil along the entire length of the bearing (see **Figure 9.13**).

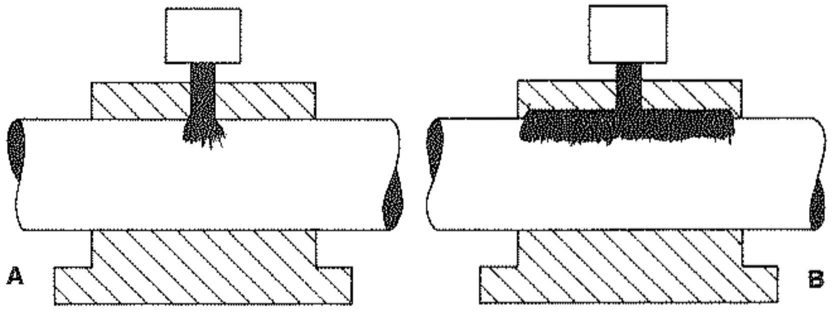
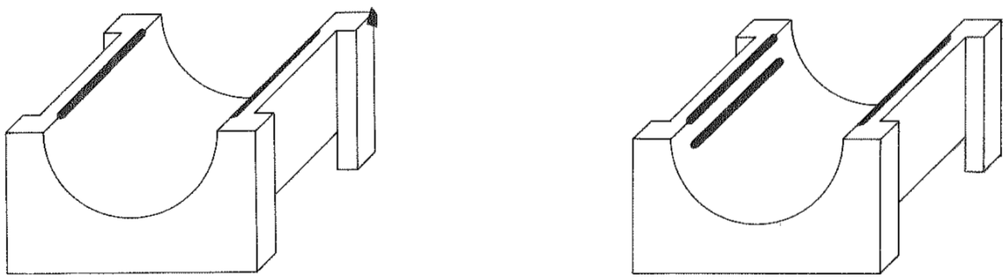


Figure 9.13 (a) No oil groove – poor oil distribution (b) Oil groove – correct oil distribution

Points to be considered in positioning oil grooves are speed of rotation, direction and possible reversal of rotation, bearing load and oil viscosity.

Oil grooves should never be cut over the entire length of a bearing as lubricant will leak out at the ends. After oil grooves have been cut, all sharp and raised edges must be cleaned up. Oil holes and grooves are usually cut in the region of lowest pressure to allow lubricant to enter without difficulty. The following are examples of oil grooves:

- Split bearings - see **Figure 9.14 (a)** and **(b)** have chamfered edges and may also have a longitudinal groove in the top half to ensure an even supply of oil.



(a) Oil grooves in split bearing

(b) Extra oil groove in front of high pressure area in heavy duty area

Figure 9.14 Split bearing

In heavy-duty bearings, where the shaft turns at slow speeds, an extra groove can be cut in the lower half, just before the high pressure area. This provides a heavy oil supply in the high pressure area where support is most needed (**Figure 9.14 (b)**).

- *Vertical bearings* (**Figure 9 .15**) require grooves around the top and oil is fed down by gravity.

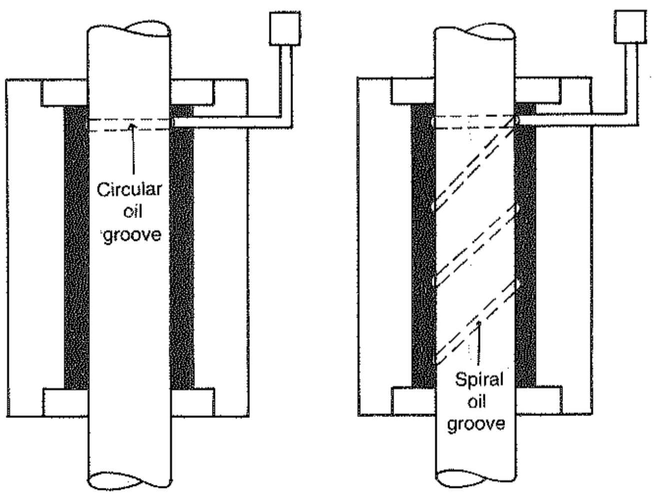


Figure 9.15 Oil grooving in vertical bearing

Thrust bearings (**Figure 9.16**) require oil to be fed to the shaft and not to the collars. Centrifugal force throws oil away from the shaft, lubricating collar sides where hydrodynamic pressure is built up to assist in supporting axial load.

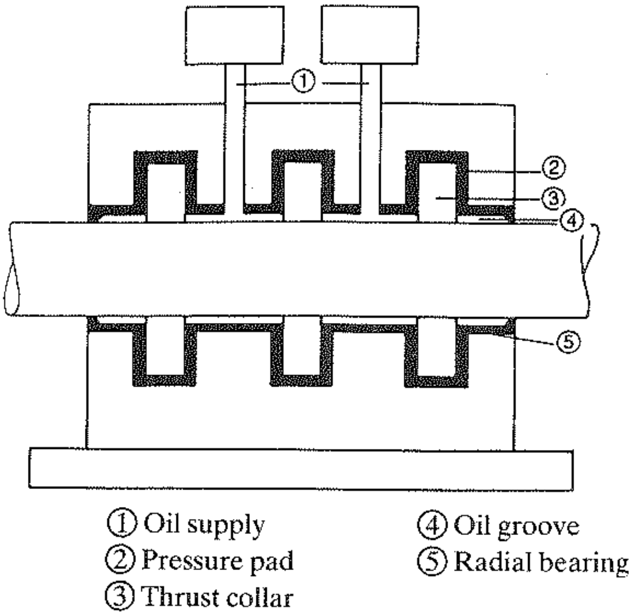


Figure 9.16 Oil grooves in thrust bearing for lubrication

- Guide bearings (**Figure 9 .17**) can be lubricated by cutting a pattern of grooves in the sliding members.

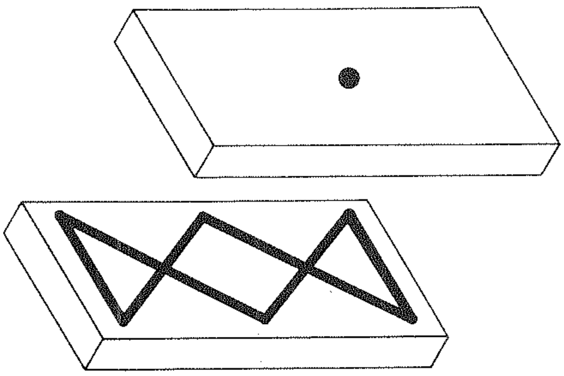


Figure 9.17 Oil grooves in guide bearing

9.10 Re-metalling a bearing

Before a bearing shell is re-metalled it should be thoroughly cleansed of dirt, grease, scale, or old white-metal. In all instances the surface should be properly tinned to ensure that the new metal will adhere perfectly.

- **Tinning of the shell.**

Heat the back of the shell with a blowlamp or gas blowpipe and apply solder with a flux.

Ensure the entire area, as well as the ends, is evenly coated. Alternatively, the shell can be dipped in a flux and then in a pot of molten solder and immediately thereafter, babbitted.

- **Lining the bearing.**

The new lining must as far as possible be cast with the bearing in a vertical position. The steps required are as follows:

<table>
<tr>
<td rowspan="2">
Step 1: Set up the bearing and a half mandrel of suitable size as shown in Figure 4 .18. Seal the joint between the bearing and plate with fire-clay.

Step 2: Heat the whole set-up with a blow flame to ensure that there will be complete fusion between the white metal and the tinned bearing surface.

Heating will ensure that the white metal will not solidify immediately as it contacts the cold surfaces of an unheated bearing.

Pre-heating also ensures that no water vapour will form in the bearing, which would probably result in blow holes and spatter.

Step 3: Cast the metal slowly at a constant rate to and fro around the opening between the bearing and the mandrel until the metal rises above the top surface.

The metal is cast slightly higher to allow for shrinkage.
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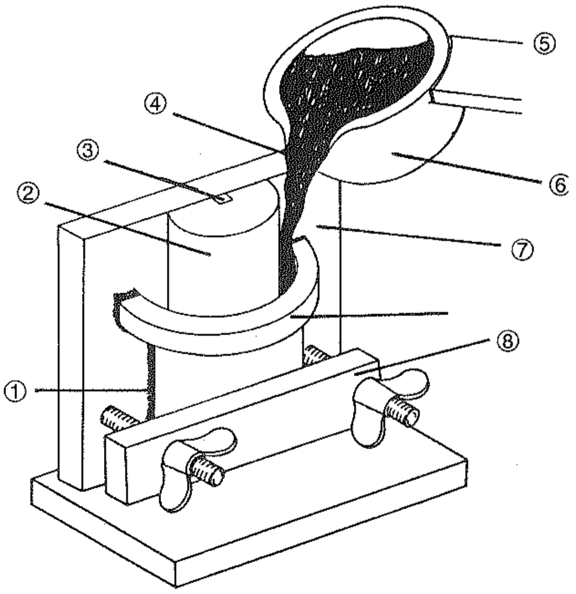
① Fire-clay
② Half mandrel
③ Key to prevent mandrel moving
④ White metal
⑤ Ladle
⑥ Fixture
⑦ Bearing half
⑧ Clamp

Figure 9.18 Bearing set-up for remetalling
</td>
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<td>
Step 4: When the bearing has cooled down, remove it from the fixture and remove excess metal on the butting faces with a hot soldering bit.

Step 5: The bearing can now be sent for machining.
</td>
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</table>

9.11 Taking up wear in bearings and slides

To take up wear in a bronze bearing of the split type, proceed as follows:

- Remove top half of bearing.

- Place a small piece of lead wire on top of shaft.
- Replace top half and pull up tightly.
- Remove top half of bearing as well as the piece of lead which has been flattened to the thickness of amount of play in bearing.
- Measure thickness of lead.
- If bearing is fitted with shims, remove to same thickness as lead. (If not fitted with shims, material must he removed from both hutting faces of both halves.)
- After removing sharp edges, shaft is put into lower half of bearing.
- Smear a thin layer of red-lead paste or mechanics' blue on the shaft.
- Turn shaft two or three revolutions.
- Remove shaft and bottom half.
- High spots on bearing will be marked and are then scraped off. (see **Figure 9.19**)This procedure is repeated until the shaft beds properly in the bearing.

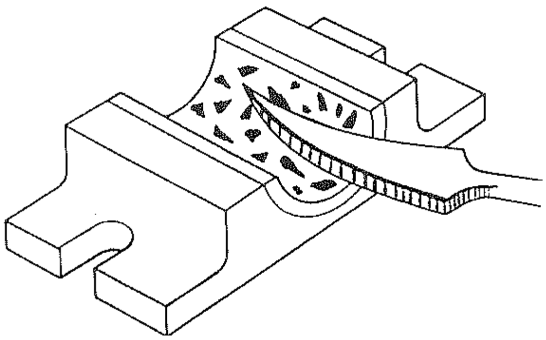


Figure 9.19 Scraping the bearing to remove high spots

- With shaft well bedded in lower half, replace top half and pull down gently.
- If bearing grips shaft and prevents rotation, loosen nuts slightly and turn shaft.
- Remove and scrape top half as for bottom half until the shaft can be revolved manually. This results in the best possible fit in the bearing.
- Wear in machine slides can be taken up as shown in **Figure 9.20**.

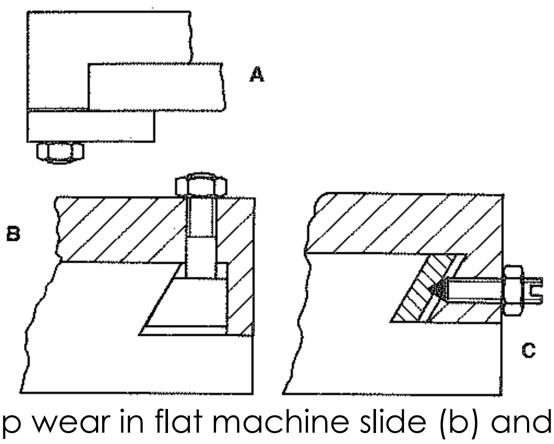


Figure 9.20 (a) Taking up wear in flat machine slide (b) and (c) Taking up wear in dovetail slides

9.12 Fitting and removing a solid bearing

A solid bearing bush can be fitted by using a steel plate and draw bolt (**Figure 9.21 (a)**). To remove the bearing bush a similar set-up is used as in **Figure 9.21 (b)**.

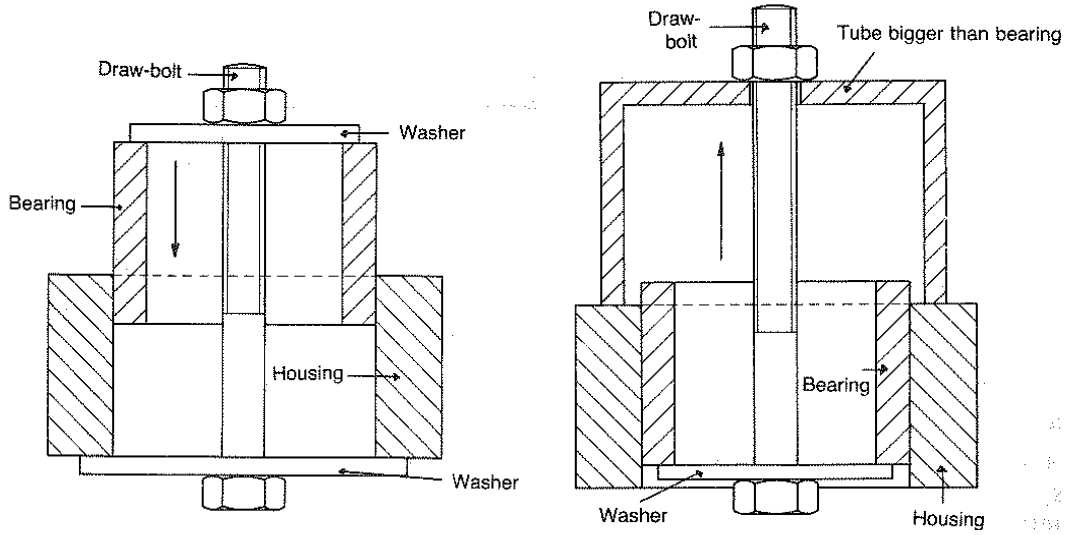


Figure 9.21 (a) Fitting a solid bearing (b) Removing a solid bearing

	Activity 9.1

1. Plain bearings fall into three groups. Name them and give an example of each.
2. Name four advantages of plain bearings.
3. Name four disadvantages of plain bearings.
4. Name any four properties that a bearing material used for plain bearings should have and describe two of these properties.
5. Name three materials used for plain bearings and name one property for each, which makes it suitable for this purpose.
6. Name three types of plain radial bearings.
7. Explain what guide bearings are used for.
8. Name four causes for plain bearing failure and explain each cause.
9. Explain why oil grooves are important in plain bearings.
10. Show with the aid of a sketch how a vertical bearing can be grooved to counteract excessive oil leakage.
11. Show with the aid of a sketch how a multi-collar thrust bearing is grooved and explain why grooves are not put on the side of the thrust blocks.
12. Explain in detail the re-metalling of a plain bearing.
13. Explain step by step how wear is taken up in a plain bearing.
14. Name eight causes for the overheating of plain bearings.
15. Explain how an overheated bearing can be cooled.

9.13 Anti-friction Bearings

Anti-friction bearings are a group name given to ball and roller bearings. They work on a principle of changing sliding friction into rolling friction. To demonstrate the difference between sliding and rolling friction, take a thick book or block of wood and place it on a table.

Give the book a push. It will be observed that it requires some force to move the book and that it stops as soon as the pushing force is removed. Now take four round pencils and place them between the book and the table. Again give the book a push.

Observe that it requires less force to move the book and that it continues to move for a short distance after the pushing force has been removed.

Rolling bearings consist of rolling elements such as balls or rollers between an outer and an inner ring. Cages, also called retainers, are used to space these rolling elements from each other.

Figure 9.22 shows two types of anti-friction bearings used on shafts.

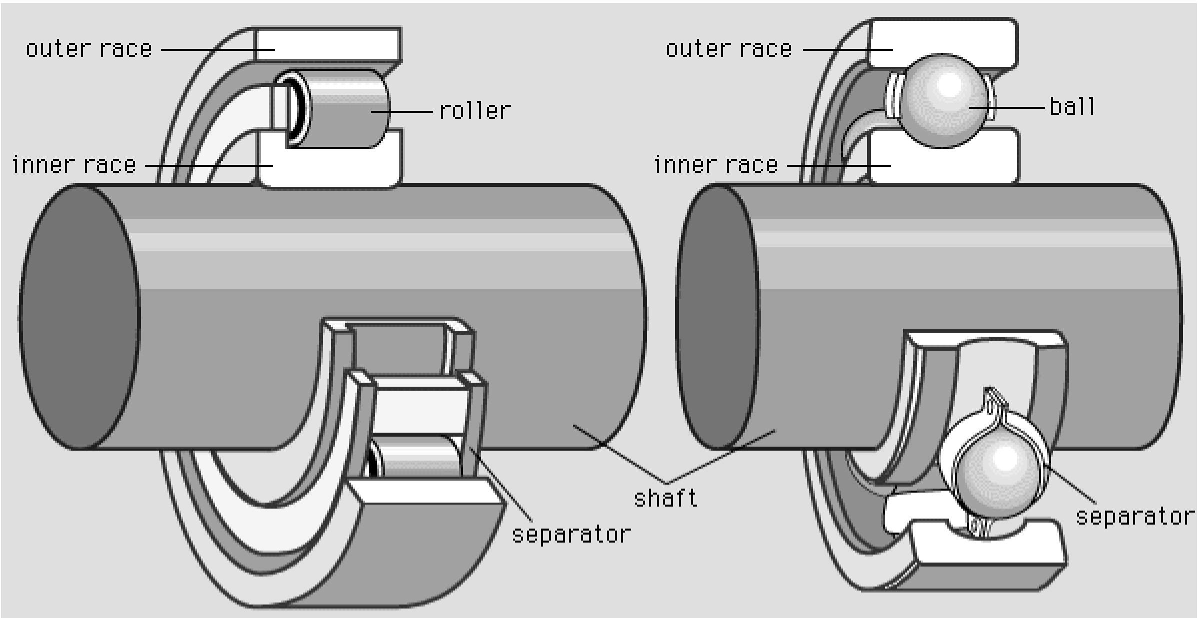


Figure 9.22 Ant-friction roller and ball bearings used on shafts

9.14 Bearing loads on anti-friction bearings

The size or magnitude of a load and the direction of the load are factors that largely determine the type and size of the bearing to use. Bearings are manufactured in different sizes and designs to provide for the variety of loads and directions of the forces acting on the bearing. Let us discuss the two areas that need to be considered:

- ***Magnitude of load*** – This is normally the most important factor in determining the size of bearing. Generally, roller bearings can carry greater loads than ball bearings of the same external dimensions. Ball bearings are mostly used to carry light and medium loads, whilst roller bearings are often the only choice for heavy loads and large diameter shafts.

- ***Direction of load*** – Cylindrical roller bearings having one ring without flanges and needle roller bearings can only carry **radial loads**. Other types of radial bearing can carry both radial and axial loads.

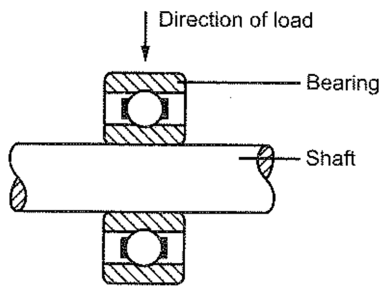
- Thrust ball bearings are only suitable for **axial loads**. Spherical roller thrust bearings, in addition to very heavy axial loads, can also carry a certain amount of simultaneously acting radial load.

- A combined load comprises **a radial and an axial load** acting simultaneously. The most important feature affecting the ability of a bearing to carry an axial load is its angle of contact.

- The greater this angle the more suitable is the bearing for axial loading. Refer to maker's catalogue for individual values. Double and single row angular contact ball bearings are mainly used for combined loads.
- Self- aligning ball bearings and cylindrical roller bearings can also be used to a limited extent. Duplex bearings and spherical roller thrust bearings should only be considered where axial loads predominate.

- Where the axial component constitutes a large proportion of the combined load, a separate thrust bearing can be provided for carrying the axial component independently of the radial load. In addition to thrust bearings, suitable radial bearings may also be used to carry axial loads only.

There are three types of loads that act on bearings, (see **Table 9.1**) these are:

Type of Load	Description
Radial Load This type of load is at right-angles to the shaft, acting towards the shaft centre.	

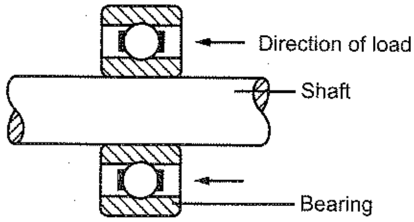
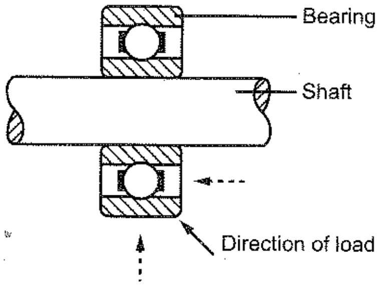
Thrust Load (Axial load) This type of load is in line parallel to the shaft, also known as axial load.	
Angular Load (Combined load) This type of load a combination of radial and thrust load.	

Table 9.1 Types of loads on anti-frictional bearings

9.15 Bearing selection

Each type of bearing has characteristic features which make it particularly suitable for certain applications. However, it is not possible to lay down hard and fast rules for the selection of bearing types since several factors must be considered and assessed relative to each other. The following recommendations will, for a given application, serve to indicate those details of greatest importance in deciding the type of bearing to be used.

9.15.1 Available space

In many instances at least one of the main dimensions of the bearing, usually the bore, is predetermined by the machine design. Deep groove ball bearings are normally selected for small diameter shafts whereas cylindrical roller bearings, spherical roller bearings and deep groove ball bearings can be considered for shafts of large diameter.

If radial space is limited then bearings with small sectional height must be selected, e.g. needle roller assemblies, certain series of deep groove bearings and spherical roller bearings.

Where axial space is limited and particularly narrow bearings are required then some series of deep groove ball bearings and cylindrical roller bearings can be used.

9.15.2 Angular misalignment

Where a shaft can be misaligned relative to the housing, bearings capable of accommodating such misalignment are required, namely self-aligning ball bearings, spherical roller bearings, spherical roller thrust bearings or spherical plain bearings.

Misalignments can, for example, be caused by shaft deflection under load, when the bearings are fitted in housings positioned on separate bases and large distances from one another or, when it is impossible to machine the housing seatings at one setting.

9.15.3 Limiting speeds

The speed of rotation of a rolling bearing is limited by the permissible operating temperature. Bearings with low frictional resistance and correspondingly little internal heat generation are most suitable for high rotational speeds.

For radial loads, the highest bearing speeds are obtainable with deep groove ball bearings or cylindrical roller bearings and for combined loads the highest bearing speeds are obtainable with angular contact ball bearings.

9.15.4 Precision

Rolling bearings with a high degree of precision are required for shafts where stringent demands are made on running accuracy, e.g. machine tool spindles and usually for shafts rotating at very high speeds.
Deep groove ball bearings, single row angular contact ball bearings, double row cylindrical roller bearings and angular contact thrust ball bearings are manufactured to high degrees of precision both as regards running accuracy and dimensions. When using high precision rolling bearings, shaft and housings must be machined with corresponding accuracy and be of rigid construction.

9.15.5 Rigidity

Elastic deformation in a loaded rolling bearing is very small and in most instances can be ignored. However the bearing rigidity is of importance in some cases, for example for machine tool spindles.

Due to the greater area of contact between the rolling elements and raceways, roller bearings, for example cylindrical roller bearings or taper roller bearings, deflect less under load than ball bearings. The rigidity of the bearings can be increased by suitable preloading.

9.15.6 Axial displacement

The normal bearing arrangement consists of a locating (fixed) bearing and a non-locating (free) bearing. The non-locating bearing can be displaced axially thus preventing cross location, e.g. by shaft expansion or contraction.

Cylindrical roller bearings having one ring without flanges or needle roller bearings are particularly suitable for use as free bearings. Their internal design permits axial displacement of the inner and outer rings in both directions. The inner and outer rings can therefore be mounted with interference fits.

9.16 Advantages and disadvantages of ball and roller bearings

Advantages	Disadvantages
• Generate very little friction compared to plain bearings	• Not as silent as plain bearings
• Can support radial and axial loads	• Cannot be repaired
• Very low starting friction.	• Higher initial costs
• Require less axial space.	• Cannot be used in halves
• Accurate shaft alignment can be maintained.	
• Except for parallel roller bearings, they can support both radial and axial loads.	
• Relatively easy replacement.	
• Heavy overloads can be carried for short periods.	
• Warning of failure by becoming noisy.	
• Require very little maintenance.	
• They can be pre-packed with lubricant and sealed.	
• Lubrication is simple.	

9.17 Types of anti-friction bearings

The specific type of anti-friction bearing we choose to use will depend on the following basic factors:

- Magnitude of the load.
- Acting direction of the load.
- Available space around the bearing.
- Any misalignment between the shaft and the housing.
- The speed at which the bearing must operate.

There are FOUR different types of rolling elements, these are:

- Ball
- Cylindrical
- Spherical roller
- Needle roller

9.17.1 Bearing Terminology

Figure 9.23 shows the various terms applied to anti-friction bearings.

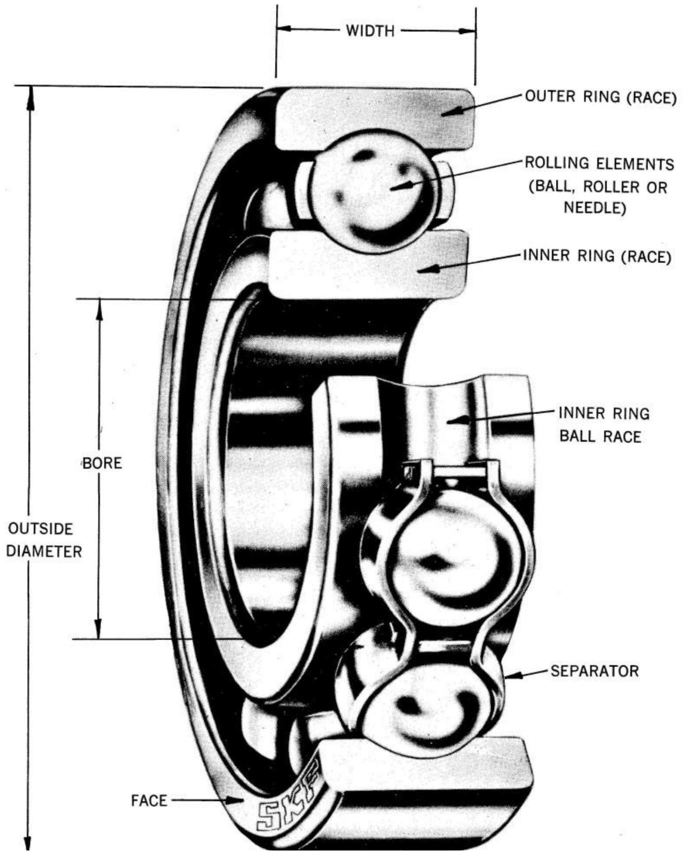
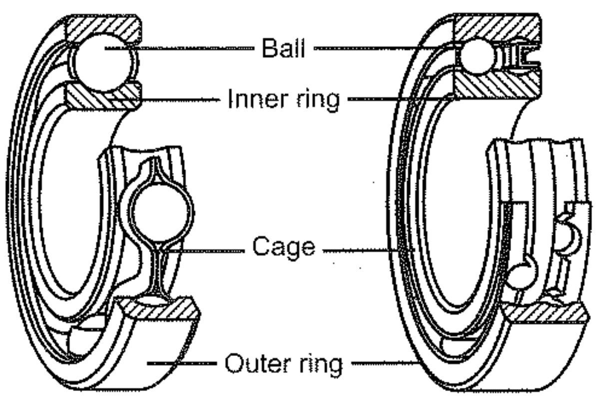


Figure 9.23 Anti-friction bearing Terminology

There are various types of anti-friction bearings. The basic types of antifriction bearings are discussed below and on the next page.

Type of anti-friction bearing	Description
• *Single and double row radial ball bearings*  Figure 9.24	Single and double row radial ball bearings are especially designed for radial loads, but are also able to carry relatively small axial loads in one or both directions. It is also possible to have a combination of the two loads within the capacity of the bearing. Axial loads on these bearings should not be more than 25% of the radial loads. The reason for this is that this type of bearing is simply not designed to carry a heavy axial load. **Figure 9.24** shows an example of these bearings.

- Single and double row radial cylindrical roller bearings

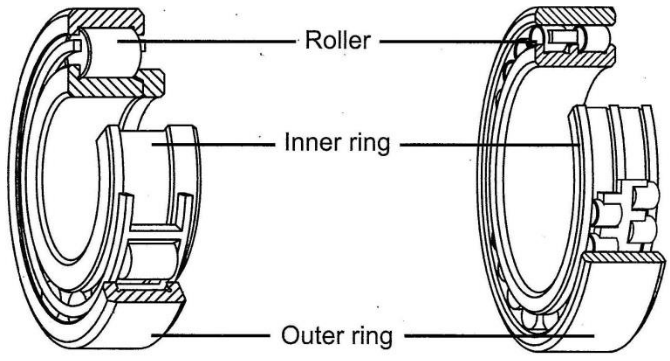


Figure 9.25

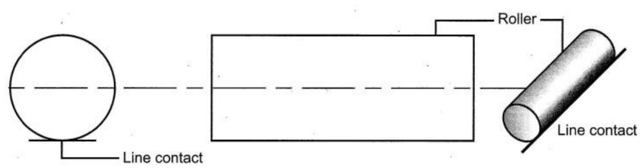


Figure 9.26 (a) Line contact in a cylindrical roller bearing

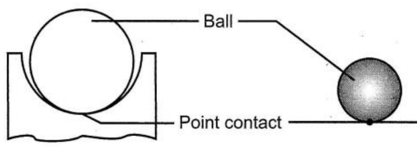


Figure 9.26 (b) Point contact in a ball bearing

Figure 9.25 shows examples of these bearings. These bearings can carry heavier loads than ball bearings of the same external dimensions. Cylindrical roller bearings are particularly suitable for heavy loads. The reason for this is the larger contact area, called line contact; the roller element in the cylindrical roller bearing has in comparison with the contact area of the ball element, called point contact, in the ball bearing.

Figures 9.26 (a) and **(b)** show the difference between line contact point contact. These bearings are able to carry heavy radial loads, but cannot carry any axial loads due to the lack of roller retaining flanges on the inner or outer rings. In some cases they can accommodate relatively small axial loads. However, this can result in a sliding contact or friction between the roller side face and the retaining flange rather than a preferable roller motion.

- *Thrust ball and roller bearings*

Examples of these bearings are the thrust ball bearing and the cylindrical roller thrust bearing. These bearings are frequently found on machine tools such as lead-screws, turn tables and crane hooks. These bearings can be either single direction or double direction.

By single direction thrust bearings we mean that the thrust bearings are used to accommodate axial loads, also called thrust loads, in one direction only.

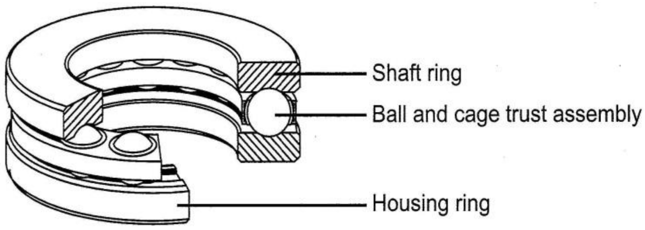
They may not be subjected to any radial loads.

Double direction thrust bearings are used to accommodate axial loads which act in both directions.

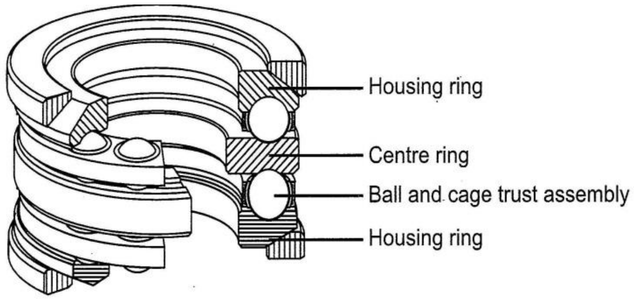
They should also not be subjected to any radial loads. If you look at **Figure 9.27 (a)** you will see that the single direction thrust bearing carries the row of balls or rollers between two rings, the shaft ring and the housing ring.

Figure 9.27 (b) shows the double direction thrust bearing consisting of two housing rings with a centre ring, also called a shaft washer that has a groove on each side.

Apart from the construction, the thrust ball bearing and the cylindrical roller thrust bearing differ from each other in that the cylindrical roller bearing can carry heavier axial loads than the thrust ball bearing.



(a) Single direction thrust ball bearing



(b) Double direction thrust ball bearing

Figure 9.27

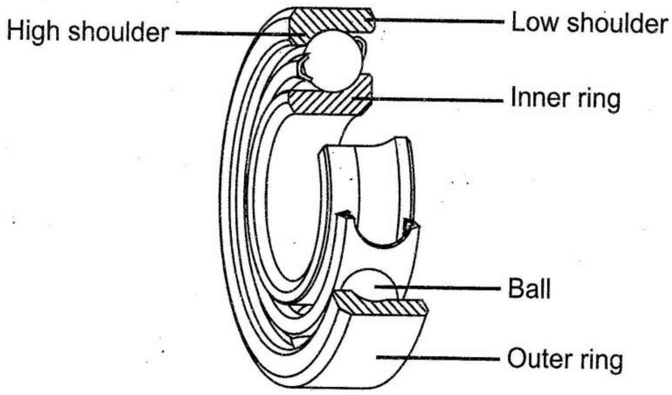


Figure 9.28 Angular contact ball bearing

- Single row angular contact bearings

If you compare these bearings with single row deep groove ball bearings you will see that one shoulder on both the inner and outer ring is machined off. **Figure 9.28** shows one high and one low shoulder on each ring. This allows a large number of balls to be incorporated, and the bearing can thus carry relatively heavy loads.

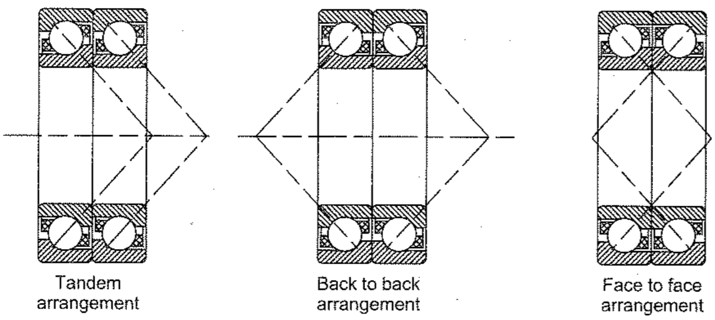


Figure 9.29 Paired mounting of a single row angular contact ball bearing

An example of this type of bearing is the single row angular contact ball bearing. This bearing can accommodate axial loads which act in one direction only.

Figure 9.29 shows paired mounting in tandem which is used when the load carrying capacity of a single bearing is inadequate. It also shows back-to-back and face-to-face arrangements when the bearing arrangement must carry axial loads in both directions.

- *Taper roller bearings*

Taper roller bearings have tapered inner and outer ring raceways between which tapered rollers are arranged as shown in **Figure 9.30(a)**.

The design of the tapered rollers makes taper roller bearings particularly suitable for carrying combined loads, that is, a combination of radial and axial loads.

They can accommodate axial loads in one direction when used singly. If the load is directed from the opposite direction, the inner and outer rings of the bearing will be pushed apart.

However, when they are used in pairs as shown in the assembly in **Figure 9.30 (b)**, they can accommodate axial loads in both directions.

With two of these bearings next to each other these bearings can carry pure radial loads. **Figure 9.30(c)** shows paired mounting that is used to obtain high radial and axial carrying capacities on these bearings. The face-to-face, back-to-back and tandem arrangements are clearly shown.

Taper roller bearings are designed in such a way that the inner and outer ring can be separated from each other. In other words, the inner ring with the roller and cage assembly forms a unit which we can mount separately from the outer ring.

We use these bearings widely in the motorcar industry, particularly for front hubs, rear-axle, pinion shafts and differential gears.

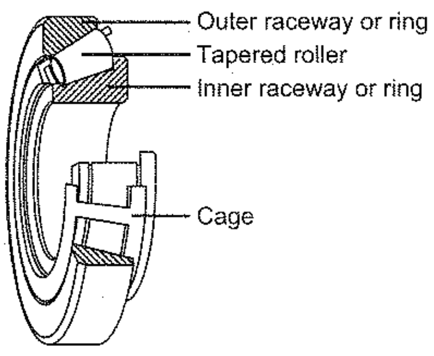


Figure 9.30 (a)Tapper roller bearing

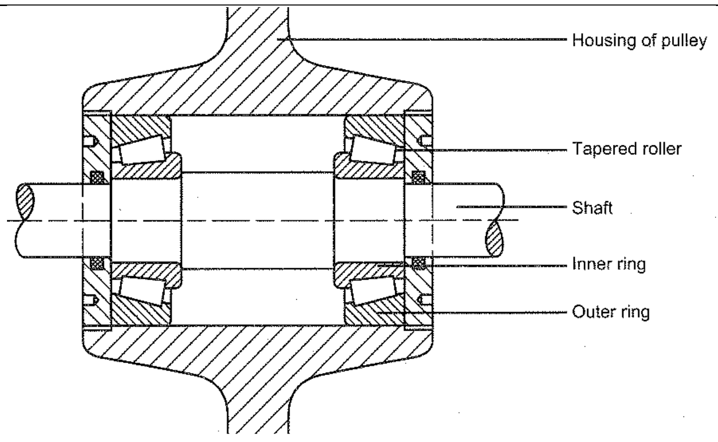


Figure 9.30 (b) Taper roller bearing assembly

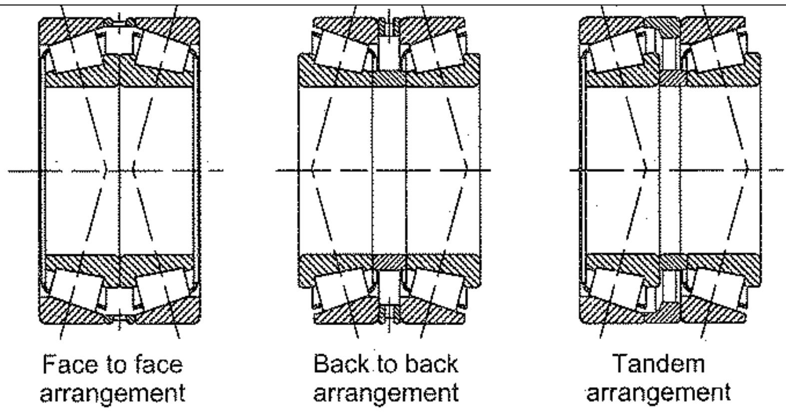


Figure 9.30 (c) Paired mounting on taper roller bearings

- *Needle roller bearings*

Needle roller bearings are roller bearings with cylindrical rollers which are thin and long in relation to their diameter as shown in **Figure 9.31**.

They are referred to as needle rollers. These bearings can carry heavy loads. They are therefore highly suitable for bearing arrangements where radial space is limited.

Radial space refers to the space around the cir cumference of the bearing. These bearings are capable of carrying radial loads. They are unable to carry axial loads. The needle roller has a profile which is slightly relieved towards the roller ends.

The consequence of this is a modified line contact between the needle rollers and the raceways. This means that damaging edge stresses because of heavy loads are avoided.

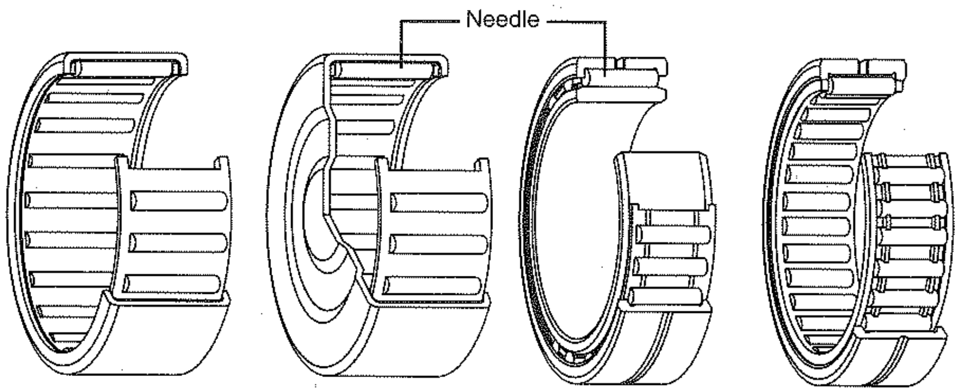
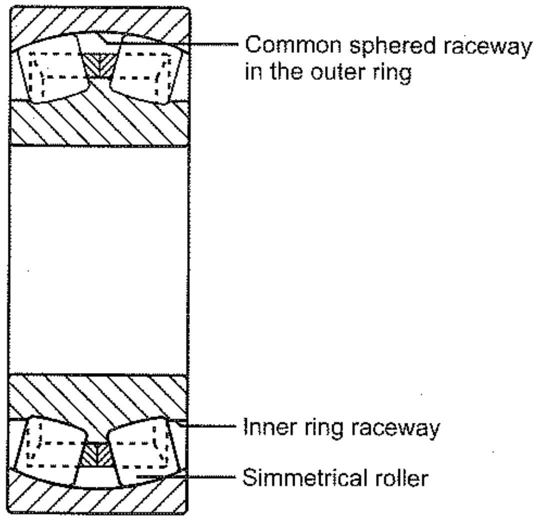


Figure 9.31 Different needle roller bearings

• *Spherical roller bearing* If you study **Figure 9.32** you will see that spherical roller bearings have two rows of rollers with a common sphered raceway in the outer ring. The two inner ring raceways are inclined at an angle to the bearing axis. Spherical roller bearings have many long, symmetrical rollers of large diameter. This feature gives spherical roller bearings a very high load carrying capacity. These bearings are self-aligning. They are thus insensitive to errors of alignment of the shaft relative to the housing and to shaft bending. In addition to radial loads, the bearings can also accommodate axial loads acting in both directions. They are found in applications such as gearboxes, steel rolling mills and paper machines.	 Figure 9.32 Spherical roller bearing

9.18 Selection of anti-friction bearing

For small high-speed machines, ball bearings are usually most suitable. For large and heavily loaded machines, roller bearings are the only satisfactory bearings.

For machines with relatively heavy thrust loads at very high speeds, deep-groove ball bearings often give the best results. Tapered roller bearings are used to advantage in some special cases, such as in motor engineering, on account of their high capacity under combined load and their adjustability.

9.19 Lubrication and sealing devices for bearings

Grease contributes considerably to the efficiency of a seal. It traps any dust particles which may have penetrated the sealing device. For oil lubrication, the sealing device has a double function. It must exclude dust and dirt from the housing and, at the same time, prevent leakage of oil.

Felt rings are generally used for sealing. Trapezoidal grooves are out in the housing or in the housing covers to accommodate them. A single felt ring is normally sufficient in a dry, protected location with only slight dust formation, and in smaller grease-lubricated housings. About once a year, however, the bearing housing must be opened and the old grease removed. If new grease is added frequently without removing the old grease, the bearing housing can be kept entirely filled with grease.

New grease should be pressed in every few weeks until it starts to ooze out through the seal.

Water turbines and centrifugal pumps frequently require a similar seal, since water seeps through the stuffing boxes and follows the shaft to the bearing.

The sealing of bearings operating in rooms filled with dust, dirt or dampness, is improved by occasionally pressing grease directly into the labyrinth.

9.20 Installation of anti-friction bearings

9.20.1 Mounting and dismounting of bearings

Bearings must be removed and installed from time to time either because they wear out or because they must be removed to disassemble a piece of equipment for repair or maintenance.

Bearings are designed to give the longest and best possible service life for a particular application. The service life of a bearing depends on the proper installation and maintenance of the bearing.

Bearings are used to reduce friction between the moving parts of pieces of equipment that have rotating shafts. There are many types of bearings in use, and there are different methods for removing and installing them. Removing and installing bearings are major parts of a fitter's job.
This module explains some of the most common methods for removing and installing bearings.

When the bearings are small, it is frequently possible to press in the removable sleeve with the aid of the shaft nut. In this case no particular mounting sleeve is required.

In most cases, especially when large quantities of small bearings with cylindrical bores are to be mounted, arbor presses may be used, by means of which the mounting is done much quicker.

The sketch in **Figure 9.33** shows a pulling device which is often used for bearings with cylindrical bores. A steady force from a press or screw arrangement has proved to be less dangerous than hammer blows.

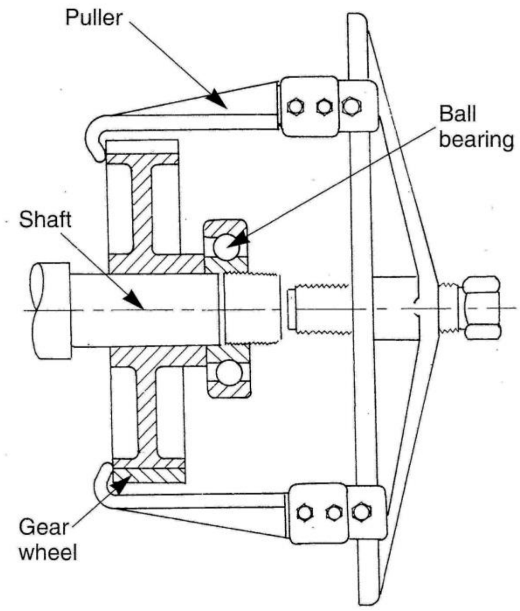


Figure 9.33 Typical bearing pulling device

IMPORTANT SAFETY WARNING
When removing, installing, and heating bearings, always wear the proper personal safety equipment, including safety glasses and heat-resistant gloves.

9.20.2 Removing of bearings

When removing a bearing, it is very important to follow the proper procedures to prevent damaging the bearing or the shaft. Sometimes a bearing is removed for maintenance or inspection and is reused on the equipment.

In this case, improper removal techniques can damage the shaft and make it unusable. When a bearing is removed because it is worn out or has failed, it is replaced with a new one. In this case, the old bearing should be kept so that it can be inspected to determine why it failed.

The information can be used for predictive and preventive maintenance purposes and to retain historical data of the equipment. The most common methods and tools for removing bearings are the following:

- Bearing pullers
- Presses
- Hydraulic removal method
- Temperature removal method
- Cutting torch

IMPORTANT SAFETY WARNING
When removing bearings, always shield the bearing with a material that is capable of withstanding the force of flying objects caused by the possible disintegration of the bearing.

9.20.3 Using bearing pullers

Using bearing pullers is the most common way to remove bearings. One advantage of a puller is that it can be taken in the field to remove the bearing from the shaft while the bearing is still in the machine. Pullers come in various styles and sizes. Most pullers come with different attachments for different applications.

Both manual and hydraulic pullers are available. The manual puller has a bolt that is turned using a wrench to provide the pressure to pull the bearing. The hydraulic puller has a hydraulic cylinder and pump that provide the pulling pressure. Both types have the same attachments. **Figure 9.34** shows manual bearing pullers.

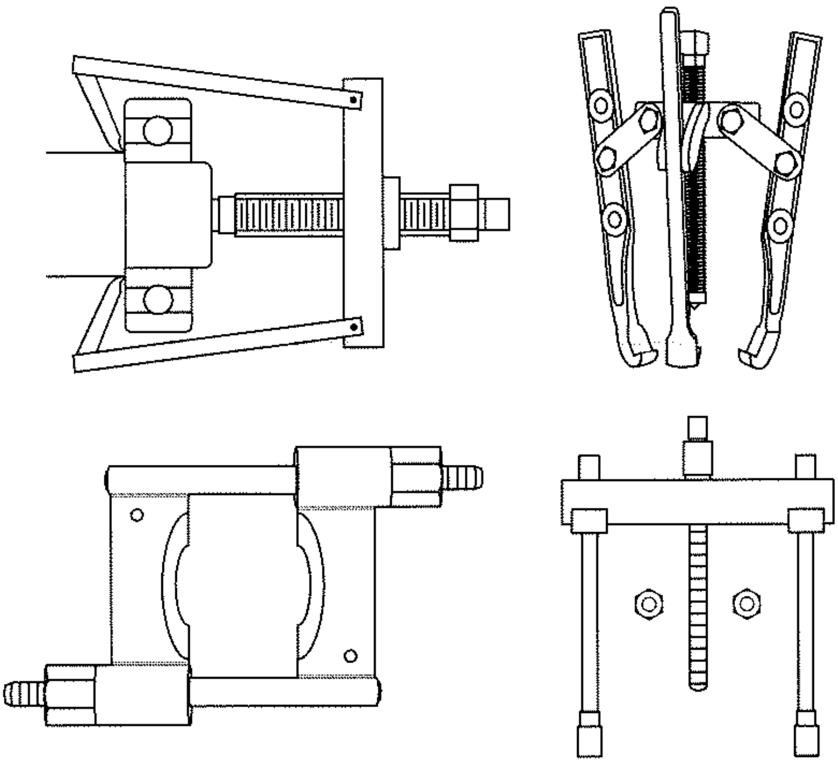


Figure 9.34 Manual bearing pullers use for removing bearings

Follow these steps to remove a bearing using a manual bearing puller:

Step 1: Ensure that the puller is clean.

Step 2: Position the puller jaws behind the bearing so that they press against only the inner race of the bearing.

CAUTION: The puller jaws must apply pressure only to the inner race of the bearing. If pressure is applied to the outer race, the bearing will be damaged and may come apart.

Step 3: Hold the jaws in place, and screw in the bolt manually until it touches the end of the shaft.

Step 4: Check the alignment of the puller to ensure that it will pull evenly on the bearing.

CAUTION: If the puller is misaligned and not pulling straight, the bearing will become cocked and may damage the shaft.

Step 5: Apply a light coat of oil to the shaft to make the bearing slide off the shaft easily.

Step 6: Turning the bolt slowly, using a wrench, to apply pressure. **Figure 9.35** shows removing a bearing using a manual bearing puller.

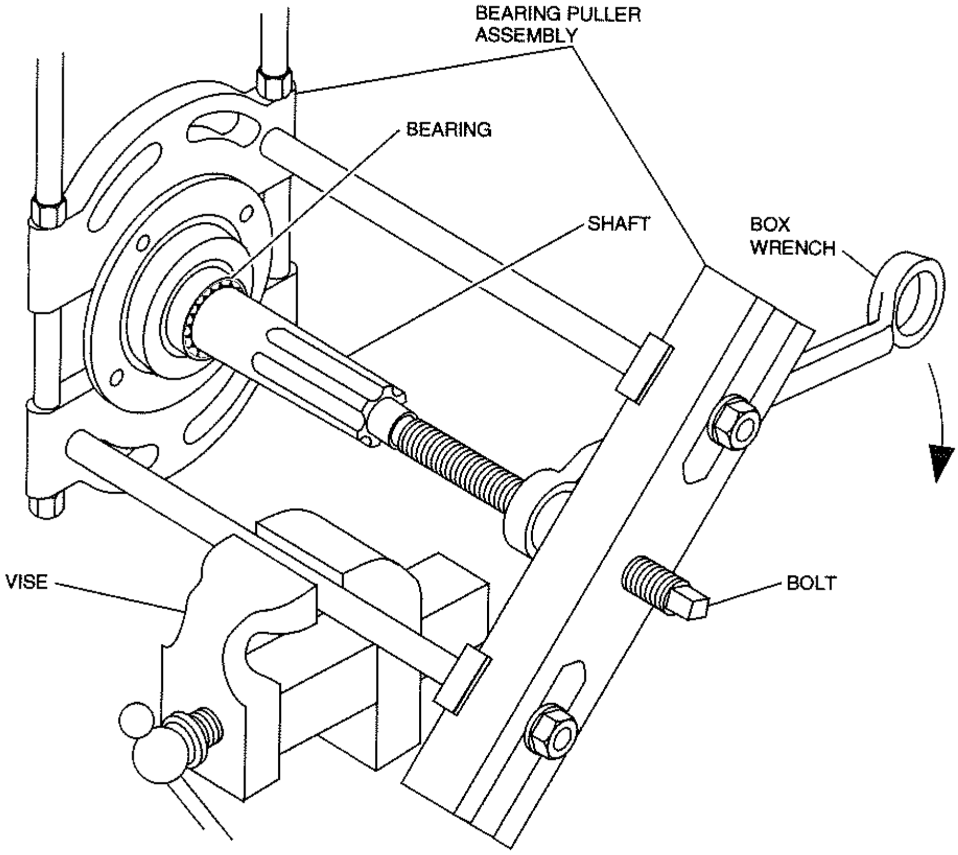


Figure 9.35 Removing Bearing, Using Manual Bearing Puller

Step 7: Continue to turn the bolt until the bearing comes off the shaft.

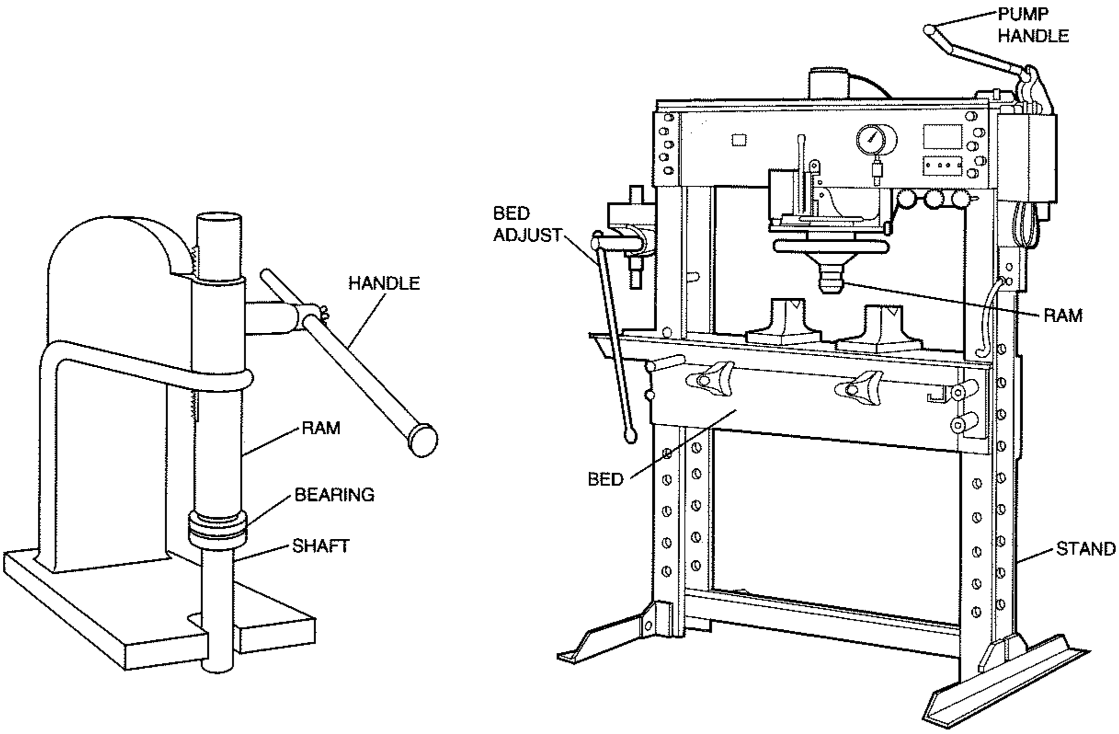
CAUTION: Do not let the bearing fall on the floor when it comes off the shaft because it could be damaged and get dirty.

9.20.4 Using presses

There are two types of presses that are used for removing bearings:

- the hydraulic press; and
- the manual, or arbor, press.

The hydraulic press can generate a great amount of force and is used on large and small bearings. The arbor press generates much less force and is used on small bearings. When using presses, the shaft usually must be removed from the equipment and brought to the press. **Figure 9.37** shows an arbor press and a hydraulic press.



ARBOR PRESS **HYDRAULIC PRESS**

Figure 9.37 Arbor Press and Hydraulic Press

Follow these steps to remove a bearing using a press:

Step 1: Place the shaft and bearing in the press so that the inner race of the bearing is supported by two blocks of the same size.

CAUTION: When removing a bearing from a shaft, position the bearing so that pressure will be exerted only on the inner ring. Pressure applied to the outer ring will damage the bearing. When removing a bearing from a housing, position the bearing so that pressure will be exerted only on the outer race.

Step 2: Lower the ram of the press so that it touches the end of the shaft.

Step 3: Ensure that the shaft is in the fully vertical position to prevent the bearing from cocking when the shaft is pressed out of the bearing.

Step 4: Apply a light coat of oil to the shaft to help the bearing slide off easily.

Step 5: Apply pressure slowly to press the shaft out of the bearing.

CAUTION: Keep the shaft vertical to prevent the bearing from cocking and gouging the shaft. Do not let the shaft fall to the floor when it is released from the bearing.

9.20.5 Performing hydraulic removal method

Hydraulic bearing removal is possible only if the shaft has been prepared in advance of the bearing installation. A hole is drilled in the shaft so that pressurized hydraulic fluid can be applied to the inner race of the bearing. The fluid is pumped into the hole through a hydraulic fitting where the fluid expands the inner race of the bearing.

This expansion allows the bearing to slip off the shaft. Hydraulic bearing removal can be done while the shaft is in the machine. **Figure 9.38** shows a hydraulic removal setup.

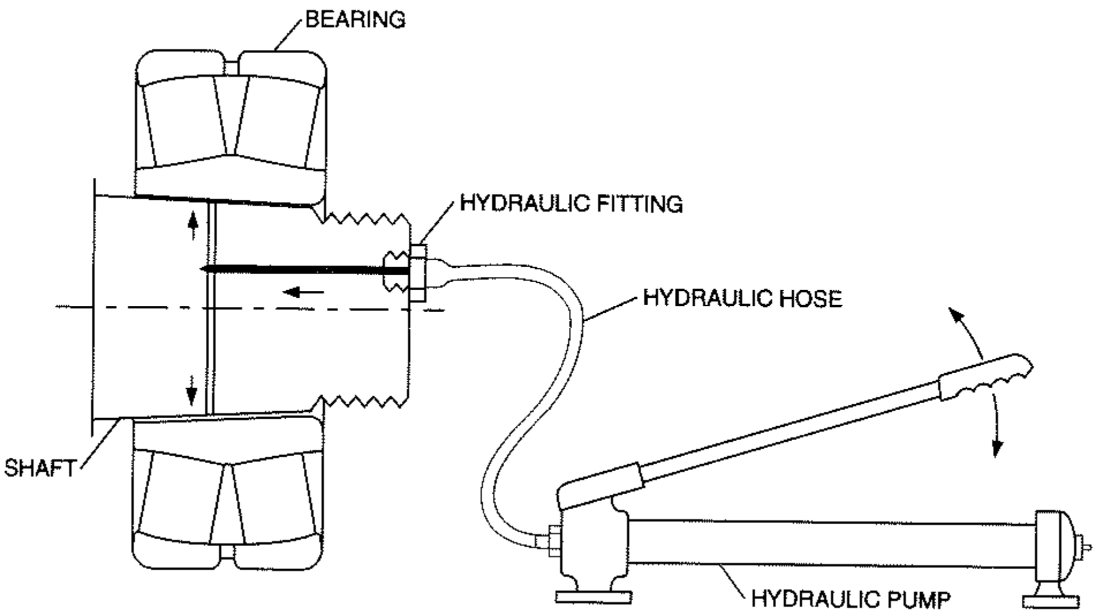


Figure 9.38 Hydraulic Removal Setup

Follow these steps to remove a bearing using the hydraulic removal method:
Step 1: Clean the shaft, including the hole for the hydraulic fluid.

Step 2: Install a hydraulic fitting in the hole.

Step 3: Connect the hydraulic pump hose to the fitting.

Step 4: Pump the hydraulic pump to apply pressure to the bearing inner race until the bearing slips off the shaft.

WARNING! Some bearings, especially tapered seat bearings, will pop off the shaft with considerable force and can cause personal injury. Do not stand in front of the bearing while applying pressure. Leave the locking nut on the end of the shaft to prevent the bearing from flying off.

9.20.6 Performing temperature removal method

Bearings that are shrink-fitted to the shaft sometimes require the use of heat to expand the bearings so that they will slip off the shaft. Timing is the most important factor when removing a bearing, using heat. The bearing must be slipped off the shaft as soon as the bearing has sufficiently expanded and before the shaft expands. The most common heating tool used for bearing removal is a torch. Another method used for heating bearings is the aluminum heating ring. **Figure 9.39** shows an aluminum heating ring.

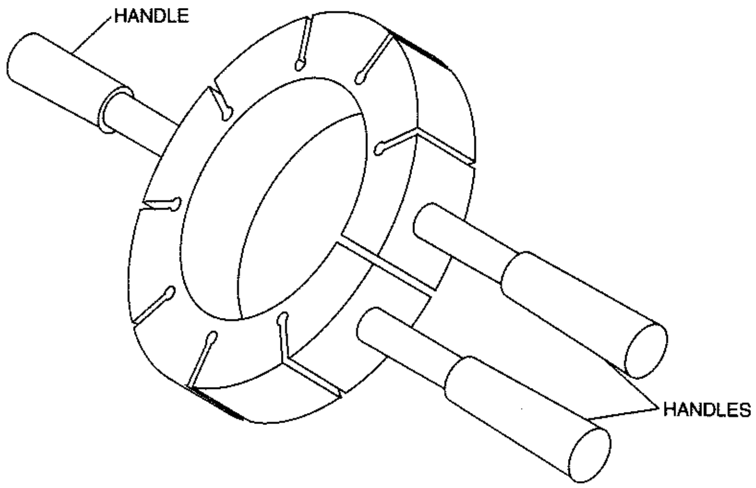


Figure 9.39 Aluminum Heating Ring

⚠	**CAUTION:** If the bearing is going to be re-used, do not heat the bearing with a torch. The direct heat from the torch heats the bearing unevenly and tends to overheat the bearing. This will ruin the bearing.

Follow these steps to remove a bearing using the aluminum heating ring:
Step 1: Clean the shaft to remove any dirt or grit.

Step 2: Dress down any burrs or nicks from the shaft.

Step 3: Disassemble the bearing, leaving only the inner ring on the shaft.

Step 4: Select an aluminum heating ring that fits the bearing ring.

Step 5: Heat the aluminium heating ring to approximately 250 degrees C, using a bearing heater or a similar method.

Step 6: Slip the heating ring over the bearing ring, and squeeze the two handles on one side together to clamp the bearing ring.

SAFETY WARNING! Wear protective gloves when handling the heating ring to avoid getting burned.

Step 7: Grip the handles on both sides of the heating ring, and apply force back and forth to turn the bearing ring.

TAKE NOTE:
When the bearing ring has sufficiently expanded, it will turn on the shaft.

Step 8: Slip the ring off the shaft.

9.20.7 Using cutting torch to remove bearings

Sometimes an inner bearing ring will become seized on the shaft, and common bearing removal methods will not work. In this situation, the bearing must be cut off the shaft, using a cutting torch. This will destroy the bearing, but if done correctly, the shaft will not be damaged. Using the cutting torch to remove bearings is a last resort. Follow these steps to remove a bearing, using a cutting torch.

SAFETY WARNING!
Follow all fire safety guidelines to ensure that the cutting operation will not present a fire hazard.

Step 1: Disassemble the bearing, leaving only the inner ring on the shaft.

Step 2: Clean the shaft and ring to remove any oil or grease that may catch fire during the cutting operation.

Step 3: Determine the best place to cut the ring.

TAKE NOTE:
If the equipment has a key, cut the ring on top of the key. This will reduce the risk of the shaft being damaged by the heat.

Step 4: Cut the ring.

CAUTION: Direct the heat across the face of the ring instead of directing it toward the shaft, and cut the ring from side to side. Make the cut as quickly as possible to keep residual heat to a minimum. Use a bent cutting tip to reduce the likelihood of damaging the shaft. Make the cut without depressing the oxygen lever.

Step 5: Drive a chisel into the cut to pry the ring open.

Step 6: Slip the ring off the shaft.

TAKE NOTE:
If the ring will not come off the shaft, make a second cut 180° from the first, and remove the ring in two pieces.

Step 7: Clean and dress the shaft to remove any slag, burrs, or scratches.

Activity 9.2

1. What are anti-friction bearings used for?
2. Why would you keep a bearing that is being replaced with a new one?
3. Which bearing removal method is the most commonly used?
4. Which part of the bearing should pressure be applied to when pullers are used?
5. Why should you not stand in front of a bearing during hydraulic removal?
6. Why should you not use a torch to heat a bearing?

Activity 9.3 – Workshop
Practice removing bearings, using each of the bearing removal methods and tools.

9.21 Installing bearings

The method used to install a bearing depends on the type of bearing being installed and on its application. Bearings are mounted in a variety of ways. Some bearings are installed on a shaft and then mounted in a specially made bore in a machine.

Shaft bearings in a transmission or gear reducer are mounted in bores in the housing. Some bearings are mounted in pillow block housings or flanged housings and support the shaft of a piece of equipment. Bearings are precision parts that must be installed as precisely as possible.

Two kinds of fits for bearings are the slip fit and press fit. The slip fit is the simplest to install because it fits fairly loosely and can usually be pushed into place by hand.
The press fit is much tighter and requires more effort to press the bearing into place. Bearings usually have a slip fit on one ring and a press fit on the other. The ring that rotates is usually press-fitted.

In most applications, the inner ring of the bearing rotates. However, in some applications the outer ring rotates and, therefore, gets the press fit. Proper bearing fit is very important because a bad fit can result in premature bearing failure.

A fit that is too loose causes the bearing and the shaft to wear rapidly due to the shaft sliding in the ring. A fit that is too tight can cause increased friction due to decreased clearances in the bearing.

This friction results in high operating temperatures. A bearing with a fit that is too tight will fail early.

Properly sizing bearings is a major part of bearing installation. Installation methods are the same for different types of bearings. Once you have learned the proper installation procedures for a few types, you should be able to install most types of bearings.

The following sections explain how to install the following types of bearings, using various methods:

- Tapered roller
- Thrust
- Spherical roller
- Pillow block
- Angular-contact ball

9.21.1 Installing tapered roller bearings
USING TEMPERATURE MOUNTING METHOD
Tapered roller bearings and angular-contact ball bearings are always mounted in pairs in opposition to each other. The clearances are adjusted at mounting.

Tapered roller bearings and angular-contact ball bearings are installed in basically the same way. They can be mounted by press mounting or temperature mounting.
This section describes installing a tapered roller bearing by the temperature mounting method. Temperature mounting can be performed in the shop or in the field while the shaft is still in the equipment.

Follow these steps to install a tapered roller bearing, using the temperature mounting method:

Step 1: Clean the shaft thoroughly.

	IMPORTANT SAFETY WARNING! Do not use carcinogenic solvents, such as methylene chloride and carbon tetrachloride. Keep the bearing in its protective wrapping until you are ready to install it to prevent contamination from dirt, dust, and grit. For the same reason, handle the bearing only with clean gloves, and keep the work area and all tools clean.

Step 2: Inspect the shaft, and dress any burrs or nicks that would interfere with the bearing installation.

Step 3: Polish the shaft lightly, using an emery cloth.

Step 4: Measure the shaft and housing in several places, using a micrometer, to ensure that the diameter of the shaft and other parts are within specifications for the bearing being installed and to ensure that the shaft is not out of round.

Step 5: Remove the new bearing from its protective wrapping.

Step 6: Place the bearing on a bearing heater. **Figure 9.40** shows a bearing heater

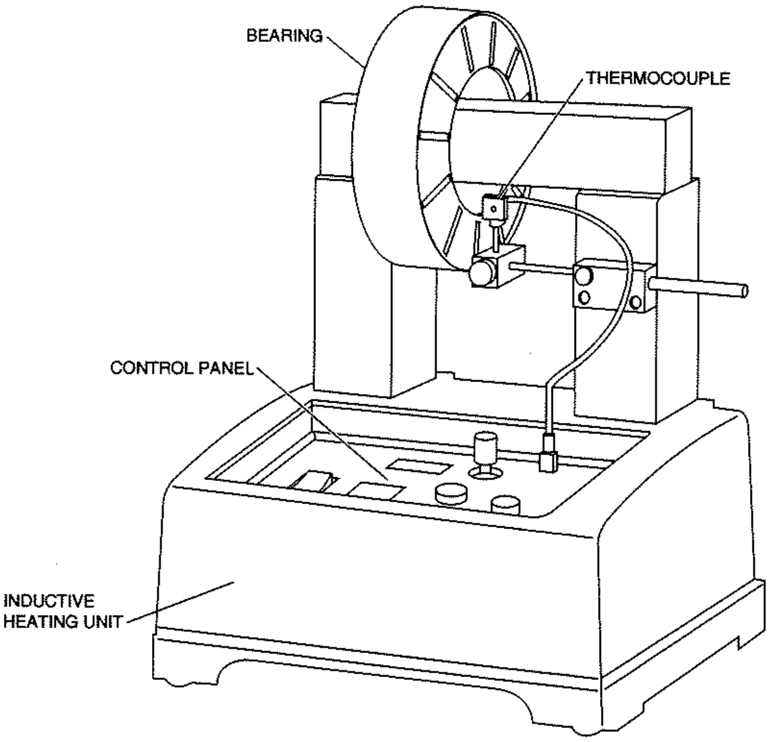


Figure 9.40 Bearing Heater

	TAKE NOTE: The shaft size and all other critical dimensions can be found in the manufacturer's specifications that come with the bearing. Follow the manufacturer's specifications and instructions when installing any bearing.

Step 7: Set the bearing heater to the temperature required by the manufacturer.

CAUTION:
The maximum temperature to which a bearing should be heated is 100° C. Overheating a bearing can adversely affect the hardness of the bearing steel.

Step 8: Check the bearing bore size periodically, using an inside micrometer or similar method, as the bearing is being heated until it has expanded to the proper size to slip onto the shaft.

IMPORTANT NOTE:
There may be no need to heat the bearing to the maximum temperature. Heat it only until it has expanded enough to slip onto the shaft. Install the backing plate and other parts at this point if necessary.

Step 9: Remove the bearing from the heater, and slip it onto the shaft.

CAUTION:
The bearing must be slipped onto the shaft, quickly moved to its proper position, and held there to prevent it from moving off the shoulder. When the bearing cools, it shrinks to fit the shaft. If it shrinks in the wrong position on the shaft, the bearing will have to be reheated, removed, and remounted.

Figure 9.41(a) shows a bearing in the installed position.

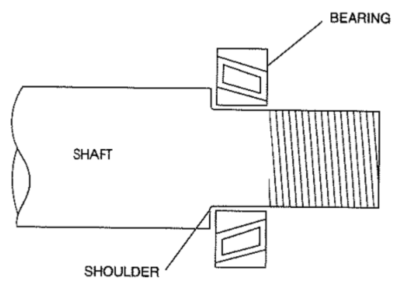


Figure 9.4 (a) Bearing in the installed position

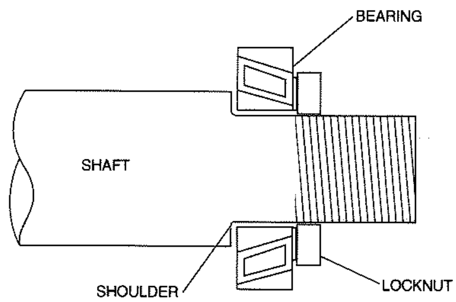


Figure 9.4 (b) Bearing locked in position

Step 10: Lock the bearing in place using a locknut.

TAKE NOTE:
The bearing should be locked in position with the locknut to prevent it from moving as it shrinks. **Figure 9.41(b)** shows the bearing locked in position with a locknut.

Step 11: Allow the bearing to cool to ambient temperature.

Step 12: Loosen the locknut.

Step 13: Turn the bearing with an un-gloved hand, and feel for rough spots.

IMPORTANT SAFETY WARNING!
Wait until the bearing has cooled before touching it with your hand to avoid being burned.

Step 14: Tighten the locknut according to the manufacturer's specifications to load the bearing.

9.21.2 Installing thrust bearings

INSTALLING THRUST BEARINGS USING PRESS MOUNTING METHOD

Thrust bearings support only axial, or thrust, loads. They may be mounted vertically or horizontally. Thrust bearings may be roller, ball, or plain.

To mount a thrust bearing, one race is fitted to the shaft, and the other race is fitted to the housing. The shaft race is usually press-fitted, and the housing race is slip-fitted.

The thrust bearing is usually pressed on the shaft in an arbor press or a hydraulic press; then the shaft is installed in the equipment, fitting the bearing into the housing.

Follow these steps to install a thrust bearing using the press mounting method:

Step 1: Clean the shaft thoroughly.

Step 2: Inspect the shaft, and remove any burrs or nicks.

Step 3: Polish the shaft lightly, using an emery cloth.

Step 4: Determine which race will be fitted to the shaft and which race will be fitted to the housing.

TAKE NOTE:
Refer to the manufacturer's installation procedures and specifications to find any critical measurements and specifications.

Step 5: Measure the shaft and housing in several places, using a micrometer, to ensure that the diameter of the shaft and other parts are within specifications for the bearing being installed and to ensure that the shaft is not out of round.

Step 6: Remove the bearing from its protective wrapping.

CAUTION:
The bearing must be slipped onto the shaft and quickly moved to its proper position.

Step 7: Ensure that the press is clean.

Step 8: Place the bearing on the press so that the shaft race is well-supported.

Step 9: Position the shaft in the bearing.

Step 10: Lower the press ram so that it touches the shaft.

Step 11: Apply pressure to slip the shaft into the bearing.

CAUTION:
Keep the shaft square with the bearing at all times. If the shaft is cocked during the pressing operation, the bearing will gouge the shaft.

Step 12: Release pressure once the bearing is in the proper position on the shaft.

Step 13: Install the shaft in the equipment, pushing the bearing into the housing.

Step 14: Install the housing covers.

9.21.3 Installing spherical roller bearings

USING HYDRAULIC NUT OR LOCKNUT

Spherical roller bearings are a type of taper-bored bearing. A taper-bored bearing is either mounted on a tapered shaft or on a tapered sleeve.

As the bearing is forced onto the shaft or sleeve, the clearance between the races and the rolling elements is reduced.

The bearing clearance must be controlled when forcing the bearing onto the shaft. To control the clearance, measure it before installation and during the tightening process.

The amount of initial clearance is reduced according to the tables supplied by the bearing manufacturer. The bearing is tightened until the proper clearance differential is achieved.

Follow these steps to install a spherical roller bearing on a tapered shaft using a hydraulic nut or a locknut:

Step 1: Clean the shaft thoroughly.

Step 2: Inspect the shaft, and remove any burrs or nicks.

Step 3: Measure the shaft in several places, using a micrometer, to ensure that it is the proper size and that it is not out of round.

Step 4: Oil the shaft lightly.

Step 5: Remove the bearing from its protective wrapping.

Step 6: Set the bearing on a clean, level surface.

Step 7: Measure the bearing clearance, using a feeler gage, and record the reading.

TAKE NOTE:
Clearance should be checked by starting with the thinnest feeler blade and using progressively thicker blades until one will not go. The last blade before the "no go" is the measurement of the clearance. **Figure 9.42** shows measuring bearing clearance.

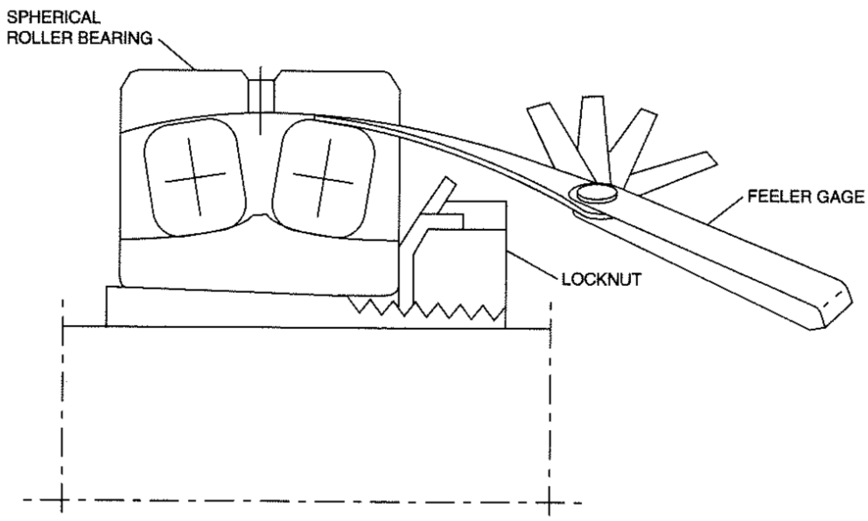


Figure 9.42 Measuring Bearing Clearance

Step 8: Slip the bearing onto the shaft, and push it as far as possible by hand.

Step 9: Screw a hydraulic nut or locknut onto the shaft against the bearing inner race.

Figure 9.43 shows a hydraulic nut in place.

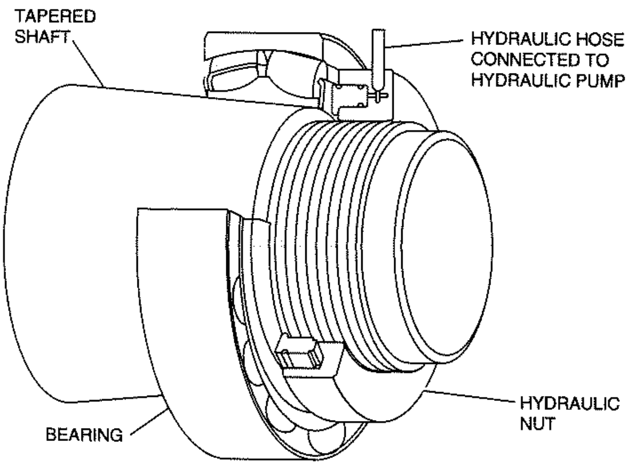


Figure 9.43 Hydraulic Nut In Place

Step 10: Tighten the nut.

TAKE NOTE:
Note: If using a hydraulic pump, turn the hydraulic nut and tighten the bearing; if installing a locknut, use a spanner wrench.

Step 11: Tighten the bearing and measure the clearance alternately until the proper clearance is obtained.

TAKE NOTE:
Note: Determine the proper clearance from the manufacturer's tables included in the bearing installation instructions

Step 12: Release the pressure, and remove the nut.

Step 13: Install the bearing locknut and washer.

Step 14: Tighten the bearing locknut to the proper bearing clearance.

CAUTION:
Do not over-tighten the locknut because this may change the bearing clearance.

9.21.4 Installing pillow block bearings

Pillow blocks bearings are used for independent mounting of antifriction bearings. The bearing is contained in the pillow block housing. The bearing is fitted on the shaft, and the housing is mounted on the equipment. Pillow block bearings can be divided into the following two groups:

• Split housing

• One-piece housing

INSTALLING SPLIT HOUSING PILLOW BLOCK BEARINGS
The split housing pillow block bearing consists of a base and a cap with a horizontal split.

The housing may be plain split or split with gibs or dowels. Housings with gibs or dowels eliminate the possibility of mismatching the cap to the base. Plain split housings should be match-marked before disassembly to ensure that the parts are not mismatched when reassembled.

Figure 9.44 shows a split housing pillow block bearing.

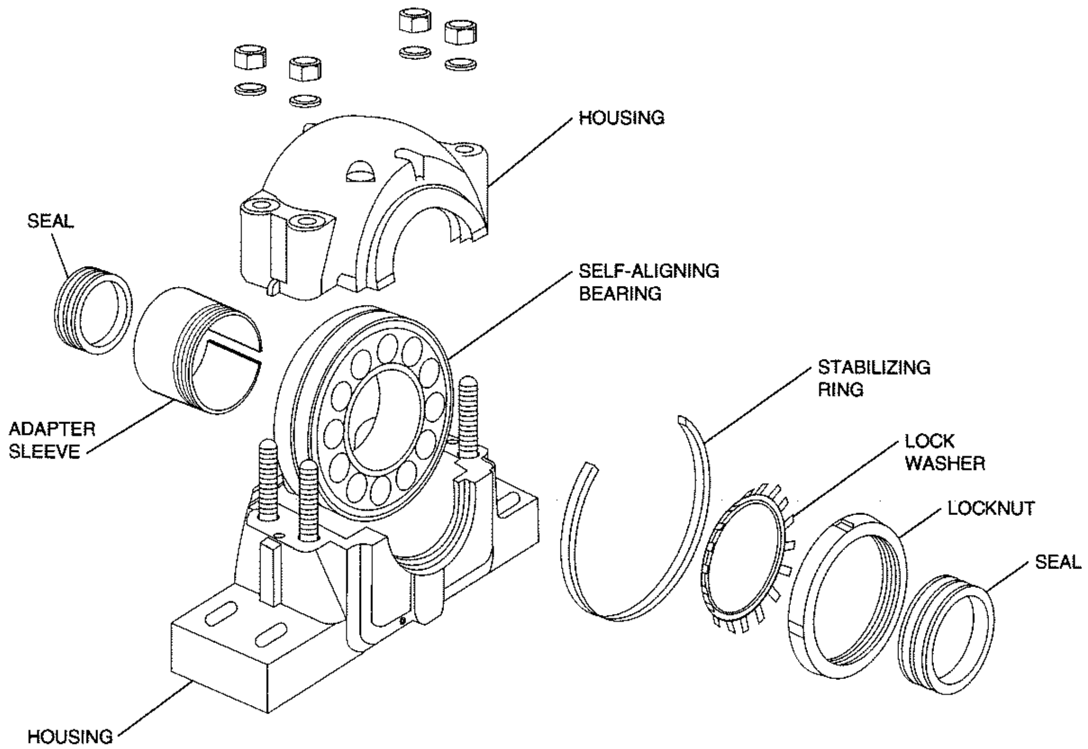


Figure 9.44 Split housing pillow block bearing

When using several pillow blocks of the same size, individually mark each bearing to prevent mixing the parts. **Figure 9.45** shows a match-marked split housing pillow block bearing.

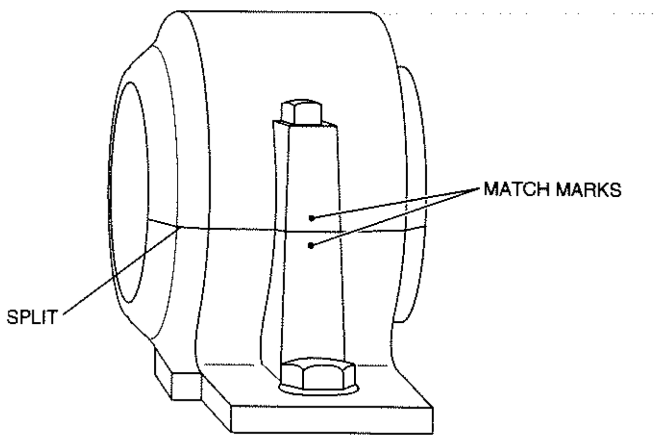


Figure 9.45 Match-Marked Pillow Block Bearing

When the pillow block bearing is assembled for installation, it must be determined if the bearing is to be an expansion bearing or a non-expansion bearing. An expansion bearing is used when the bearing will be subjected to high temperatures.

In an expansion bearing, the stabilizing ring is left out and the bearing is installed so that the bearing will be centered in the housing to allow for thermal expansion. In a non-expansion bearing, the stabilizing ring is installed to hold the bearing in position in the housing and to prevent axial movement.

9.21.5 Installing One-Piece Housing Pillow Block Bearings

Pillow block bearings that have a one-piece housing are completely assembled units. They are slipped over the shaft and bolted in position. They have an extra-long inner race to distribute the load over a wide area on the shaft. Some common designs used in one-piece pillow block bearings are the following:

- Single-groove ball bearings
- Double-taper roller bearings
- Spherical roller bearings

These bearings are self-aligning in the housing. A one-piece pillow block bearing allows for more misalignment than a split housing bearing. The bearings are usually held in place on the shaft with set screws threaded into a collar and passed through matching holes in the inner ring to engage the shaft or by a self-locking collar that is held in place by a set screw.

The bearing should be installed with the set screw on the inside, away from the end of the shaft so that any scoring caused by the set screw contacting the shaft will not hinder the removal of the bearing from the shaft.

9.21.6 Installing angular-contact ball bearings

An angular-contact ball bearing supports thrust load in one direction, sometimes combined with moderate radial load. The bearing has a high thrust-supporting shoulder on the inner ring and a similar high shoulder on the opposite side outer ring.

These bearings can be mounted singly or in tandem for constant thrust load in one direction. They can also be mounted in pairs (duplex mounting), either face-to-face or back-to-hack, for combined loads.

When two or more bearings are mounted together on the shaft, you should be able to turn the outer ring of each bearing individually.

Face-to-Face Mounting

Face-to-face mounting is used when the bearing takes both thrust and radial loads. This mounting allows for small amounts of misalignment. When mounted face-to-face, both the inner and outer rings are always clamped. **Figure 9.46** shows face-to-face mounting.

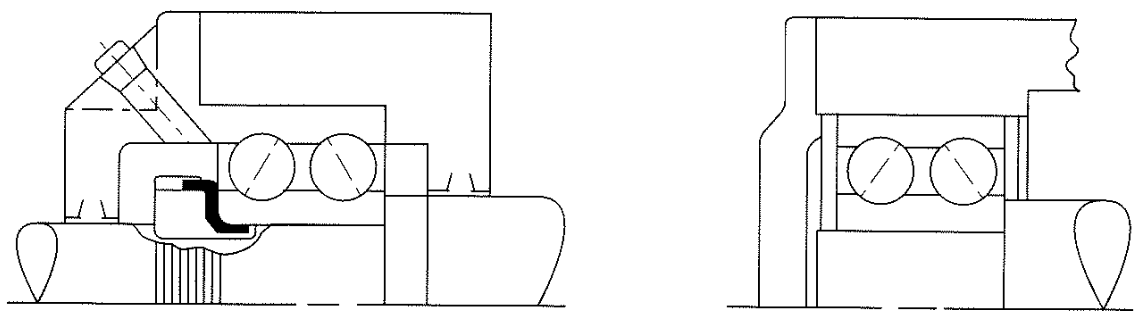


Figure 9.46 Face-to-face mounting

Back-to-Back Mounting

Angular-contact bearings can be mounted back-to-hack with the inner ring clamped and the outer ring floating endwise or with both rings clamped. When the outer ring is floating, the bearing handles radial loads only. When both rings are clamped, the bearing handles both radial and thrust loads.

With both rings clamped, the back-to-hack mounted bearing has high resistance to misalignment and shaft deflection. **Figure 9.47** shows back-to-hack mounting.

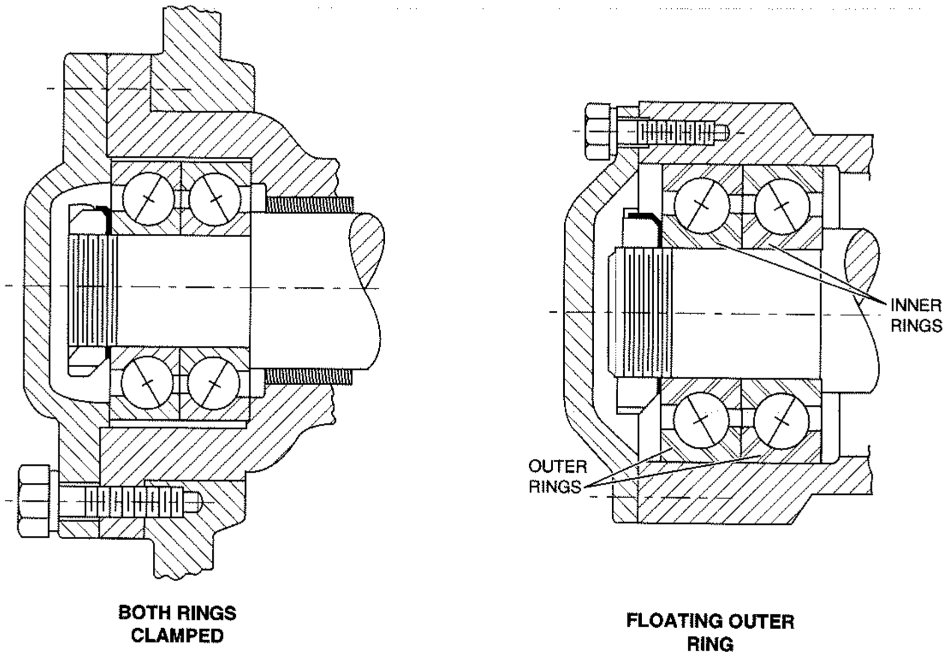


Figure 9.47 Back-To-Sack Mounting

Tandem Mounting
Bearings are mounted in tandem to support extremely heavy thrust loads. Some applications require more than two bearings mounted in tandem. Bearings mounted in tandem will take thrust in one direction only. For the bearing to take thrust in both directions, one bearing must be mounted face to face with the tandem bearings. This bearing will take the reverse thrust load. **Figure 9.48** shows tandem mounting.

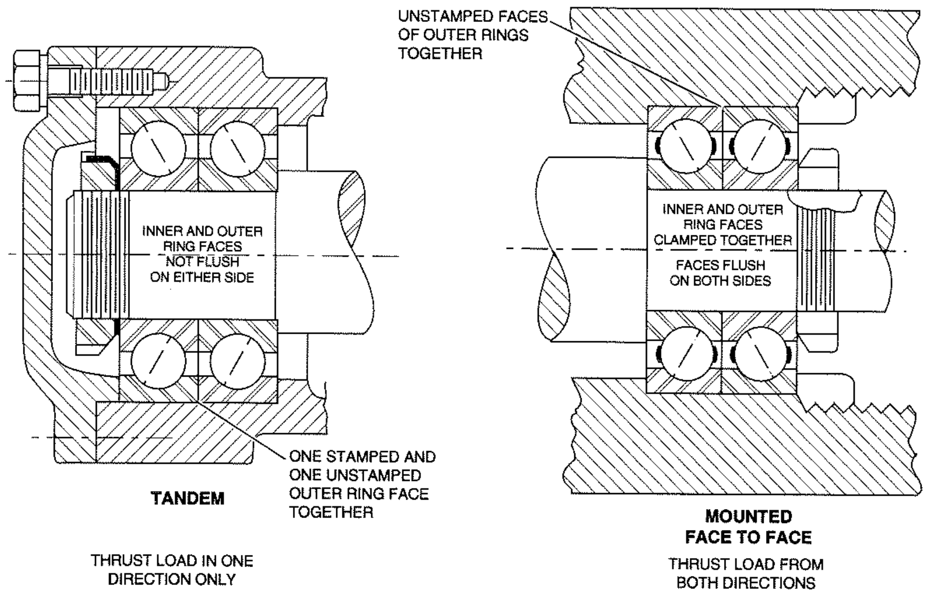


Figure 9.48 Tandem mounting

Activity 9.4

1. What are the two types of fits for bearings?
2. Where do you find the critical dimensions for a new bearing?
3. What is the maximum temperature for heating a bearing?
4. Which bearing supports axial loads only?
5. What type of bearing is contained in its own housing?
6. What type of load can an angular-contact ball bearing mounted back to back with the outer ring floating handle?

Activity 9.5 – Workshop

Practice installing each type bearings, using various methods.

9.22 Troubleshooting antifriction bearings

Troubleshooting bearings means identifying the causes of bearing failure.
We will now study factors that we must avoid because they have a harmful effect on anti-friction bearings.

- **Overheating of anti-frictional bearings**
  Overheating of anti-frictional bearings can be caused by:

  - Insufficient lubrication.
  - Excessive lubrication in the housing of the bearing.
  - Poor properties of the lubricant.
  - Foaming of oil.
  - Grease liquefaction. This means that the grease loses the force that holds the substance together. The result is that the grease starts to flow.
  - Raceways turning in the housing or on the shaft.
  - Corrosive or abrasive dirt in the bearing.
  - Inadequate internal clearance of the bearing after its installation which means it will fit too tightly in the housing or on the shaft. Its operating temperatures will therefore be affected.
  - An operating speed which is too high. This generates excessive frictional heat.
  - Insufficient cooling conditions.

- **Vibration and noisy bearings**
  Vibration and noisy bearings can be the result of:

  - Insufficient lubrication.
  - A flattened roller or ball.
  - Variation in the sizes of the rollers or balls.
  - An indent in the raceways due to incorrect handling or assembly or because of shock loads.

- o Contamination or pollution.
- o The bearing slipping on the shaft or in the housing.
- o The shaft not being round.
- o Races turning in the housing or on the shaft.
- o Excessive clearance between the shaft and the bearing or between the housing and the bearing.

9.23 Bearing failure and how to prevent it

Even when good quality bearings are supplied, it is still possible that bearings may be poorly designed, manufactured, installed or maintained. One or more of the following conditions can cause bearing failure:

- **Relation between temperatures and clearance**. There is a difference between the internal clearance of a bearing before it is mounted and the internal clearance in a mounted bearing which has reached its operating temperature.

- **Speed.** There is a limit to the speed at which bearings can be operated. The permissible speed at which bearing temperature is reached depends on the following:

  - o Frictional heat generated in the bearing, including any externally applied heat.
  - o The amount of heat which can be transported away from the bearing.
  - o Bearing type and size.
  - o Magnitude of the load.
  - o Lubrication and cooling conditions.
  - o Design of the cage.
  - o Internal clearance.
  - o Installation accuracy.

- **Lubrication and maintenance**. If rolling bearings are to operate reliably, they have to be adequately lubricated to prevent or to be protected from:

  - o Direct metallic contact between the rolling elements, raceways and cages.
  - o Wear of any moving parts.
  - o Corrosion of the bearing surfaces.

The choice of a suitable lubricant and method of lubrication for each individual bearing is therefore important.

- **Bearing inspection and cleaning.** Rolling bearings must be cleaned and examined frequently. It is possible to determine the condition of the bearing during service by:

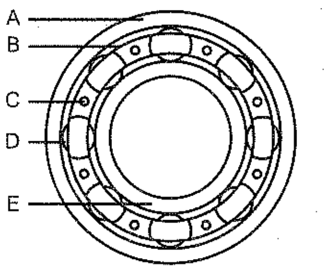
  - o Listening to the sound of the bearing when it is running.

- o Measuring the temperature.
- o Examining the lubricant.

If this is done it is usually sufficient if the rings, cage and rolling elements are thoroughly cleaned and inspected annually. Where the load is heavy, the frequency of inspection must be increased. After the bearing components have been cleaned with a suitable solvent, they should be oiled or greased immediately to prevent corrosion.

Activity 9.6

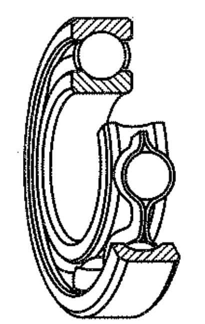
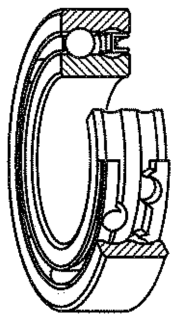
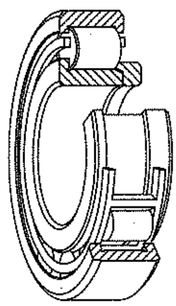
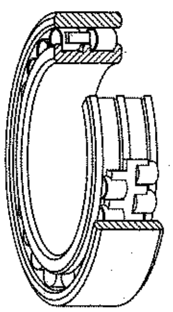
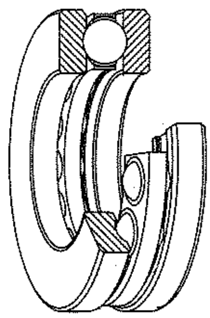
1. Explain the working principle of a friction bearing.
2. List the different types of friction bearings and indicate what type of load they are able to carry.
3. Explain the working principle of an anti-friction bearing.
4. Label the different parts or elements of an anti-friction bearing on the figure below.

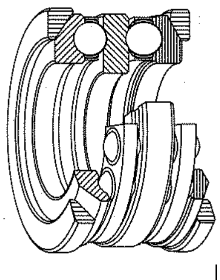
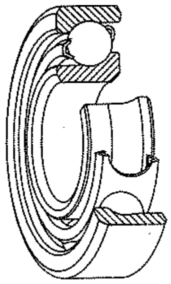
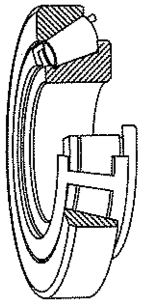
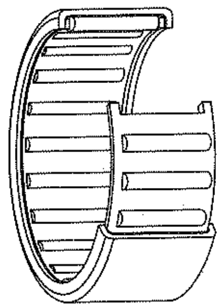
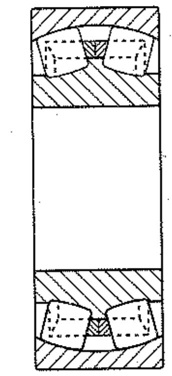


5. Describe the two main factors which will determine the type as well as the size of bearing to be used.
6. Describe the three types of bearing loads. Make simple drawings to clarify your explanation.
7. The way we use a specific type of anti-friction bearing will depend on certain basic factors. List these factors.

Activity 9.7

Identify the following (a to j) basic anti-friction bearings from the given drawings and indicate the type of load that each bearing can carry.

(a)	(b)	(c)	(d)	(e)
				
(f)	(g)	(h)	(i)	(j)

Activity 9.8

1. Explain the difference between line contact and point contact as it applies to ball and roller bearings.
2. We must avoid certain factors that have a harmful effect on antifriction bearings, such as overheating, vibration and noise. List the possible causes of each of these factors.
3. Bearing failures can be linked to one or more possible conditions or areas. Discuss these possible conditions or areas.
4. When selecting the correct type and size of bearing by using a manufacturer's catalogue, we must take some important basic factors into account. Name and explain these basic factors.
5. Use a simple sketch to explain why a grooved type of ball bearing can be used to take radial as well as thrust roads.
6. Explain with the aid of a simple sketch the reason for employing cages in roller bearings.
7. Lubrication and sealing devices play a major part in the efficient operation of ball and roller bearings. Give reasons for this and add a simple sketch to illustrate your answer.
8. Explain with the aid of a simple sketch how you would go about inserting a roller bearing into its housing.
9. Explain with the assistance of a simple sketch how you would remove a roller bearing from a bearing housing.
10. Give five advantages for the use of ball and roller bearings in preference to ordinary journal bearings.
11. Ball and roller bearings sometimes become overheated during use. Give reasons for this occurrence.
12. Name eight advantages of ball and roller bearings.
13. Explain the purpose of a double row self-aligning bearing. State what types of load it can carry.
14. State an important feature of a tapered roller bearing and state what types of load it can carry.

15. Explain how a rolling bearing is cleaned.
16. Name three causes of rolling bearing failure.
17. Name four causes of rolling bearing vibration.
18. Show with the aid of a sketch the types of loads the following bearings can support: deep-groove ball bearing; parallel cylindrical roller bearing; single-row angular-contact ball bearing.
19. Under what conditions will a self-aligning bearing are used?
20. Name three different types of self-aligning bearing.
21. Name six reasons for rolling bearings to overheat.
22. Name four causes for rolling bearings to vibrate.
23. Name eight factors, and give a short description of each, to be taken into consideration when mounting rolling bearings.
24. Give a short description of the correct procedure for the mounting of rolling bearings.
25. Describe a method for mounting a ball bearing on a shaft by heating.
26. Sketch and describe the mounting of a ball bearing on a shaft with the aid of an arbour press.

Self-Check

I am able to:	**Yes**	**No**
• Explain the difference between friction bearings (bush type) and anti-friction bearings (rolling bearings)		
• Identify and name the following anti-friction bearings from a given drawing:		
o Single and double row radial ball, and cylindrical roller bearings		
o Thrust ball and thrust roller bearing (single and double direction)		
o Single row angular contact bearing		
o Tapered roller bearing		
o Needle roller bearing		
o Spherical roller bearing		
• Name three main types of loads and those relative to the above bearings		
• Describe bearing failures, and failure prevention methods		
• State factors that have a detrimental effect on the bearings mentioned above		
• Select the correct type and size bearing using a manufacturer's catalogue (calculations are not necessary).		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 10

Water Pumps

Learning Outcomes
On completion of this module, the student should be able to:

- Describe the difference in working principles between a centrifugal (non-positive displacement) water pump and a reciprocating (positive displacement) water pump
- Identify the main parts from a given drawing and explain the functions of the main parts for:
  - Reciprocating water pumps- single and double acting (piston and plunger types)
    - Main parts: inlet valve, outlet valve, piston with rings, plunger with or without packing, stuffing box, air vessel, and piston
  - Centrifugal water pumps (single and multistage types)
    - Main parts: impeller, casing, (inlet and outlet), shaft, mechanical seal, stuffing box, balancing disc and stages
- Explain the following regarding water pumps:
  - Reading of basic pump curves
  - Maximum suction head with respect to atmospheric pressure +/- 10m
  - Incapability to pump hot water
- Describe the stopping and starting procedures of a centrifugal water pump for positive and negative suction
- Identify from a given drawing basic components in a water pump system
- Explain the reasons for good, planned maintenance procedures under the following headings:
  - service, inspection (maintenance plan, maintenance requirements), repair (planning), reconditioning (overhauling plan) and testing
- Interpret the functions of maintenance control sheets such as a fluid record, fluid inspection plan, discrepancy report and a data test sheet

10.1 Introduction

Generally speaking, pumps may be grouped into two main classes, those with valves and those without. Thus piston, plunger and bucket pumps require valves and give an intermittent flow, while centrifugal, rotary and air-lift pumps do not require valves and produce a continuous flow of the liquid.

In this module the following pumps will be discussed according to their classification:

- Centrifugal pumps, both single and multi-stage.
- Rotary pumps, including the gear pump, helical screw gear pump, vane pump and flexible impeller pump.
- Reciprocating pump terminology

10.2 Function of pumps

In this module we will be looking at various pumps are machines for the transport of fluids. The movement of the fluid may be effected in several ways, such as:

- By means of a reciprocating piston or plunger, operating within a cylindrical barrel.
- By an oscillating or rotating blade, or a pair of meshing gear wheels, working inside a casing, as in semi-rotary pumps.
- By a rotating vaned wheel such as in a centrifugal pump, or
- By a current of air, as in air-lift pumps.

10.3 Centrifugal pumps, both single and multi-stage

A centrifugal pump operates by increasing the velocity of a liquid. Fluid entering the pump is rotated by an impeller. This rotation creates centrifugal force within a stationary casing.

The force raises the pressure and causes the fluid to be discharged at high speed. **Figure 10.1** shows a centrifugal pump.

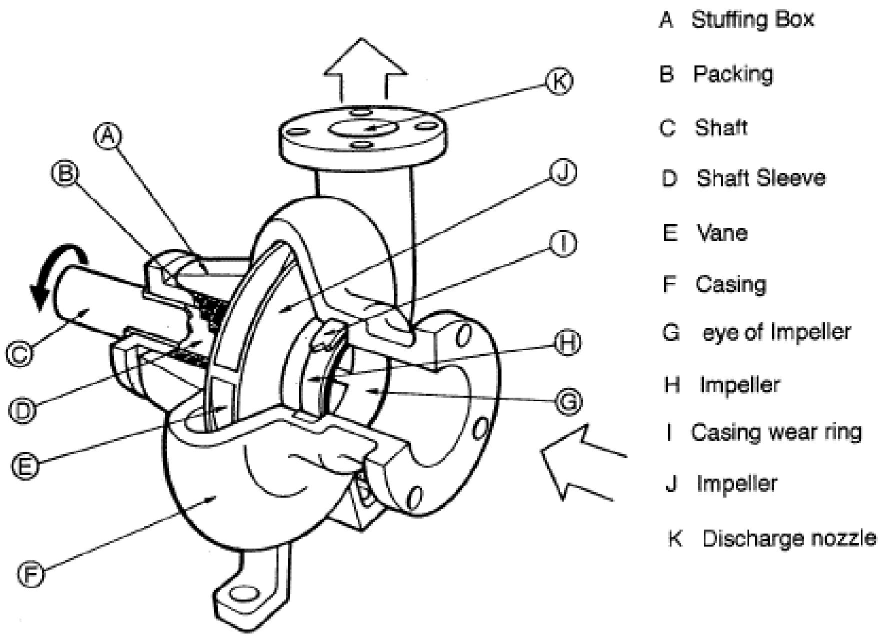


Figure 10.1(a) Components of a centrifugal pump

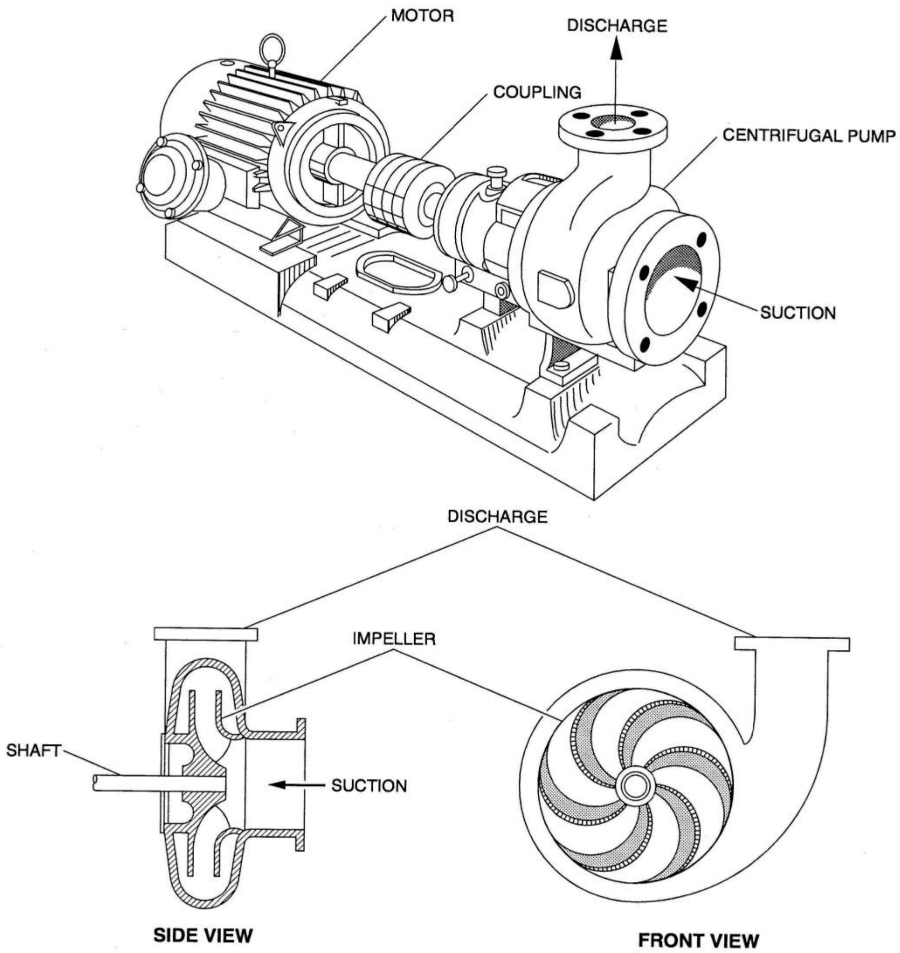


Figure 10.1(b) Centrifugal pump

10.3.1 Working principle and operation

An open or closed wheel with curved blades or vanes, termed the impeller, rotates at a high speed in a pump casing, as illustrated in **Figure 10.2**. The casing is initially filled with the liquid to be pumped, and on setting the pump in motion, the liquid is caught up by the blades.

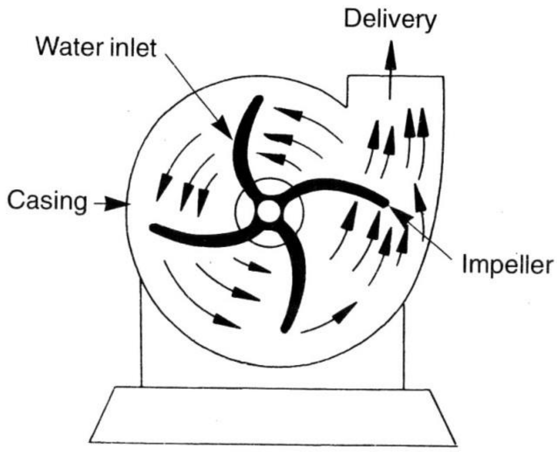


Figure 10.2 Centrifugal pump

Because of the centrifugal force, the liquid is kept moving continuously from the centre to the outside circumference.

Thus the liquid is delivered from the suction pipe into the delivery pipe while further liquid is drawn into the suction so that the pump delivers continuously.

When large quantities of liquid have to be lifted against low heads, the pump is fitted with impellers of relatively small diameter but greater lift to provide larger passages for the liquid; small quantities pumped against high heads require impellers with large diameters.

10.3.2 Parts of a centrifugal pump

The parts of centrifugal pumps may vary in size and shape, depending on the manufacturer, but will have the same functions. Centrifugal pump parts include the following:

- Pump casing- The part surrounding the shaft, bearings, packing gland, and impeller.
- Pump casings can be of split or solid design.
- Suction port - The place where fluid enters the pump.
- Discharge port - The place where fluid is discharged into the piping system.
- Pump shaft -A bearing-supported part that holds and turns the impeller when the shaft is coupled to a motor.
- Bearings -The parts that support the shaft and impeller in the casing.
- Impeller- A rotating part that increases the speed of the fluid. There are many different types of impellers used for different purposes.
- Impeller vanes or blades - The parts of the impeller that direct the flow of fluid within the pump.
- Impeller shrouds -The parts that enclose the blades and keep the flow of fluid in the impeller area.
- Wearing rings - Replaceable rings used in some pumps to allow some fluid leakage between the impeller and the casing in the suction area. The leakage makes a hydraulic seal and helps the pump operate more efficiently.
- Packing gland - Contains an adjustable follower that exerts force upon the packing to control fluid leakage around the shaft.
- Mechanical seal - Seals the fluid flow in the pump. Used instead of packing in some pumps.

Figure 10.3 shows a centrifugal pump with a vertically split case.

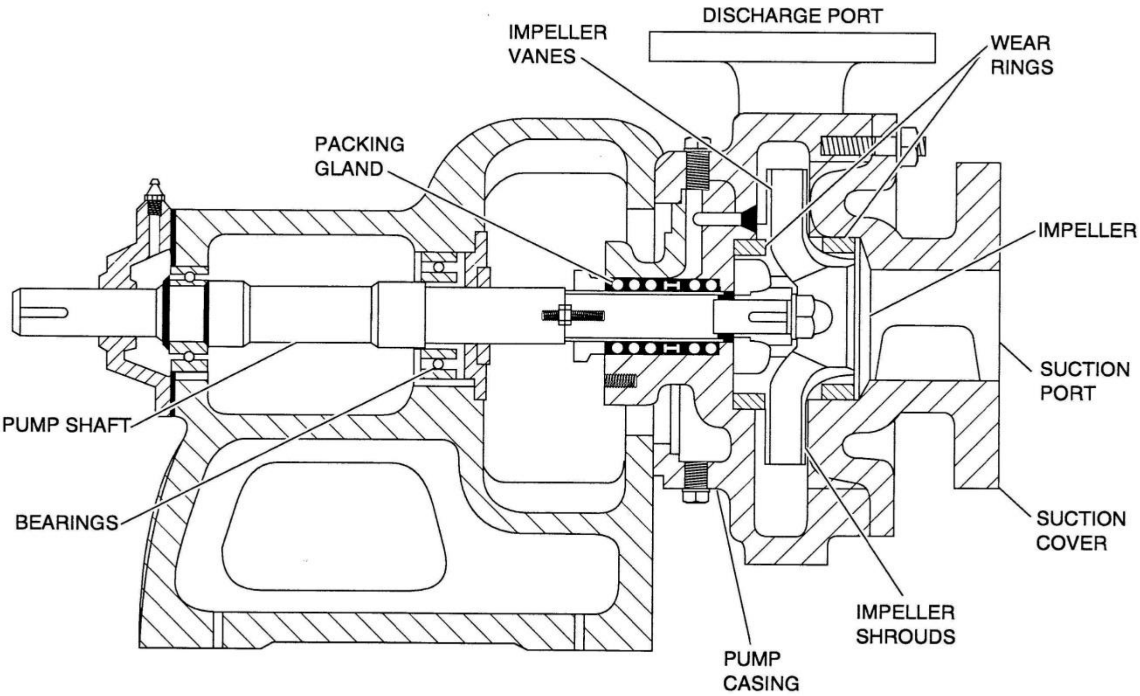


Figure 10.3 Parts of a centrifugal pump

10.3.3 Pumps with volute casing

The impeller discharges directly into the spiral casing with varying cross-sections.

⚠	**TAKE NOTE** The casing gets larger on the way around. This is because each successive vane adds liquid, so that additional space must be provided. The main purpose of volute pumps is to pump large quantities of liquid against comparatively low heads. They are used for pumping sandy or gritty liquids. These pumps are normally single-stage pumps with a maximum efficiency of 60-65%

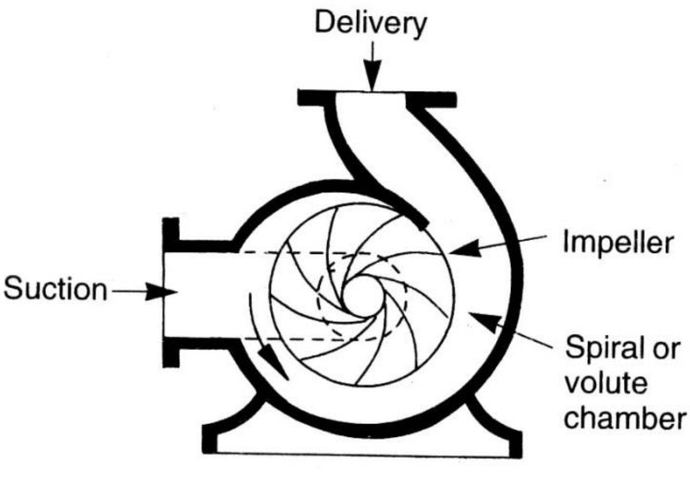


Figure 10.2 Volute type pump

10.3.4 Double-suction centrifugal pumps
A double-section centrifugal pump is used to pump large volumes of fluid. Fluid is drawn in through suction openings on both sides of the impeller and passes out through a single discharge opening. **Figure 10.3** shows a double-suction centrifugal pump with a horizontally split case.

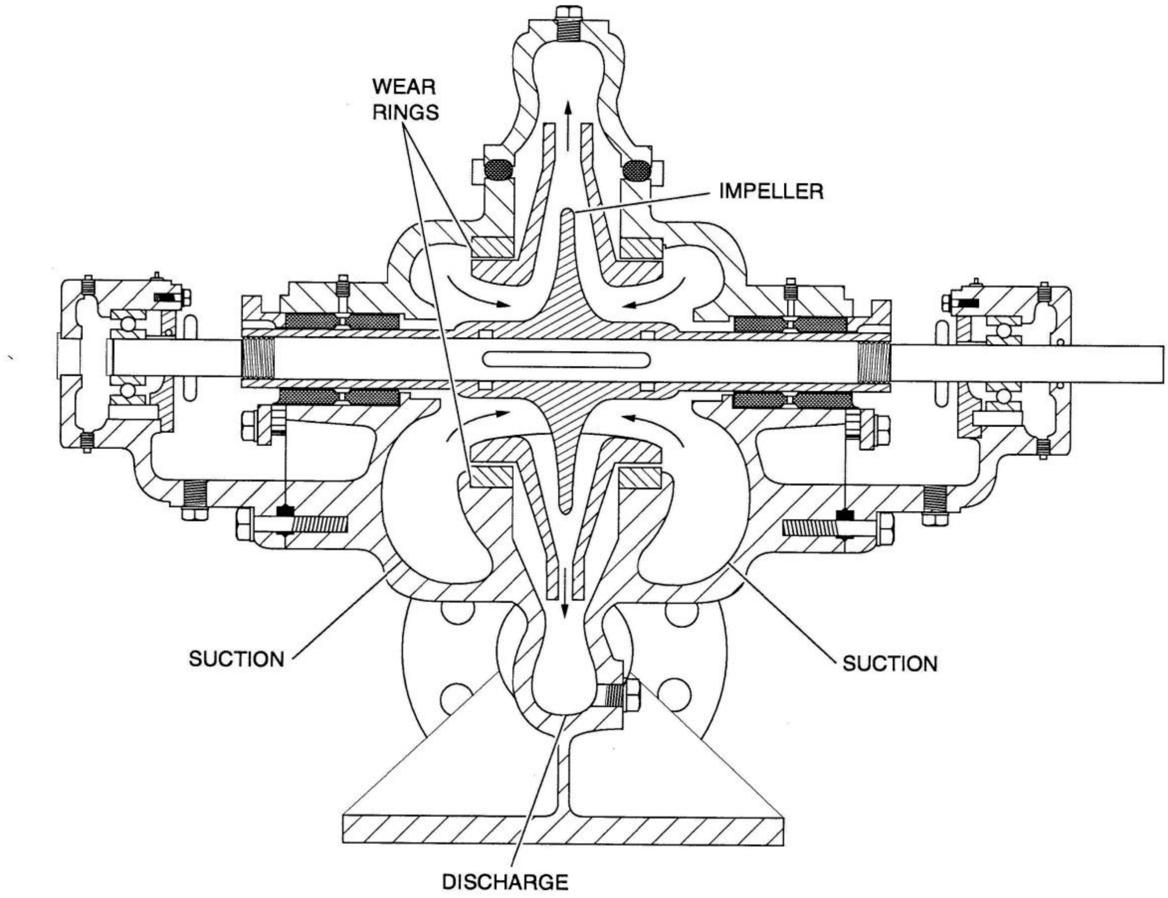


Figure 10.3 Double-suction centrifugal pump

10.3.3 Multi-stage pumps
Multistage centrifugal pumps contain two or more stages and can be either single or double suction. Fluid is discharged from one stage to the next through passages in the pump casing.

Each stage increases the speed of the fluid until the desired pressure is reached. **Figure 10.4** shows a multistage pump.

These are a set of turbine pumps where the outlet of the first pump discharges into the inlet of the next and so on. From the last stage it flows into the main delivery column. (See **Figure 10.5(a)** and **(b)**)

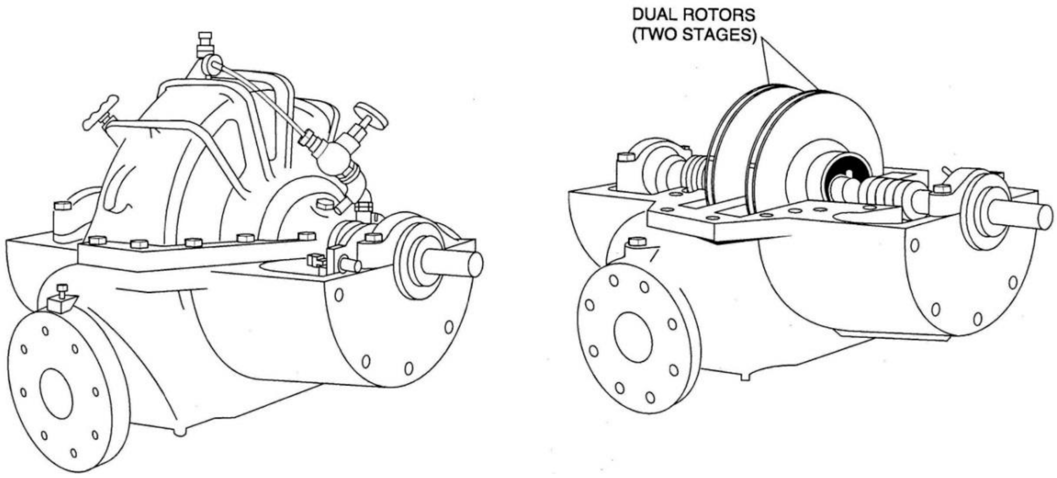


Figure 10.4 Multi-stage pump

The main advantages of centrifugal pumps over reciprocating pumps are:

- Very small floor space required
- Low i low maintenance cost, since all motion is rotary
- No sensitive parts such as the moving valves of reciprocating pumps (centrifugal pumps have no valves)
- High working speeds allow direct coupling to primary power sources
- Small and light foundations are required
- The ability to handle muddy and dirty, corrosive liquids, hot water up to 400°C and circulating oil at high temperatures, provided they reach the pump at a high pressure
- The motor for centrifugal pumps is smaller than the motor for reciprocating pumps because of the higher speed of the centrifugal pump
- There is little, if any, vibration
- Discharge of liquid is continuous and without shock
- No air vessels or alleviators are required

The flow of water can be controlled automatically from full flow to no flow, without shutting down the pump or damaging the pump or pipes.

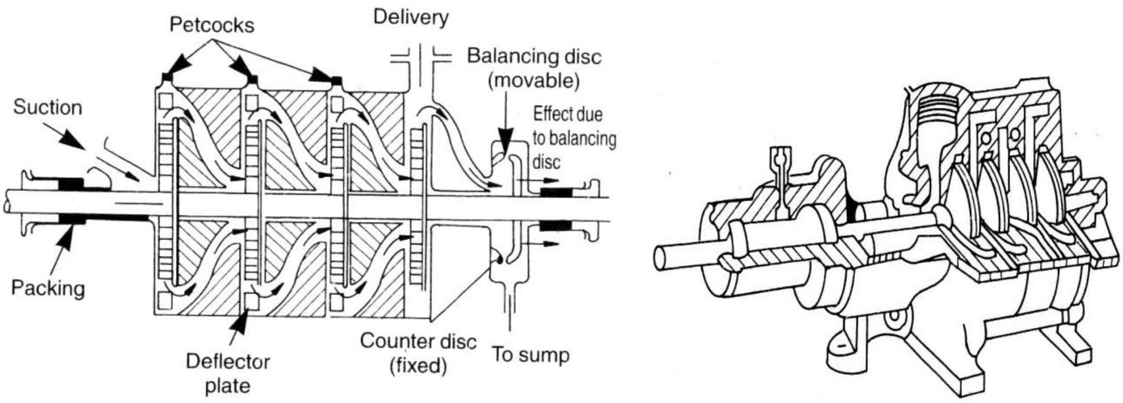


Figure 10.5(a) Multi-stage centrifugal pumps (b) Four-stage centrifugal pump

10.4 Rotary pumps

A rotary pump operates by a turning motion. Rotary pumps may be gear, screw, vane, and flexible impeller types. Rotary pumps are used in hydraulic systems. They are also used to transfer fluids such as oils, solvents, chemicals, and paints.

10.4.1 Gear pump

The gear pump is the most common type of rotary pump. Gear pumps are used mainly in hydraulic systems. They are also used for bearing lubrication in industrial machines and automotive engines. Gear pumps may be either external or internal design.

Gear pumps can generally be classified into three main groups: external gear, internal gear and screw pumps. All gear pumps are basically duo directional units and reversal of flow is simply obtained by changing the direction of rotation of the driving motor.

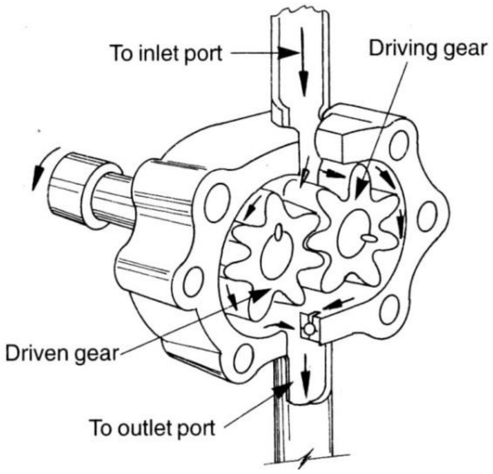


Figure 10.6 (a) Rotary gear pump

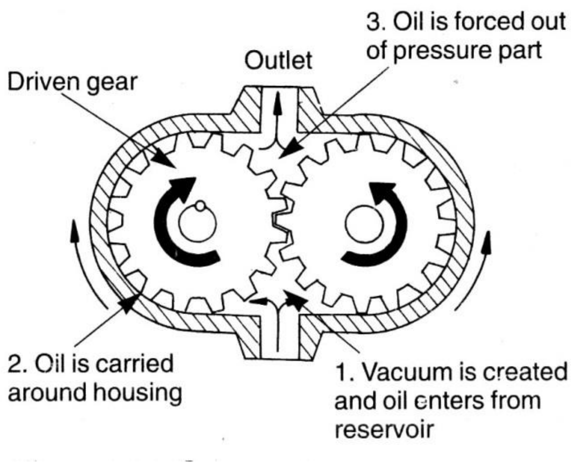


Figure 10.6 (b) Gear pump

External gear pumps can be subdivided into spur, helical and herringbone-type gear pumps. Of these the straight spur gear is by far the most widely used. One of the main reasons for using helical tooth pumps is that they are quieter in operation at high rotational speeds.

Figure 10.6 (a) and **(b)** shows the cross-section through a typical gear pump and illustrates the pumping action. If the pump driving shaft is rotated as shown, the un-meshing of the gears will produce a partial vacuum so that the liquid will be drawn into the pump.

This liquid is trapped between the gear teeth and carried round to the opposite side of the pump by both gears before it is forced out of the discharge port. It will also be readily seen that these pumps are most compact and usually without valves.

Working principle - In gear pumps, the fluid being pumped is drawn into the intake port by the gear teeth. The fluid is then forced through the space between the pump casing and the impellers and out the discharge port. The meshing of the gear teeth prevents the fluid from flowing back out the intake port. **Figure 10.7** shows the fluid flow in an external gear pump.

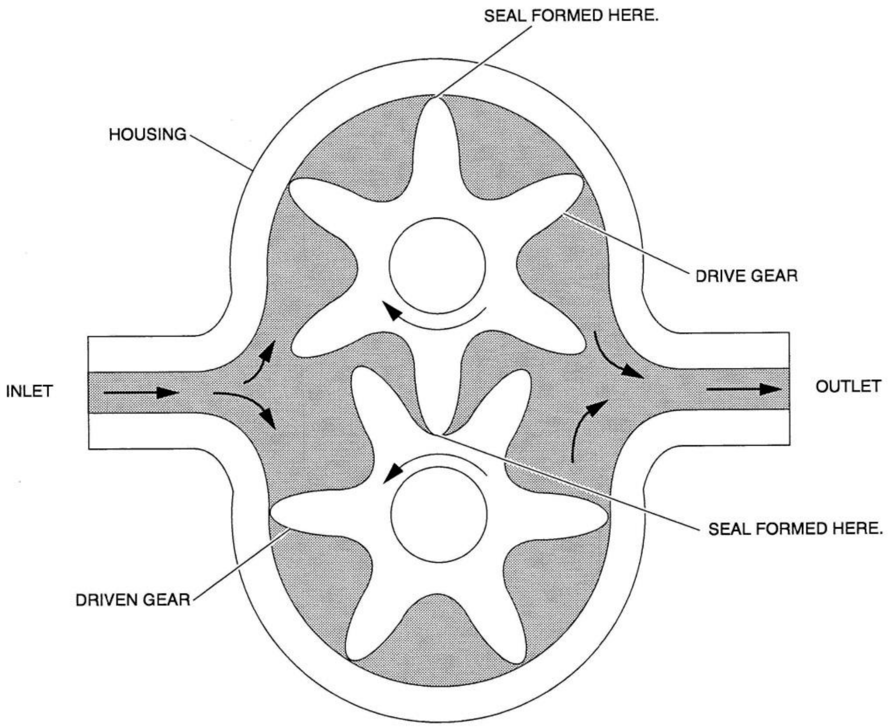


Figure 10.7 Working principle of an external gear pump

Spur gear impellers are the most common type used in gear pumps. They are economical to manufacture and maintain. Where a smooth fluid flow and transfer of power is needed, helical and herringbone gears are used. Helical and herringbone gears are often used in pumps that handle larger capacities and higher speeds than spur gear pumps.

10.4.2 Helical screw gear pump

Liquid enters in the direction shown and is carried round between the vanes and the pump casing until it is pushed through the pump outlet.
Causes of rotary pumps jailing to delivery liquid:

- Suction head is too large
- Strainer is choked and therefore liquid cannot flow to pump casing
- Pump is not properly primed
- There are air leakages at inlet pipes and packed stuffing boxes
- Pump may be badly worn or have some or other mechanical fault
- Strainer not properly submerged under liquid thus permitting air to be drawn in with water.
- Speed of pump too low to build up pressure

This pump is often used to transfer oil from one point to another. Screw pumps are simple and capable of operating at high speeds.

For the operation of the pump, see **Figure 10.8**. The side screws (1) are driven by the central screw (2) and the liquid is drawn in through the opening (3), where it travels along grooves (4) to be pumped out through the delivery hole (5).

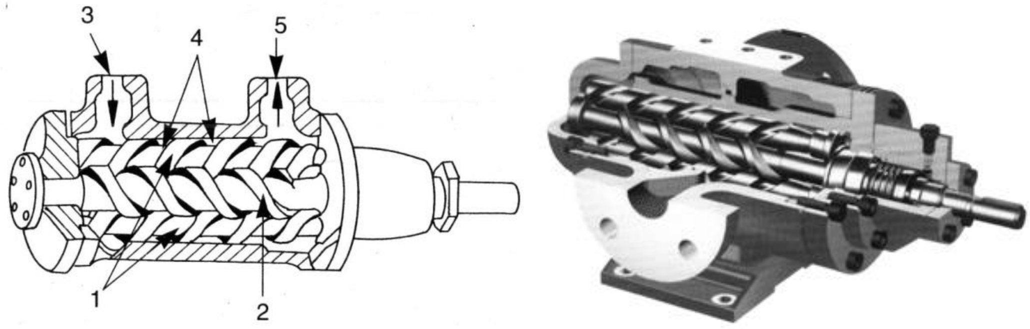


Figure 10.8 Operation of the screw pump

10.4.3 Blade pumps
The rotor has slots into which the sliding blades or vanes fit. The pump depends on centrifugal force to swing out the blades and cause them to ride lightly against the cylinder walls during rotation. It should be noted that these pumps will not operate unless properly primed.

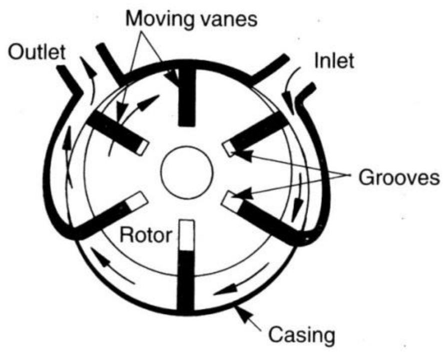


Figure 10.8 Blade-type rotary pump

10.4.4 Vane pump
The operation of the vane-type pump is as follows:

It is based on the principle of increasing the size of the cavity to form a vacuum, allowing the space to be filled with fluid, and then forcing the fluid out of the pump under pressure diminishing the volume.

The rotor has slots into which the sliding blades or vanes fit. The pump depends on centrifugal force to out the blades and cause them to ride lightly against the cylinder walls during rotation. Liquid enters in the direction shown in **Figure 10.9** and is carried round between the vanes and the pump casing and then pushed through the pump outlet.

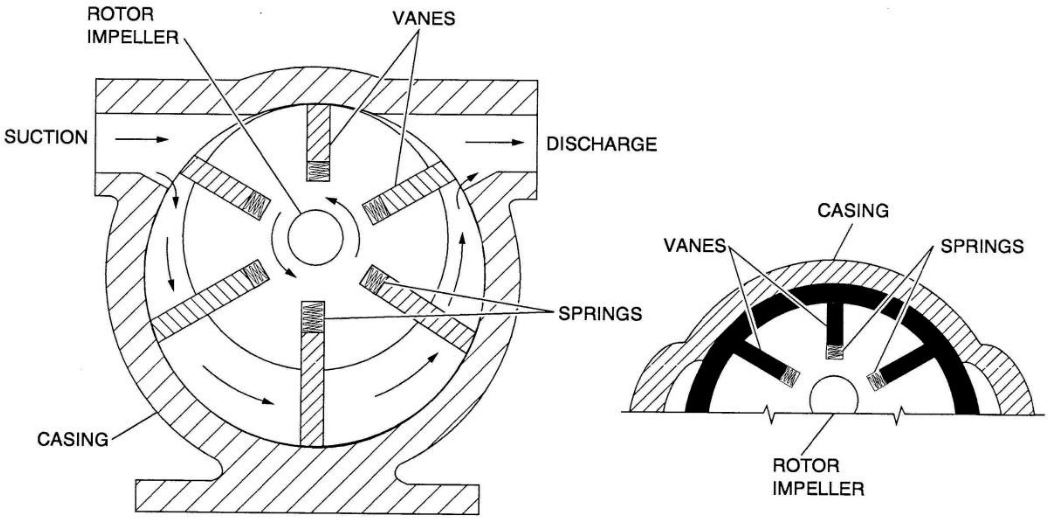


Figure 10.9 (a) Spring-load impeller vane pump

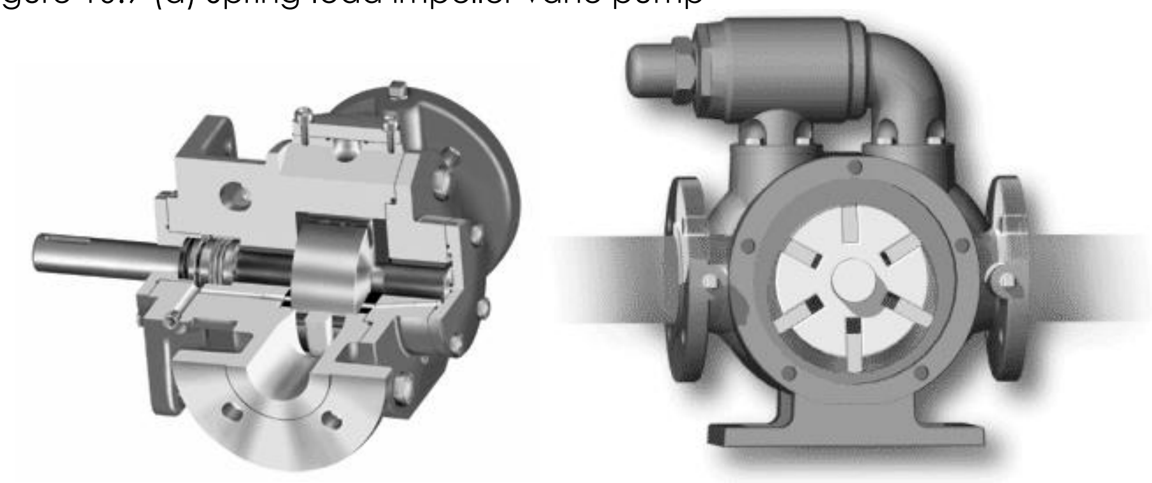


Figure 10.9 (b) Vane-type pump

Advantages of vane pumps
- Handles thin liquids at relatively higher pressures
- Compensates for wear through vane extension
- Sometimes preferred for solvents, LPG
- Can run dry for short periods
- Can have one seal or stuffing box
- Develops good vacuum

Disadvantages of vane pumps
- Can have two stuffing boxes
- Complex housing and many parts
- Not suitable for high pressures
- Not suitable for high viscosity
- Not good with abrasives

10.4.5 Flexible impeller pump

Flexible impeller pumps are rotary pumps that are used to pump chemicals. Each pump has a flexible impeller made from rubber or plastic compounds. **Figure 10.10** shows flexible impeller pump parts.

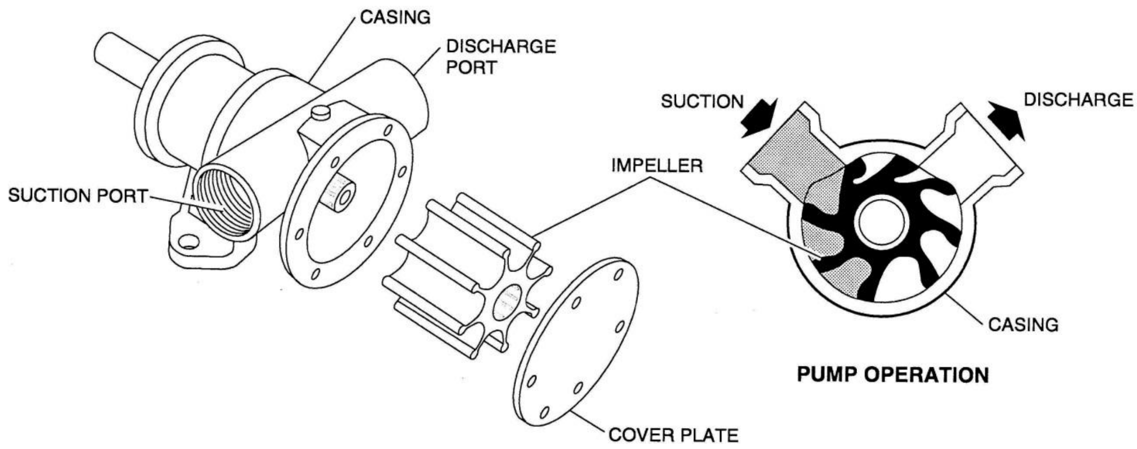


Figure 10.10 Flexible impeller pump

Pump principle - The flexible impeller vanes deform slightly to pump the liquid inside the pump and move it to the discharge port at a steady flow rate. This principle combines gentle pumping with a high self-priming action.

10.5 Reciprocating pumps

Reciprocating action is a backward and forward or up and down movement developed from a circular movement. **Figure 10.11** clearly shows the reciprocating action of a pump. A connecting rod joined to a crank which moves or rotates through a circular path drives a cross head forward and backward in a straight line.

The most important characteristic of reciprocating pumps is that the moving portion inside the cylinder may consist of a bucket, a plunger or a piston.

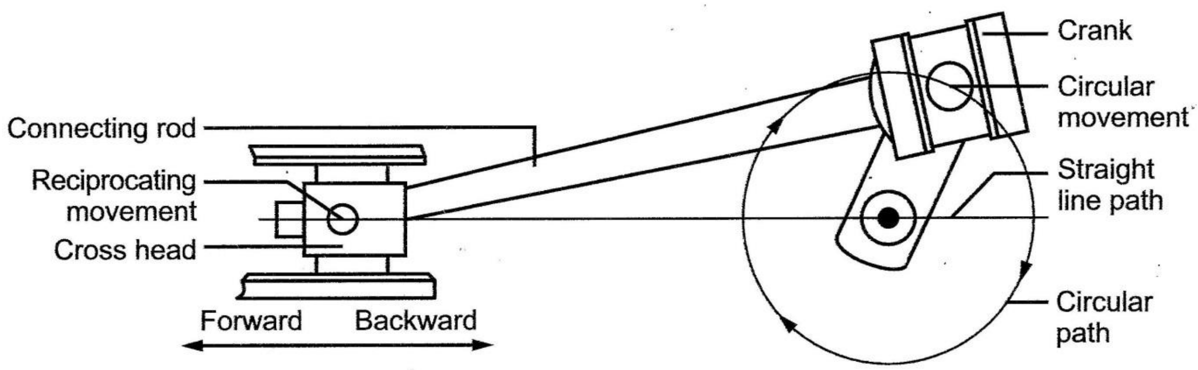


Figure 10.11 Reciprocating action of a pump

A reciprocating pump has three main moving elements. They are:

- An inlet valve, also called an admission valve.
- An outlet valve, also called a discharge valve.
- A plunger or a piston.

Reciprocating pumps operate by back-and-forth or up-and-down, straight-line motion. Reciprocating pumps require a suction, or intake, stroke and a discharge stroke to move the fluid.

During the suction stroke, a check valve in the suction line opens and a check valve in the discharge line closes. During the discharge stroke, the suction check valve closes and the discharge check valve opens. The action of the check valves prevents the liquid from flowing back out the suction line on the discharge stroke. **Figure 10.12** shows check valves in the suction and discharge lines.

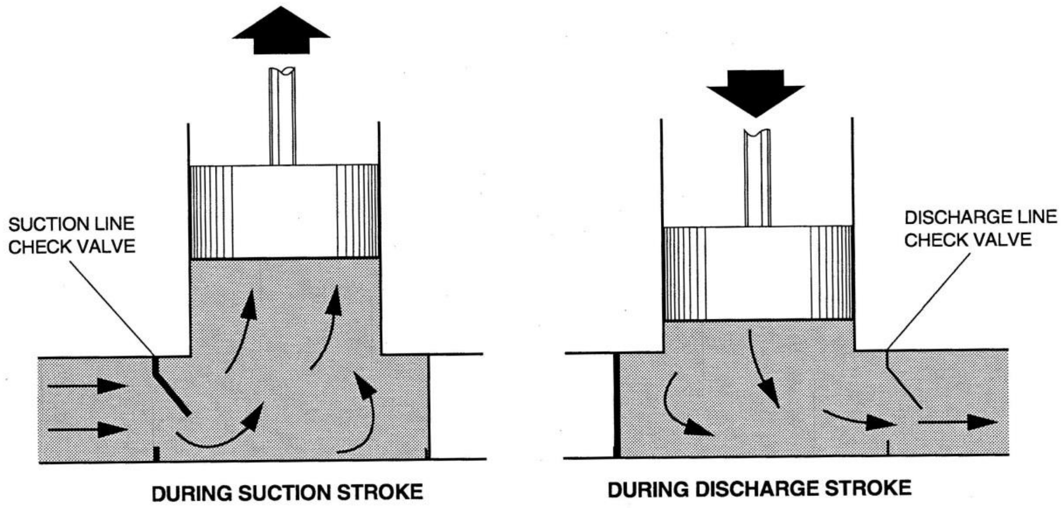


Figure 10.12 Check valves in the suction and discharge lines

A plunger and a piston perform the same work. They differ from each other in the following two ways:

- The length of a plunger is longer than its stroke. The stroke is the distance the plunger or piston moves in one direction before returning back. The length of a piston is shorter than its stroke.
- The packing of the plunger is housed in a stuffing box with soft packing at the end of the cylinder. The piston has packing rings that are inserted on the rim to prevent leakage. These differences are shown in **Figures 10.13 (a)** and **(b).**

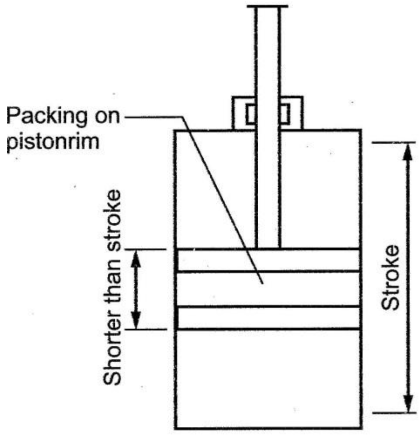


Figure 10.13 (a) Piston

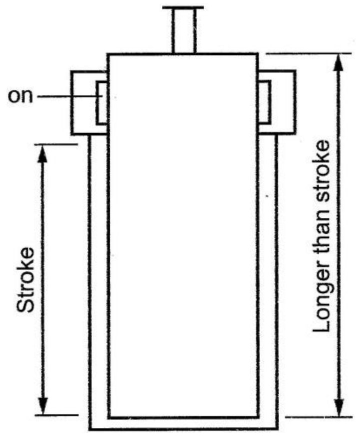


Figure 10.13 (b) Plunger

10.5.1 Piston pump

The piston pump almost always has suction and delivery valves connected to each end of the cylinder and are thus double-acting. This type of pump operates most satisfactorily at medium pressures.

As the piston moves to the right, fluid is drawn through the left suction valve and delivered through the right delivery valve. On moving to the left, fluid is drawn through the right suction valve and delivered through the delivery valve situated on the left side.

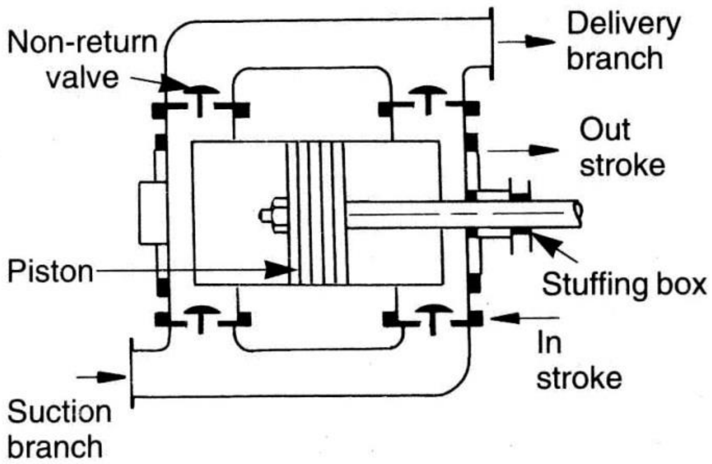


Figure 10.14 Double-acting piston pump

10.5.2 Plunger pump

The plunger pump is worked by compressed air. The air cylinder on the right-hand side has a piston which is directly connected to the water plunger. When the air piston operates with a reciprocating movement from left to right, or from right to left, the water plunger follows similarly.

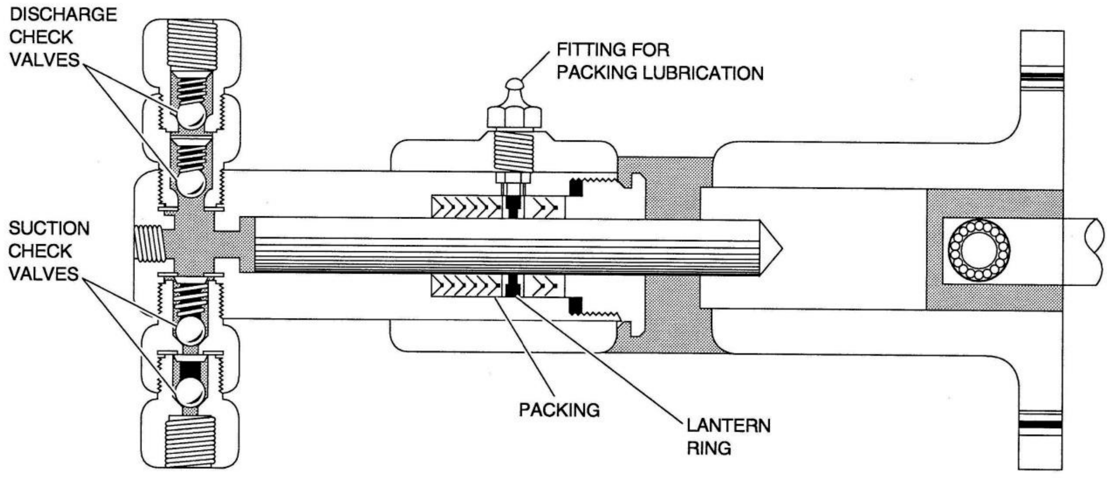


Figure 10.15 Plunger pump

10.5.3 Externally-packed plunger pump (Cameron type)

This plunger operates in two separate water boxes which are only connected via the suction and delivery pipes. Each water box has two valves, i.e. an inlet and an outlet valve for the water.

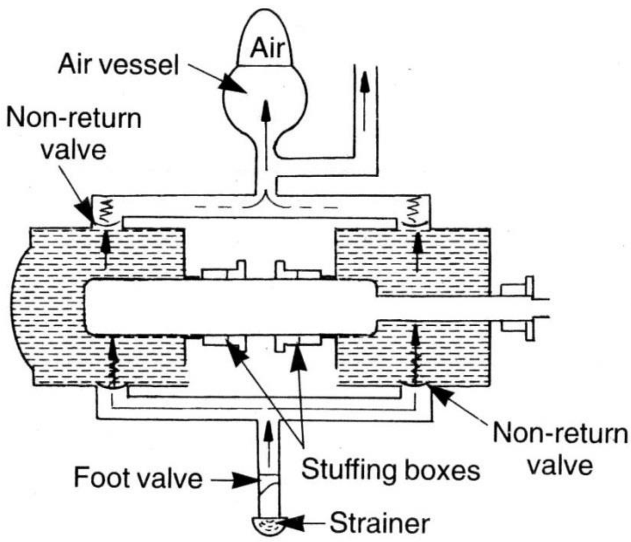


Figure 10.16 Externally packed plunger pump

When referring to **Figure 10.16** it will be noticed that when the plunger moves from the left-hand side to the right-hand side, the water in the box will be compressed, therefore the upper valve will open, allowing water to flow out into the delivery and the bottom valve will close, preventing water from running back into the sump.

Simultaneously a vacuum is created in the left box, which will cause the top valve to close and the bottom valve to open, "sucking in" more water.

10.5.4 Internally-packed pump

The plunger is reduced at the front to take up cup leathers or rings of square hard rubber packing. Under compression the packing forms a tight seal between the plunger and the inner wall of the cylinder. (See **Figure 10.17**)

The disadvantage of this type of pump is that one cannot ascertain if any leakage occurs while the pump is in operation.

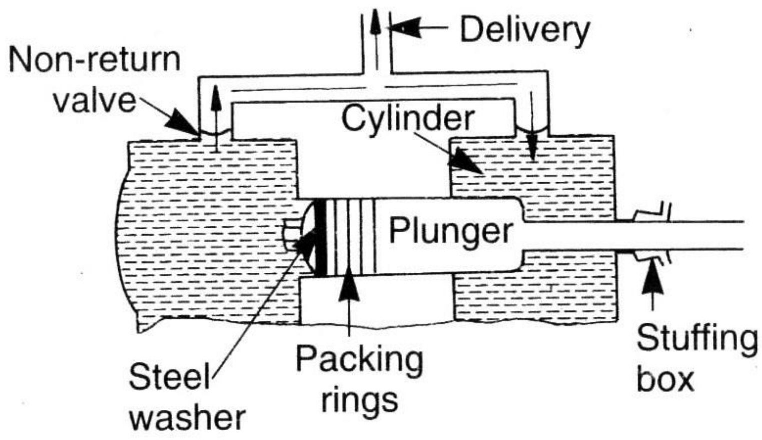


Figure 10.17 Internally packed plunger pump

10.6 Advantages of centrifugal pumps over reciprocating pumps

Centrifugal pumps have several advantages over reciprocating pumps.
Some of these advantages are:

- Centrifugal pumps are more compact, which means they need less floor space.
- The initial cost is relatively low.
- Maintenance costs are low due to the rotating motion of the main parts.
- Centrifugal pumps are quite adaptable. They can pump sandy, muddy and dirty fluids with ease.
- The construction of the pump is simple and reliable.
- The pump works at high speeds and it can therefore be connected directly to the motor.
- Water hammer and shocks do not occur because the pump delivers a regular and continuous stream of fluid. There is therefore no need for air vessels.
- There are almost no vibrations, thus there is no need for sturdy and heavy foundations.
- The delivery of fluid can be regulated from no flow to full flow without switching off or damaging the pump.
- Centrifugal pumps have no moving valves or sensitive parts.

10.7 Reading Pump curves

The key thing to remember when reading a pump curve is all curves are based upon the principle of plotting data using the x and y axis. With this in mind, the curves typically plotted are head verses capacity, power input verses capacity, and pump efficiency verses capacity. Therefore the constant between each curve is the capacity or x-axis. To determine the performance data at a particular point, first locate the operating point of the pump.

This is the point where the system head curve crosses the pump's head vs. capacity curve. From this point move horizontally to the left until you intersect the y-axis. This will give you the head at which the pump will operate.

Next go back to the operating point. By moving vertically down to the x-axis, you can find the capacity that the pump will operate. Now, at the determined flow rate, moving vertically to the input power curve intersection, then move horizontally to the kW input y-axis the appropriate value for motor input can be read. In like manner the pump efficiency can be read by keeping the flow constant once again.

Activity 10.1

1. Explain the function of pumps.
2. Name the three categories into which pumps are classified.
3. Describe the difference in working principles between a centrifugal (non-positive displacement) water pump and a reciprocating (positive displacement) water pump.
4. Describe the stopping and starting procedures of a centrifugal water pump for positive and negative suction.
5. Identify, classify, name and explain the working principle of the following pumps and explain with the aid of a freehand drawing the function of various components:
   (a) Centrifugal pumps, both single and multi-stage
   (b) Rotary pumps
   (c) Gear pump
   (d) Helical screw gear pump
   (e) Vane pump
   (f) Flexible impeller pump
6. Name the types of reciprocating pumps.
7. Make a freehand drawing to explain the working principle of reciprocating pumps.
8. Explain the term water hammer and name two causes for this.

Self-Check

I am able to:	Yes	No
• Describe the difference in working principles between a centrifugal (non-positive displacement) water pump and a reciprocating (positive displacement) water pump		
• Identify the main parts from a given drawing and explain the functions of the main parts for:		
o Reciprocating water pumps- single and double acting (piston and plunger types)		
– Main parts: inlet valve, outlet valve, piston with rings, plunger with or without packing, stuffing box, air vessel, and piston		
o Centrifugal water pumps (single and multistage types)		
– Main parts: impeller, casing, (inlet and outlet), shaft, mechanical seal, stuffing box, balancing disc and stages		
• Explain the following regarding water pumps:		
o Reading of basic pump curves		
o Maximum suction head with respect to atmospheric pressure +/- 10m		
o Incapability to pump hot water		
• Describe the stopping and starting procedures of a centrifugal water pump for positive and negative suction		
• Identify from a given drawing basic components in a water pump system		
• Explain the reasons for good, planned maintenance procedures under the following headings:		
o service, inspection (maintenance plan, maintenance requirements), repair (planning), reconditioning (overhauling plan) and testing		
• Interpret the functions of maintenance control sheets such as a fluid record, fluid inspection plan, discrepancy report and a data test sheet		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 11

Cooling

Learning Outcomes

By the end of the module, you should be able to:

- Describe the need for cooling of the following:
  - Internal combustion engines (petrol and diesel)
  - Compressors
  - Electric motors
  - Welding machines (AC and DC)
- Discuss and compare the advantages and disadvantages of the following air cooling systems:
  - Direct cooling
  - Indirect cooling
- Compare the advantages and disadvantages of the following water (coolant) cooling systems:
  - Thermosiphon cooling system
  - Impeller assisted cooling systems
- Describe the principle and function of:
  - Heat exchangers
  - Oil coolers
- Explain the causes, dangers and prevention of:
  - Overcooling
  - Overheating

11.1 Introduction

Cooling is the transfer of thermal energy via thermal radiation, heat conduction or convection.

11.2 Cooling for internal combustion engine

An internal combustion engine produces a lot of heat. In fact, when you burn fuel in an engine to create motion, most of the gasoline (like 75%) produces heat rather than motion. The engine therefore needs a way to eliminate all this heat or the engine will melt.

There are TWO common cooling techniques for internal combustion engines:

1) Air cooling – The air cooling technique is common on lawn mowers and other lawn/garden equipment, motorcycle engines, some airplane engines and some car engines. For example, the original Volkswagen beetle's engine was air cooled. Porsche offered air-cooled engines into the 1990s. Compared to water cooling, air cooling is much lighter and simpler.

Some air-cooled engines supplement the cooling process with an oil radiator. Heat that the oil picks up is dissipated in the radiator. Since the oil, the oil pump and the piping are already in place, the oil radiator is a simple add-on.

2) Water cooling – Water cooling is far more common on car engines because it is more reliable, especially in big engines on hot days. The basic idea is simple. Water flows around the engine's cylinders to cool them. The hot water is then pumped to a radiator where air flowing through the radiator can dissipate the heat (a better name for the radiator would be the convector, since the main way it loses heat is by convection).

11.3 Compressors

To prevent overheating of a hermetic compressor's internal motor, some type of cooling method must be employed. Compressor manufacturers will use one of three methods to provide the necessary cooling for their motors.

One method is to use the returning suction vapor to cool the motor windings. This is used on all fully-hermetic compressors, as well as many semi-hermetic compressors.

Another method used is to pass a sufficient amount of air across the body of the compressor. This design is used on many semi-hermetic compressors and the compressor is generally referred to as an air-cooled compressor.

The third method used is to wrap a water jacket around the body of a semi-hermetic compressor and use the water leading to a water-cooled condenser to cool the motor's windings. These compressors are generally referred to as water-cooled compressors.

Both the compressor and drive produce heat when operating, which must be dissipated to the surroundings. Most of the heat is removed with the refrigerant. Still, some forced air circulation should be passed across the compressor and the motor drive to ensure they do not operate at elevated temperature. In most cases, a dedicated air fan is not necessary.
But, a modest amount of airflow from the condenser fan is enough to maintain adequate cooling and safe temperatures.

Main reasons for cooling system needed:

- Allows for more air to be stored in the pressure tank if it is kept cooled.

- Keeping the pressure tanks cooled will prevent the tank from explosion.
- Allows the correct viscosity of the lubricant to seal off.
- Lubrication is easier if the temperature in the cylinder is reduced.

11.4 Electric motors

All rotating electrical machines generate heat as a result of the electrical and mechanical losses inside the machine. Losses are high during starting or dynamic braking. Also, losses usually increase with increased loading. Cooling is necessary to continuously transfer the heat to a cooling medium, such as the air.

Main reasons for cooling system needed:

- Prevent wear and tear on electric motor.
- Poor power and torque if not kept cool.
- Overheating will cause short-circuit and breakdown.
- Bearings on motor will not cease and will remain sealed.

11.5 Welding machines (AC and DC)

Welding takes place at high temperatures and welding machine operate at high temperature conditions.

Main reasons for cooling system needed:

- Overheating will cause short-circuit and breakdown.
- Insulation materials could burn up and disintegrate if not cooled.
- Due high temperature and overheating will cause the resistance to increase.

11.6 Air cooling systems

Air cooling is a method of dissipating heat. It works by making the object to be cooled have a larger surface area or have an increased flow of air over its surface, or both.

An example of the former is to add fins to the surface of the object, either by making them integral or by attaching them tightly to the object's surface (to ensure efficient heat transfer).

In the case of the latter it is done by using a fan blowing air into or onto the object one wants to cool. In many cases the addition of fins adds to the total surface area making a heat sink that makes for greater efficiency in cooling.

In all cases, the air has to be cooler than the object or surface from which it is expected to remove heat. This is due to the second law of thermodynamics, which states that heat will only move spontaneously from a hot reservoir (the heat sink) to a cold reservoir (the air. The two different types of cooling systems are:

- Direct cooling
- Indirect cooling

11.6.1 Direct cooling

Motorcycle and aircraft engines are an example of direct air cooling. The heat generated from the engine is transferred from the cylinder to the fins that surround the cylinder block; this is shown in **Figure 11.1.** The air will blow through the fins and the heat is removed by the direct cold air.

Figure 11.1 Direct cooling system: Motor cycle engines

11.6.2 Indirect cooling

An example of an indirect cooling system is that of a motor car (see **Figure 11.2).**

The cooling system is made up of:

- The passages inside the engine block and heads,
- A water pump to circulate the coolant,
- A thermostat to control the temperature of the coolant,
- A radiator to cool the coolant,
- A radiator cap to control the pressure in the system,
- Some plumbing consisting of interconnecting hoses to transfer the coolant from the engine to radiator and
- Also to the car's heater system where hot coolant is used to warm up the vehicle's interior on a cold day.

A cooling system works by sending a liquid coolant through passages in the engine block and heads.

As the coolant flows through these passages, it picks up heat from the engine. The heated fluid then makes its way through a rubber hose to the radiator in the front of the car.

As it flows through the thin tubes in the radiator, the hot liquid is cooled by the air stream entering the engine compartment from the grill in front of the car. Once the fluid is cooled, it returns to the engine to absorb more heat.

The water pump has the job of keeping the fluid moving through this system of plumbing and hidden passages.

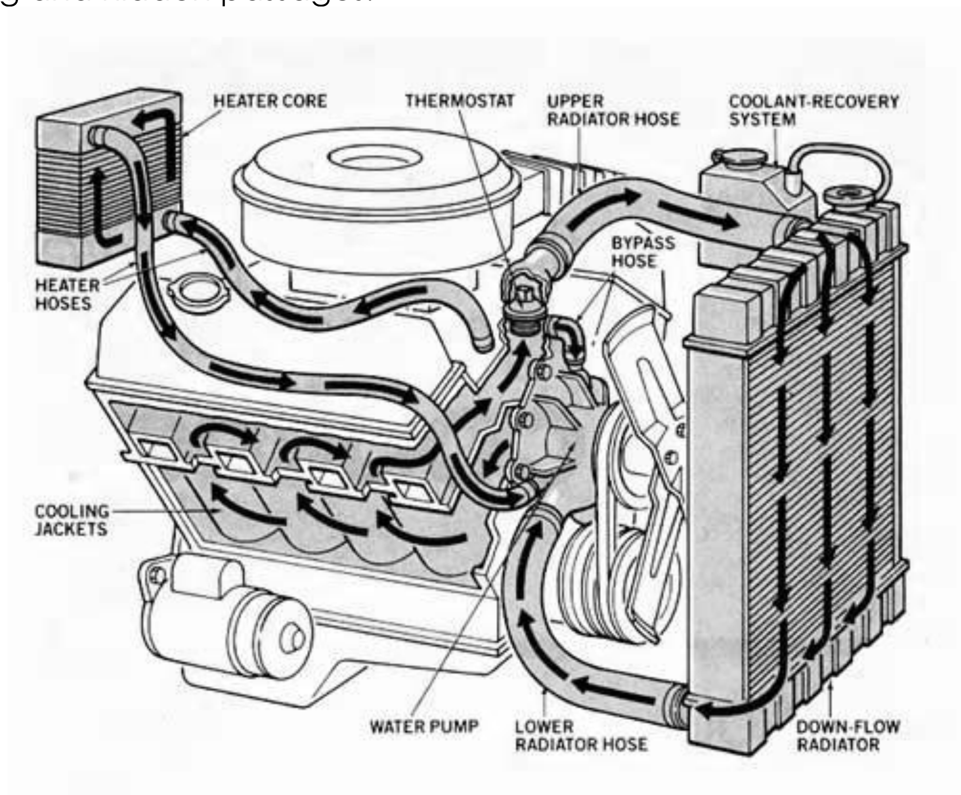


Figure 11.2 Indirect cooling system: Motor car engine

Advantages and disadvantages of direct cooling system compared to indirect cooling system are:

Advantages	Disadvantages
• Saves on both cost and mass. No radiator, water pump, hoses or water jackets are necessary.	• In the direct cooling system there is a greater distortion of components because operating temperatures are higher.
• There is no coolant that can 'boil' or 'freeze', whereas the water in the radiator of an indirect cooling	• Water jackets in indirect cooling systems absorb sound, reducing engine noise. Directly cooled

system can cause great damage to the engine if it boils or freezes.	engines are thus noisier.
• Because of the fewer parts needed in an engine using the direct cooling system, less servicing is required.	• A fan fitted to blow air over the engine in the direct cooling system, absorbs a certain amount of engine power, making the engine less efficient.

11.7 Water cooling systems
The two water cooling systems are:

- Thermosyphon cooling system
- Impeller assisted cooling system

11.7.1 Thermosyphon cooling system
Thermosiphon is a property of physics and refers to a method of passive heat exchange based on natural convection, which circulates a substance (liquid, or gas such as air) without the necessity of a mechanical pump.

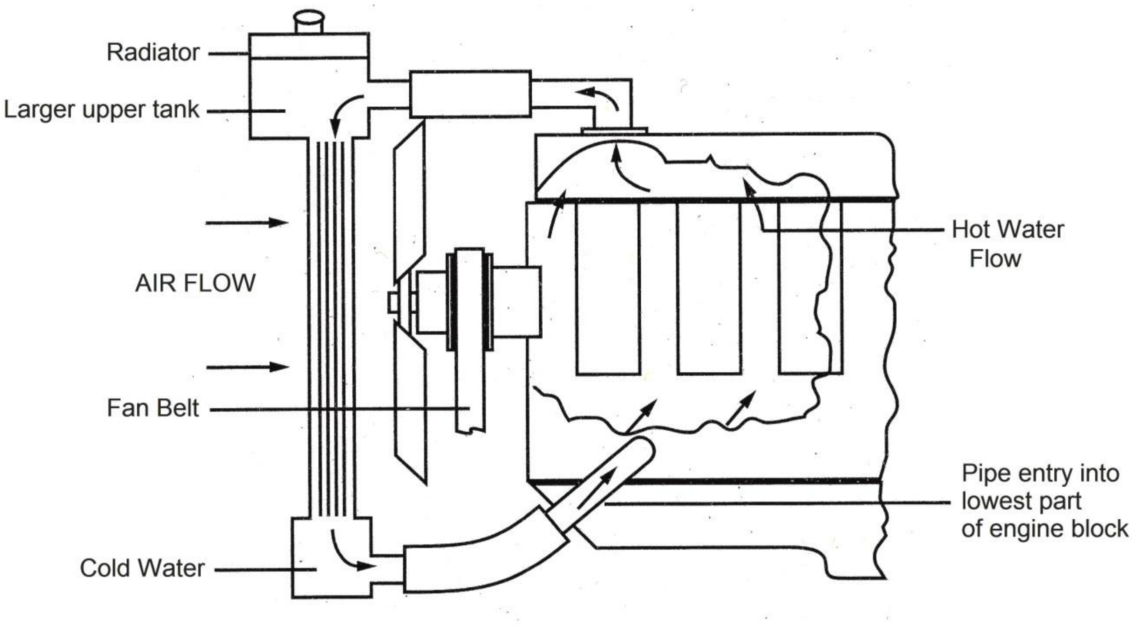


Figure 11.3 Thermosyphon cooling system on a motor car

Thermosiphoning is used for circulation of liquids and volitile gasses in heating and cooling applications, such as heat pumps, water heaters, boilers and furnaces. Thermosiphoning also occurs across air temperature gradients such as those utilized in a wood fire chimney, or solar chimney.

Early cars and motor vehicles used thermosyphon circulation to move cooling water between their cylinder block and radiator. As engine power increased,

increased flow was required and so engine-driven pumps were added to assist circulation (see **Figure 11.3**).

More compact engines then used smaller radiators and required more convoluted flow patterns, so the circulation became entirely dependent on the pump and might even be reversed against the natural circulation.

An engine cooled only by thermosiphon is also very sensitive to low coolant level i.e. missing only a small amount of coolant stops the circulation, a pump driven system is much more robust and can handle low coolant level.

11.7.2 Impeller assisted cooling system

The impeller assisted cooling system is a system of parts and fluid that work together to control an engine's operating temperature for optimal performance.

The system is made up of passages inside the engine block and heads, a water pump and drive belt to circulate the coolant, a thermostat to control the temperature of the coolant, a radiator to cool the coolant, a radiator cap to control the pressure in the system, and hoses to transfer the coolant from the engine to the radiator.

Figure 11.4 shows how the impeller assisted cooling system works)

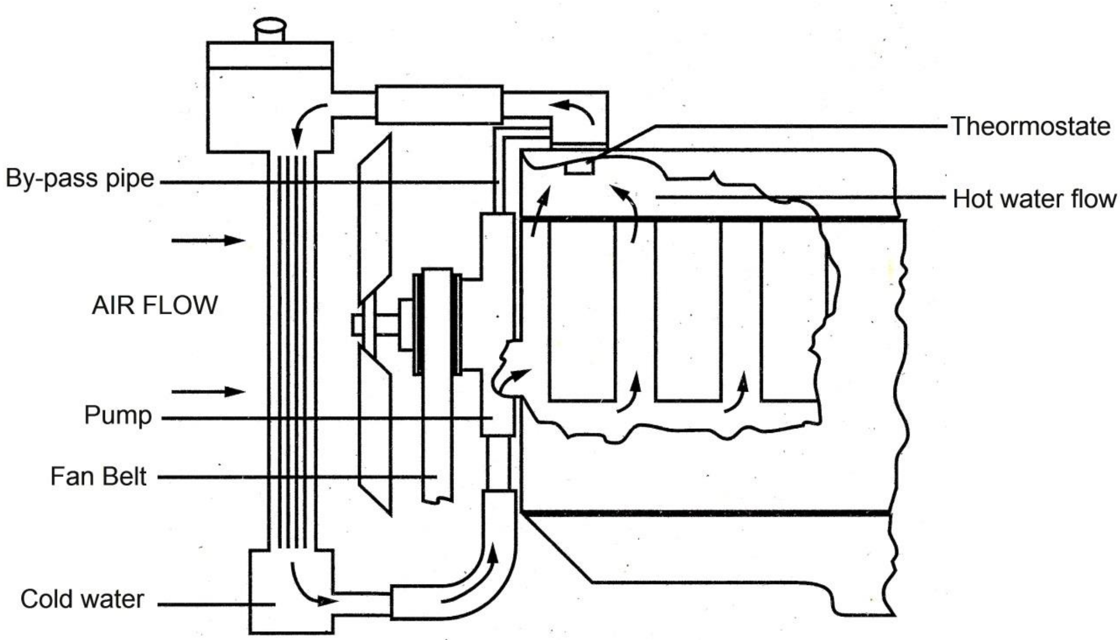


Figure 11.4 Impeller assisted cooling system

11.8 Heat exchanges

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall to prevent mixing or they may be in direct contact.

They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment.

The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

A Shell and Tube Exchanger consists of a number of tubes mounted inside a cylindrical shell. **Figure 11.5** illustrates a typical unit that may be found in a petrochemical plant.

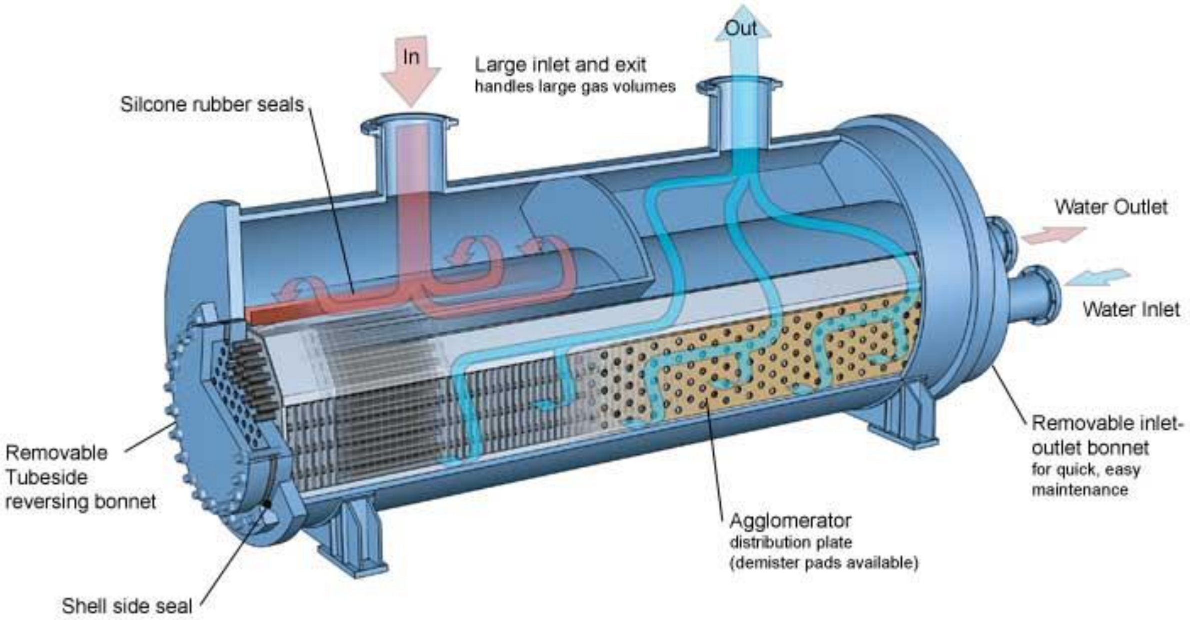


Figure 11.5 Heat exchanger cooling system

Two fluids can exchange heat, one fluid flows over the outside of the tubes while the second fluid flows through the tubes. The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement. The shell and tube exchanger consists of four major parts:

- Front end–this is where the fluid enters the tubeside of the exchanger.
- Rear end–this is where the tubeside fluid leaves the exchanger or where it is returned to the front header in exchangers with multiple tubeside passes.

- Tube bundle–this comprises of the tubes, tube sheets, baffles and tie rods etc. to hold the bundle together.
- Shell—this contains the tube bundle.

11.8.1 Different kinds of heat exchanger

There are so many kinds of heat exchanger, we will concentrate on just two:

- The shell and tube heat exchanger (see **Figure 11.6**)
- The plate heat exchanger (see **Figure 11.7**)

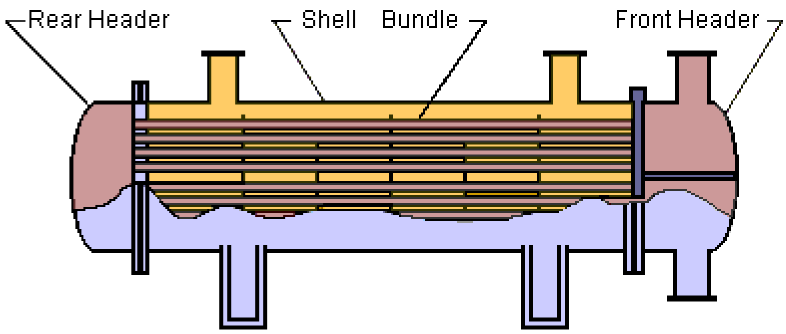


Figure 11.6 Shell and tube heat exchanger

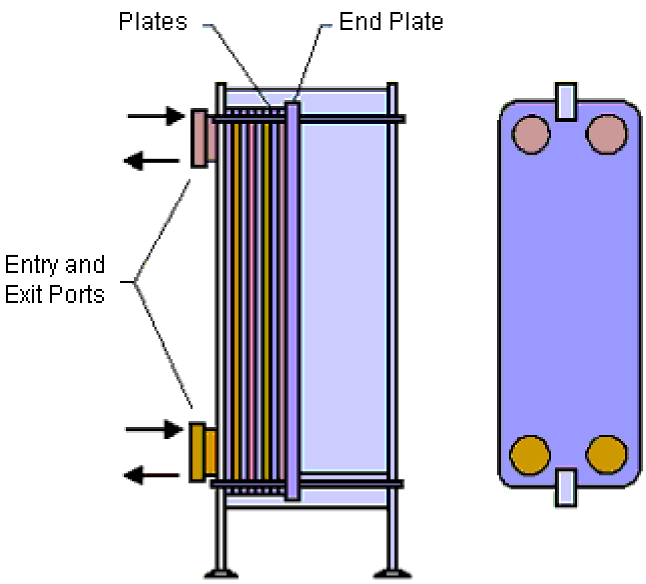


Figure 11.7 Plate heat exchanger

11.9 Oil coolers

Oil cooling refers to a process in which oil is used as a coolant. The oil is heated by the object it cools and then usually passes through a cooling unit such as an oil cooler, typically a type of radiator, or less commonly a gas de-compressor. The cooled oil flows back into the hot object to cool it continuously.

Oil cooling is most commonly used to cool high-performance motorcycle engines that are not water-cooled. The cylinder barrel is air-cooled, as is commonly used for motorcycles, but the cylinder head may require additional cooling.

As there is already an oil circulation system available for lubrication, this oil is also piped to the cylinder head and used as a liquid coolant. Compared to an oil system used solely for lubrication, oil cooling requires additional oil capacity, a greater flow rate through the oil pump and also oil-air oil cooler or larger oil cooler if one is already present.

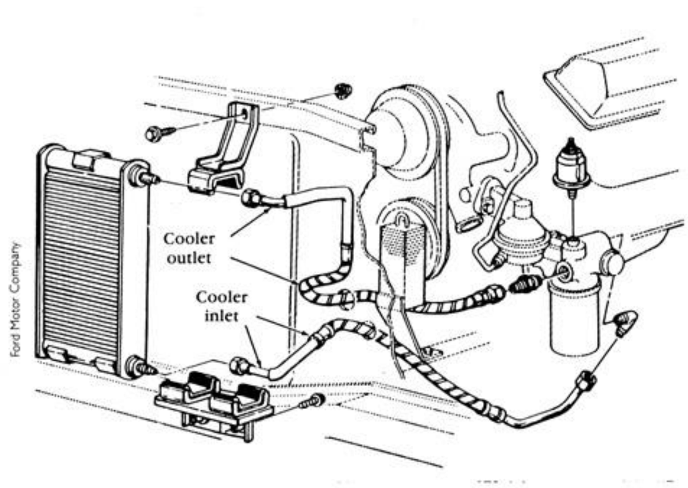


Figure 11.8 (a)Oil cooler fitted to engine

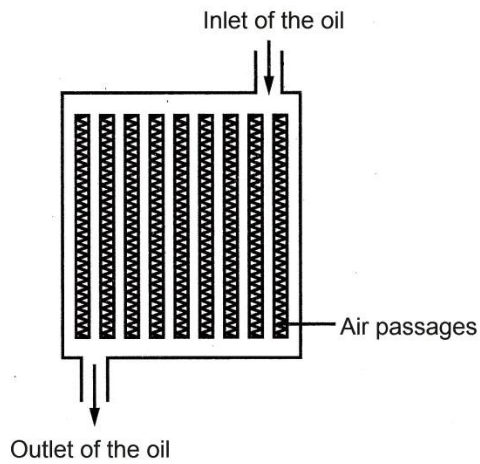


Figure 11.8 (b) Oil cooling system

11.10 Overcooling and overheating

In all combustion engines, a great percentage of the heat generated escapes through the exhaust, not through either a liquid cooling system or through the metal fins of an air-cooled engine. A certain percentage of the heat energy finds its way into the oil, which although primarily meant for lubrication, also plays a role in heat dissipation via a cooler.

Any problem, obstruction, restriction or modification in the cooling system of an engine will result in either overheating or over-cooling of same.

11.10.1 Overcooling

Engines are designed to function optimally at certain temperature range (usually between 80°C and 100°C). Anything lower indicates over-cooling, while above indicates overheating.

11.10.2 Overheating

Modern engines are designed to run within a narrow range of temperature. Because the metals used in an engine, expand at different rates, excess temperature causes a great many problems. Above a certain temperature, permanent engine damage will result.

Cylinder heads warp when subjected to overheating. Once the cylinder head warps, the sealing surface is no longer flat. A warped cylinder invites a leaking head gasket, but that is not the only problem.

Camshafts that pass through overhead cam cylinder heads also depend on the head being straight and true. A warped cylinder head may cause the camshaft to bind and cause damage. A binding camshaft may also cause the timing belt or chain sprocket to slip. When the sprocket slips, valve timing is altered.

Causes of overheating are:

- Poor air circulation
- Blockage or restriction in cooling air passage
- Leak in cooling air passage or pipe, no water
- Thermostat blockage or not working
- Incorrect engine tuning
- Faulty fan unit.

Result of overheating are:

- The most common cause of cylinder head cracking is overheating.
- When a vehicle overheats, it puts stress on all of its metal components, including the cylinder head, which is often at the center of the heat.
- This can cause the head gasket to fail, which may lead to cylinder head cracking as the components warp and pressure begins to leak.
- Lack of regular service and maintenance.

Preventing over heating:

- To prevent overheating make sure that your radiator is filled and in good condition, with a tightly sealed cap.
- Check to be certain that your engine thermostat is in good working order, and accurately reflecting the temperature.
- Make sure that you have no stretched belts or leaky hoses, and that the fan is working effectively.
- If your car does overheat, stop, turn off the engine, and allow it to cool completely before adding water.
- All drivers should properly maintain their vehicles to prevent overheating

Activity 11.1

1. Describe the need for cooling of the following:
    a) Internal combustion engines (petrol and diesel)
    b) Compressors
    c) Electric motors

d) Welding machines (AC and DC)

2. Discuss and compare the advantages and disadvantages of the following air cooling systems:
   a) Direct cooling
   b) Indirect cooling
3. Compare the advantages and disadvantages of the following water (coolant) cooling systems:
   a) Thermosiphon cooling system
   b) Impeller assisted cooling systems
4. Describe the principle and function of:
   a) Heat exchangers
   b) Oil coolers
5. Explain the causes, dangers and prevention of:
   a) Overcooling
   b) Overheating

Self-Check

I am able to:	**Yes**	**No**
• Describe the need for cooling of the following:		
o Internal combustion engines (petrol and diesel)		
o Compressors		
o Electric motors		
o Welding machines (AC and DC)		
• Discuss and compare the advantages and disadvantages of the following air cooling systems:		
o Direct cooling		
o Indirect cooling		
• Compare the advantages and disadvantages of the following water (coolant) cooling systems:		
o Thermosiphon cooling system		
o Impeller assisted cooling systems		
• Describe the principle and function of:		
o Heat exchangers		
o Oil coolers		
• Explain the causes, dangers and prevention of:		
o Overcooling		
o Overheating		

If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 12

Lubrication

Learning Outcomes
By the end of the module, you should be able to:

- Describe the need for lubrication of the following:
  - Bearings
  - Gearboxes (including reduction gearboxes)
  - Compressors
  - Internal combustion engines (petrol and diesel engines)
- Discuss the purpose of oil filtering
- Explain the working concept and applications of the following lubrication methods:
- Lubrication by mixing oil and petrol
  - Splash lubrication
  - Siphon wick lubrication
  - Sight feed lubrication (gravity feed)
  - Force-feed lubrication
  - Dry-sump lubrication
  - Manual feed

12.1 Introduction

Lubrication is the process, or technique employed to reduce wear of one or both surfaces in close proximity, and moving relative to each other, by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces.

12.2 The theory of lubrication

When two bearing surfaces are correctly lubricated, they are separated by a thin film of oil, which is probably 0,025mm thick. The object of lubricating surfaces is to eliminate the friction between them and to introduce a fluid whose reaction to friction is very small.

No matter how smooth the surfaces in contact are made, they always retain a certain amount of roughness and unevenness, and when one surface slides over the other, the roughness of the one interlocks with that of the other, and a force is required to start the movement and to keep it up.

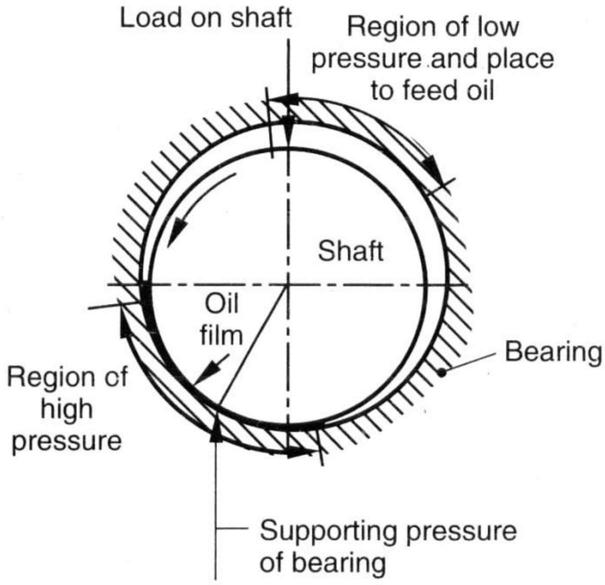
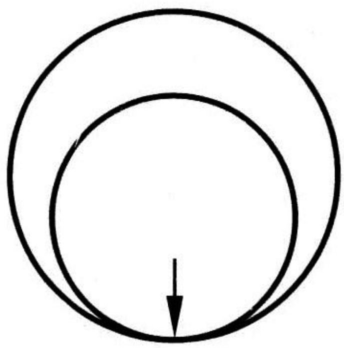
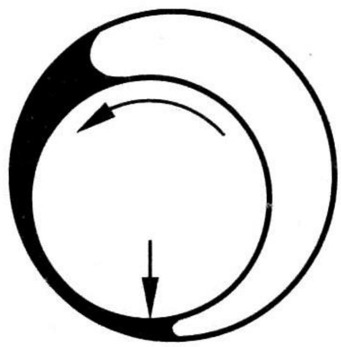


Figure 12.1 Action of journal bearing

The basic theory of hydrodynamic lubrication can be explained by showing how the lubricant inside the bearing behaves while the journal is stationary in its bearing, and through the various stages, until its normal running condition is reached (See **Table 12.1**)

Step 1 Under unidirectional loading the stationary shaft rests on the bottom of the bearing with metal-to-metal contact.	 Figure 12.2 Stationary shaft in bearing
Step2 As the shaft begins to rotate, the high friction between the contacting metal surfaces will cause the shaft to climb to the left. Oil will now be present at the point of closest contact, and the friction will decrease as the film is formed.	 Figure 12.3 Oil film forms as shaft begins to turn

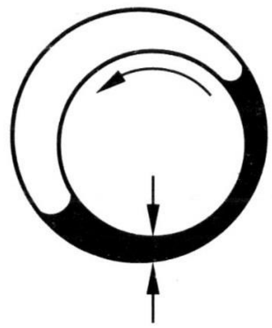
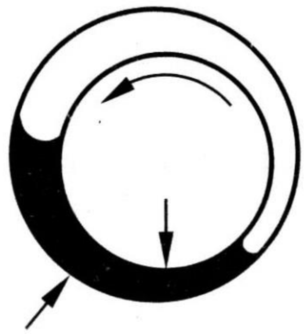
Step3 The force of the pressure area and the shaft load will cause the shaft to move down, past the vertical axis, and upwards on the opposite side to a point where the upward force of the pressure area is equal to the downward force of the load.	 Figure 12.4 Forces acting on the shaft
Step4 The shaft will remain in this position, separated from the bearing surface by a film of constantly changing oil, as long as the rotational speed is sufficient to maintain the pressure.	 Figure 12.5 Shaft separated from bearing surface by oil film

Table 12.1 The basic theory of lubrication

12.3 Hydrodynamic and hydrostatic lubrication

12.3.1 Hydrodynamic lubrication

Hydrodynamic lubrication means that the load-carrying surfaces of a bearing are separated by a relatively thick film of lubricant to prevent a metal-to-metal contact.

Hydrodynamic lubrication does not depend on the application of the lubricant under pressure. The main feature is to provide a sufficient quantity of lubricant at all times.

The disadvantage of this method is that the oil can leak from the bearing when the shaft is not rotating, and the metal-to-metal contact which then occurs could damage the bearing.

12.3.2 Hydrostatic lubrication

This is the term used when the pressure of the lubricant builds up as a result of an external source, such as an oil pump, supplying the pressure.

	**NEED FOR LUBRICATION** It is very important to lubricate bearings, gearboxes, compressors and internal combustion engines in order to ensure that their working life is trouble free.

12.4 Lubricants

An efficient lubricant is one which is able to hold its thickness of film and not be broken down under load or temperature. It must also not offer too much resistance in motion. The thicker the oil; the greater the fluid friction. The oil should therefore be "thick" enough so that the film is not broken, but "thin" enough not to induce excessive fluid friction.

Lubricant should also not gum up, since it loses its fluidity and collects dust and grit. This will increase friction and wear. The lubricant should also be without any acidity.

12.4.1 Choice of a lubricant

The following facts should be considered before deciding on the necessary lubricant for the job:

- Price of the lubricant
- Rubbing pressure between the two surfaces
- Rubbing speed of the two bearing surfaces
- Temperature to which the lubricant will be exposed
- Clearance between the two surfaces.

Rubbing pressure

The lubricant should have a good deal of body (viscosity or thickness) for heavy pressures, while less body is necessary for lighter pressures.

Rubbing speed

The lubricant should possess a good deal of fluidity for rapid speeds, while less fluidity is recommended for slow speeds, to prevent wastage.

Temperature

It is clear that to prevent ·the lubricant from being decomposed by heat, the flash point of the oil or grease should be greater than the maximum temperature which is reached.

Flash point

The temperature at which an oil or grease gives off inflammable vapours.

Burning point

The temperature at which the oil catches fire.

Cold point: the temperature at which any grade of oil or grease will freeze.

12.4.2 Classes of lubricants

Lubricants may be classified as follows:

- Solid

- Semi-solid
- Liquid.

Solid lubricants
Several types of solid lubricant are used, such as graphite, white lead, talc or soapstone, mica, etc. Graphite is the most widely used, because it is not affected by acid or heat.

Solid lubricants are used in bearings or such parts of machinery which are apt to be neglected from a lubricating point of view and particularly those which operate at low pressures and low speeds.

Semi-solid lubricants (grease)
Grease should only be used in special conditions, such as in cement mills, collieries, etc., where there is dust and dirt. It is used where spattering or leakage is undesirable, such as in food or sweet factories.

It is used on slow-running bearings under heavy loads. Rough, heavy machinery is generally lubricated with grease.

Liquid lubricants (oil)
Oils may be classified as animal, vegetable or mineral, according to their origin.

- **Animal oils:** lard, sperm oil, tallow, etc.
- **Vegetable oils:** castor oil, palm oil, olive oil, linseed oil, etc.
- **Mineral oils:** They occur under the surface of the earth in the form of crude petroleum. Special methods are used to refine and grade the oil. Mineral oils retain their properties well in air and, if they are pure, do not gum or dry up. A thin, light lubricant such as oil is used chiefly for high speeds and light loads.

12.4.3 Other uses of lubricants
Apart from reducing friction, lubricants have other uses such as:

- Prevention of corrosion
- Washing away of particles of dirt or dust
- Cooling of the bearing surface.

Ball and roller bearings do not usually require oil or grease for the purpose of forming a film between the balls (or rollers) and the tracks. In fact, the intensity of pressure at the points of contact is so high that no film could be maintained.

However, some lubricant is needed to prevent the highly-polished surfaces from rusting, and moreover, the lubricant will help to prevent dirt from entering the housing

12.4.4 Conditions of bearing and journal surface

No metal surface is really smooth. Highly honed areas when examined under a microscope, show "craggy peaks" and "deep valleys". If a journal is turned in an un-lubricated bearing, considerable friction will be encountered since "peaks" and "valleys" tend to lock together.

Friction creates heat, and heat in sufficient quantity will reduce the wearing properties of a bearing lining to a point where rapid deterioration, or even entire breakdown, of the lining may occur.

The insertion of a lubricant in the space between the journal and the bearing (oil clearance) will reduce friction by creating an oil film that will prevent metal-to-metal contact. The decrease in friction will allow the journal more freedom of motion and will effect a great reduction in the amount of heat generated.

12.4.5 Properties of the lubricant

The properties of cohesion and adhesion play an important part in fluid film formation.

Cohesion is the force that holds a substance together. For example, grease is more strongly cohesive than oil, and oil is more strongly cohesive than paraffin.

Adhesion is the ability of one substance to cling or stick to another material.
For example, oil strongly adheres to steel, while water does not. It is worthwhile considering what occurs in the oil film between a journal and bearing.

If it were possible to develop a film pressure with sufficient adhesive strength, the journal and bearing surfaces would be separated, and the journal would turn with no interlocking of the protruding parts.

Therefore, with the help of fluid motion, the journal would turn freely with a minimum of friction. The high adhesive strength of the oil would cause layers of molecules (very small oil particles) to cling to the two metal surfaces. The low cohesive strength of the lubricant would allow the molecules in the intermediate layers (**Figures 12.6 to 12.8**).

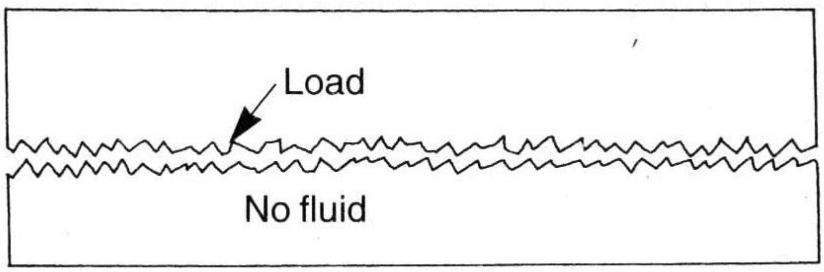


Figure 12.6 Enlarged view of “smooth” bearing surface

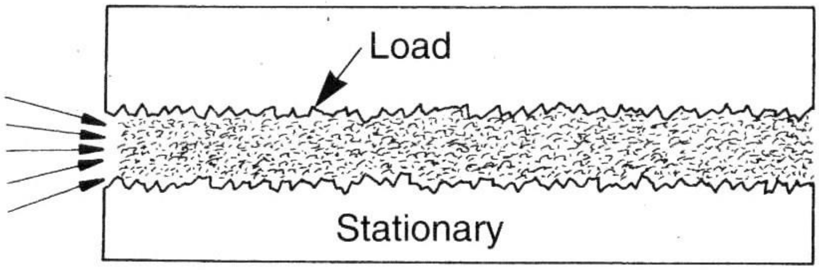


Figure 12.7 Addition of a lubricant

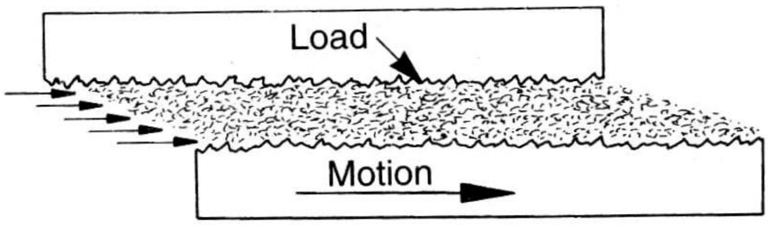


Figure 12.8 Action of the oil film layers

12.5 Lubrication

Let us now have look at why it is necessary to lubricate:

- Bearings
- Gearboxes
- Compressors and
- Internal combustion engines

12.5.1 Lubricating Bearings

Proper lubrication for rolling bearings is essential for reliable operation. Lubrication of bearings is provided for the following reasons:

- The lubricant provides a separating film between the bearing rolling elements, raceways and cages to prevent metal-to-metal contact.
- By controlling surface contact, the lubricant is able to minimize the effect of surface contact, namely undesired friction that otherwise would generate excessive heat, metal fatigue and wear.
- The lubricant must also prevent corrosion and contamination damage.
- Provides cooling and serves as a seal against dirt and moisture.

12.5.2 Lubrication of thrust bearings

The oil should be fed at the point of least pressure, which is at the smaller diameter of the thrust area. Centrifugal force will then fling the oil outwards, away from the shaft portion on to the thrust collars where it is needed most.

12.5.3 Lubrication of ball and roller bearings

The main functions of lubricants for ball and roller bearings are:

- To reduce friction between the various rolling parts of the bearing
- To assist in dissipating the heat generated within the bearing
- To protect the highly-polished working surfaces of the bearing from corrosion and rusting
- To assist in sealing the bearing against the entry of contaminants such as dust and moisture.

12.5.4 Oil lubrication of ball and roller bearings

Oil is generally more effective than grease, provided there are adequate sealing arrangements. It is applied particularly for high temperatures and high speed.

Viscosity depends on the design and function of the bearing. Oil bath and splash systems of application are used for slow and medium speeds, circulating systems 102 for medium speeds, and spray or mist application for high speeds.

12.5.5 Grease lubrication of ball and roller bearings

Grease is used as a lubricant where temperatures are not excessive and the sealing arrangements do not allow for satisfactory oil lubrication.

12.5.6 Lubrication for gearboxes

As a general rule, gearboxes are often lubricated by a simple combination of bath and or splash. Bath lubrication is the simplest method, where any component requiring the presence of oil (the expected lubricant in these cases) will be either partially or completely submerged in the sump oil. Bath lubrication is usually used in medium sized gearboxes where all shafts are on one horizontal line and the reducer remains horizontal.

Providing proper lubrication for gearboxes is essential for reliable operation.
Lubrication of gearboxes is provided for the following reasons:

- To provide oil film at the contacting surfaces of all working components to reduce friction and wear.
- The oil serves to remove and dissipate heat from where it is generated, preventing gearing component temperatures from rising to excessive levels.
- Other lubrication functions include the transfer and or removal of wear particles, as well as the filtration of rust and corrosion and any other undesirable contaminants.
- Prevents corrosion of gear teeth surfaces
- Absorbs vibration and shocks within the gearbox.

12.5.7 Lubrication for compressors

Nearly all compressors require a form of lubricant to either cool, seal or lubricate internal components. Providing proper lubrication for compressors is essential for reliable operation. Lubrication of compressors is provided for the following reasons:

- Long life without need for replacement
- Prevention of acidity, sludge, deposit formation
- Excellent protection against rust and corrosion, even during shutdown
- Easy filterability without additive depletion
- Prevents ware due to low-friction film between rubbing surfaces
- Protects against atmospheric contamination

12.5.8 Lubrication for internal combustion engines

Lubrication plays a key role in the life expectancy of an engine. Without oil, an engine would succumb to overheating and seizing very quickly. Lubricants help mitigate this problem, and if properly monitored and maintained, can extend the life of your motor.

Providing proper lubrication for internal combustion engines is essential for reliable operation. Lubrication of internal combustion engines is provided for the following reasons:

- Provides cooling and serves as a seal against dirt and moisture.
- Excellent protection against rust and corrosion.
- To provide oil film at the contacting surfaces of all working components to reduce friction and wear.
- Absorbs vibration and shocks within the engine

12.6 Overheated bearings

An overheated bearing may be caused by various factors, such as:

- The halves of the bearing may be adjusted too closely;
- The journal may be oval
- The bearing surfaces may be scored, grooved or even cracked
- The temperature of the surrounding atmosphere may be too high, such as in an engine or boiler room
- The load on the bearing may be too high or the shaft may turn at too high a speed
- The method of applying lubricant to the bearing may be wrong
- Treatment of hot bearings where machine or engine cannot be stopped immediately.

When it is not practicable to stop the rotating part (as in the case of marine engine bearings), it is quite normal practice to turn a stream of soapy water on the heated part.

Remedies such as salt and brick dust have also proved quite successful in very serious cases of overheated large bearings. The idea is to grind the rough parts away rapidly. The brick dust may be mixed with thick oil in order to obtain a thick film.

12.7 Oil filtration

An oil filter is a filter designed to remove contaminants from engine oil, transmission oil, lubricating oil, or hydraulic oil.

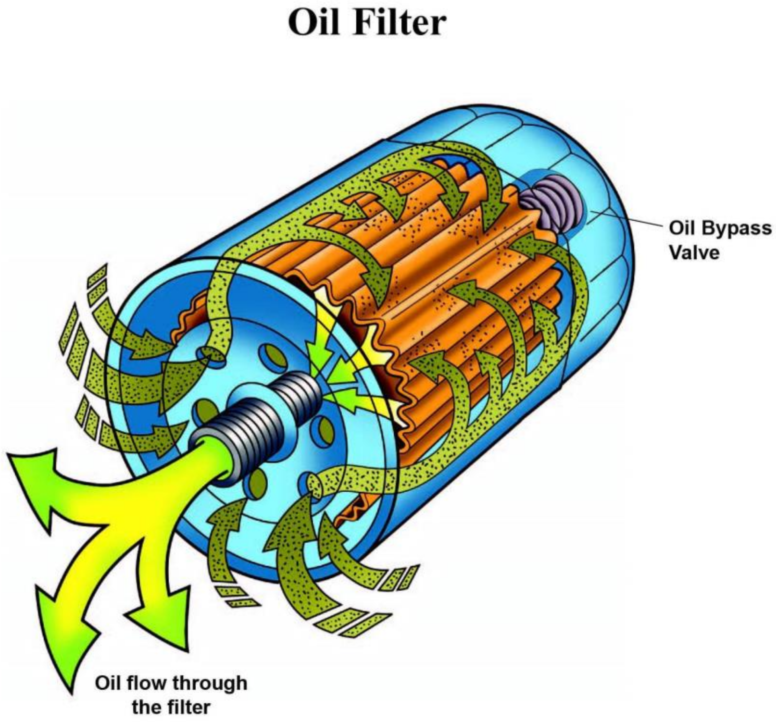


Figure 12.9 Oil filter

Oil filters are used in many different types of hydraulic machinery. A chief use of the oil filter is in internal-combustion engines in on- and off-road motor vehicles, light aircraft, and various naval vessels. Other vehicle hydraulic systems, such as those in automatic transmissions and power steering, are often equipped with an oil filter.

Gas turbine engines, such as those on jet aircraft, also require the use of oil filters. Aside from these uses, oil production, transport, and recycling facilities also employ filters in the manufacturing process.

The oil filter's job is to remove oil contaminants. It sifts out the solid particles while allowing the oil to flow unrestricted through the engine. When the oil filter becomes full or "clogged," the oil and contaminants will flow around the filter. This "by-passing" is a safety mechanism.

As far as your engine is concerned, dirty oil is better than none at all. However, when by-passing occurs, contaminants head straight for the engine where they can eventually cause permanent damage. Studies also show that fuel economy and emissions are adversely affected during by-passing.

12.8 Lubricating methods and devices

These devices are used for supplying a controlled amount of oil or grease to machine bearings, gears, engine parts, etc.

Some of them are quite simple in construction, while others, which are intended to give a more definite and better-regulated supply, are more complicated. The five general methods of lubrication are described in the paragraphs that follow.

12.8.1 Gravity feed

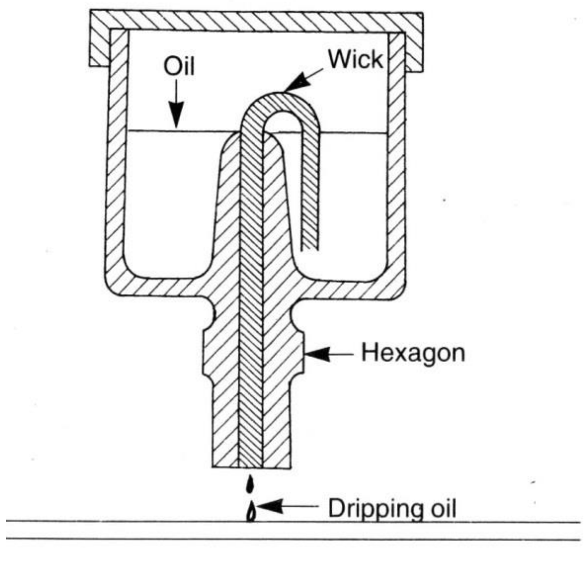
There are many examples of this method, but the siphon-wick and the sight-feed lubricator are the most common.

- **Siphon-wick lubricator**

This lubricator is filled with oil to within 10mm of the top of the central tube, and the wick soaks up the oil by capillary action until it is saturated. The part of the wick inside the tube is carried on a piece of twisted wire which compresses the wick and reduces its capacity to retain the oil.

Gravity and vibration cause the oil to drip off the lower end of the wick within the tube. The amount of lubricant may be adjusted by changing the size of the wick or by tightening the twisted wire which encloses it.

More strands of the wick are necessary in cold weather than in hot weather since the oil is thicker when cold. (See **Figure 12.9**)



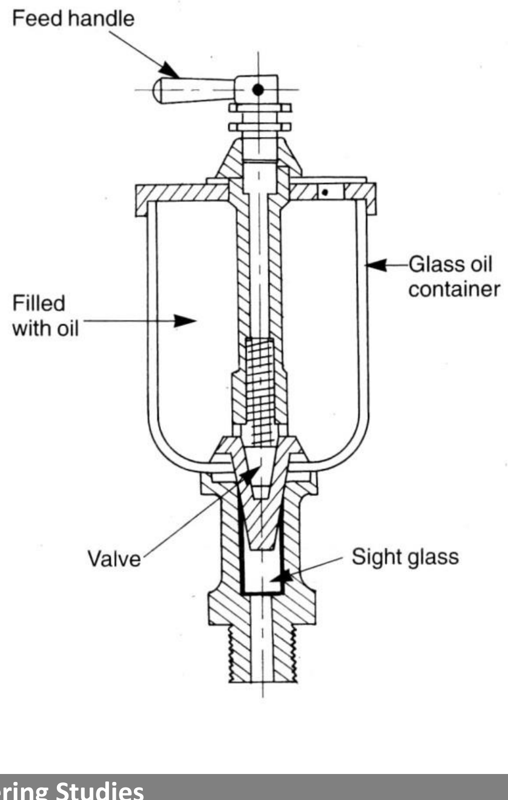


Figure 12.9 Siphon-wick lubricator

Figure 12.10 Sight-feed lubricator

- **Sight-feed lubricators**

This is a device which shows the lubricant passing through a glass tube drop by drop.
The oil flow is regulated by means of the screwed sleeve immediately below the feed handle. In **Figure 12.10** the handle and needle valve are pulled into the closed position and the screwed sleeve is just clear of the handle.

The adjustment of the flow is made when the handle is vertical, and the round knurled nut is then used to lock the sleeve in the desired position. A filling hole is provided in the metal cap and dust is kept out by means of a sliding cover.

12.8.2 Mechanically-operated sight-feed lubricator
Figure 12.11 shows how the lubricant is forced to the bearing by an eccentric shaft and plunger. The eccentric shaft is connected to some suitable part of the machine. The lubricant is fed in as soon as the engine starts; and the oil is fed in direct proportion to the speed of the engine. No lubricant is fed when the machine is idle.

12.8.3 Needle-lubricator
It generally consists of an inverted globe shaped glass vessel, with a stopper of wood or other suitable material inserted into its neck. The needle passes through this stopper, which is provided with a slight clearance in the hole. The needle touches the shaft and is long enough to reach about two-thirds the length of the vessel (see **Figure 12.12**).

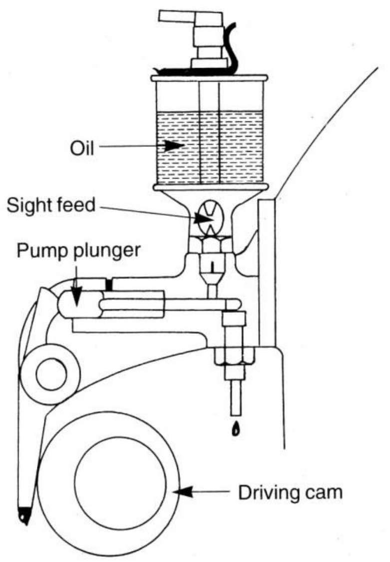


Figure 12.11 Mechanically operated sight-feed lubricator

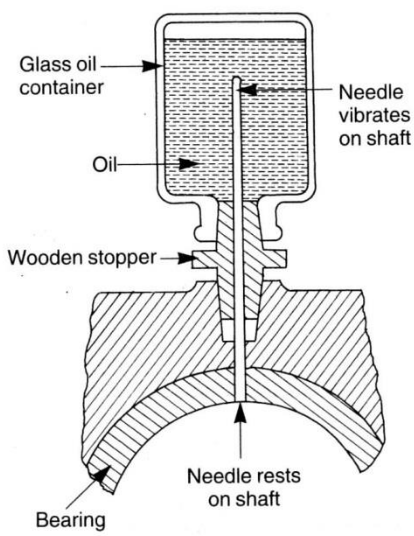


Figure 12.12 Needle lubricator

When the shaft is running, the needle vibrates, and this enables the oil to tiow down through the small annular space between the needle and the stopper.

When the shaft is stationary, the oil ceases to flow.

The oil is retained by capillary action and the flow can be increased by running a file across the needle – a touch being enough to cause a considerable increase in flow.

12.9 Grease lubrication

Only those plain bearings which move at slow speeds and do not carry heavy loads should be lubricated with grease, and care should be taken not to force grease into oil nipples or oil holes.

12.9.1 Stauffer grease cup

The knurled or fluted cap is filled with grease and screwed down. This forces grease to the bearing surface. It may be refilled by unscrewing the cap. (See **Figure 12.13**)

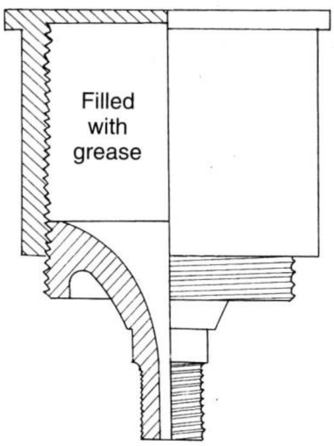


Figure 12.13 Stauffer grease cup

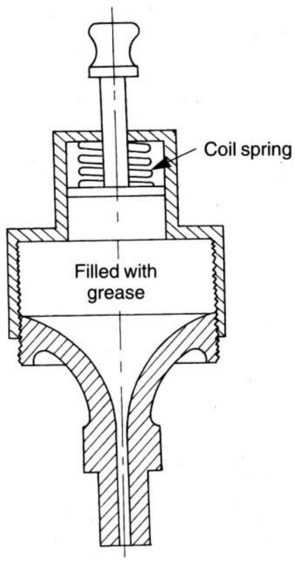


Figure 12.15 Tell-tale grease cup

12.9.2 Tell-tale grease cup

The fluted upper cup carries a spring-loaded piston. It has a smaller diameter than the cap, thus preventing the spring action from emptying the cap of its grease.

The spring-loaded piston pushes the grease on to the part to be lubricated. The height of the knob above the cap is a guide to when it is necessary to refill the lubricator with grease. (See **Figure 12.14**)

12.10 Splash lubrication

With this form of lubrication a stream of oil is continually splashed around the parts requiring it. Splash lubrication is generally used in the following ways: ring oiling, oil bath with worm, splashing oil on to cylinders of petrol engines, etc.

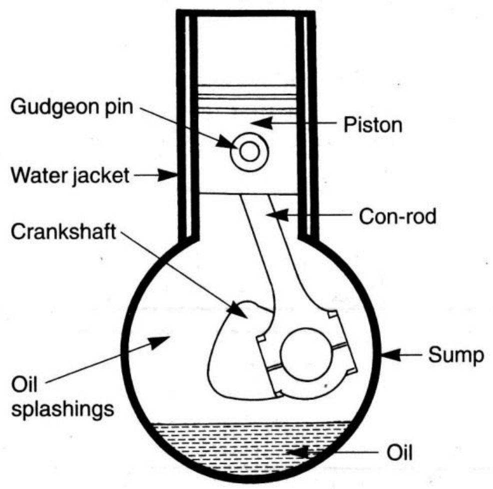


Figure 12.15 (a) Oil “splash: system

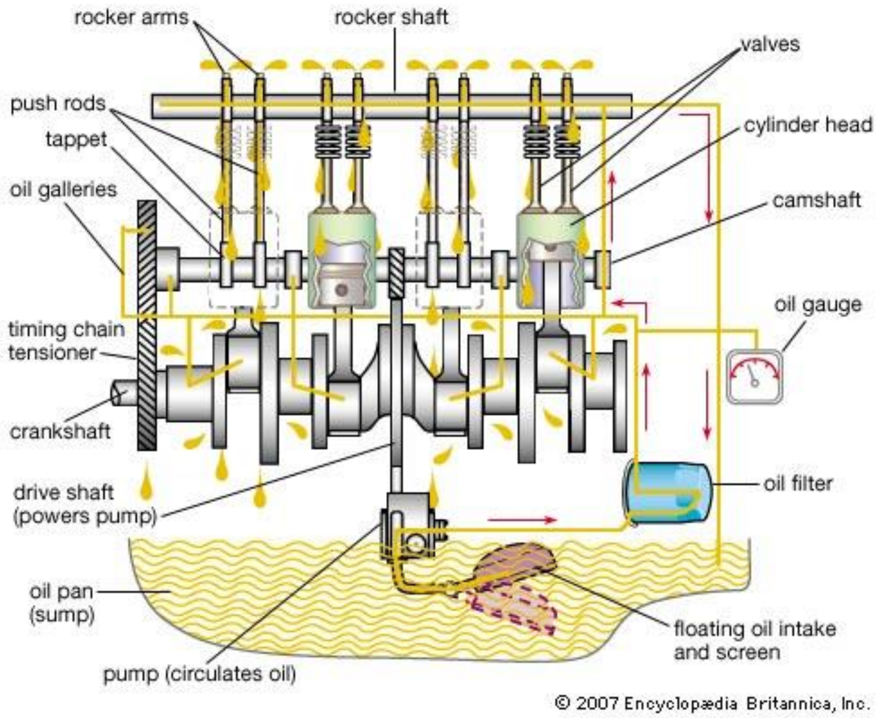


Figure 12.15 (b) Splash lubricating system in internal combustion engine

12.10.1 Oil ring lubricator

The rings are in rolling contact with the shaft and dip into the oil at their lowest part. In operation, oil is brought up by the rings which revolve due to frictional contact with the shaft.

In this manner the oil is brought up to the top of the bearing and distributed along the shaft, and then gradually drips back into the oil sump. A drain cock is provided in the sump to periodically drain the oil away to allow cleaning of the sump and refilling with clean oil. It is quite clear that no oil will be supplied to the shaft when it is stationary. (See **Figure 12.16**)

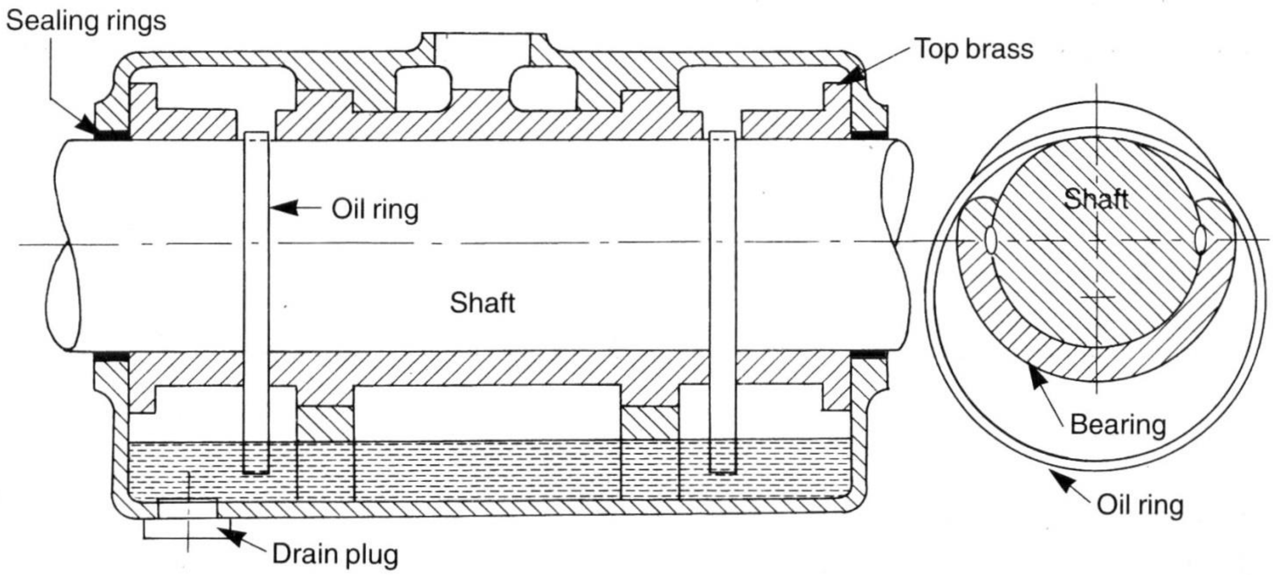


Figure 12.16 Oil ring lubricator

12.10.2 Splashing oil on to cylinders of a petrol engine

The cylinders and many other parts of the petrol engine obtain their oil by the "splash" system. Oil is scooped up by the connecting rods as they move around and a mist of oil vapour fills the entire inside of the engine to lubricate the various parts

12.10.3 Worm and worm-wheel lubrication

The worm is submerged in the oil bath and picks up some of the oil to lubricate the bearings as well as the meshing faces of the drive (**Figure 12.17**).

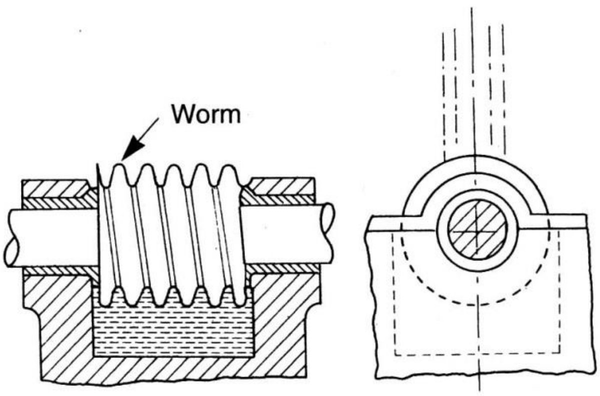


Figure 12.17 Oil bath

12.11 Forced or pressure-feed lubrication

An oil or grease gun can be used. The hole leading to the bearing surface is fitted with a nipple on to which the oil gun is pressed and the lubricant forced to the bearing.

- A hand pump may be used to force the oil to the bearing surfaces at intervals by the machine operator, say twice a day.
- Oil can be delivered to all bearing surfaces by an oil pump, driven by the machine.

12.13 Full-pressure lubricating system

The full-pressure system (**Figure 12.18**) lubricates the vital parts of the engine under full pressure from the oil pump. The parts include the main and connecting rod bearings, camshaft bearing and piston pin bushings.

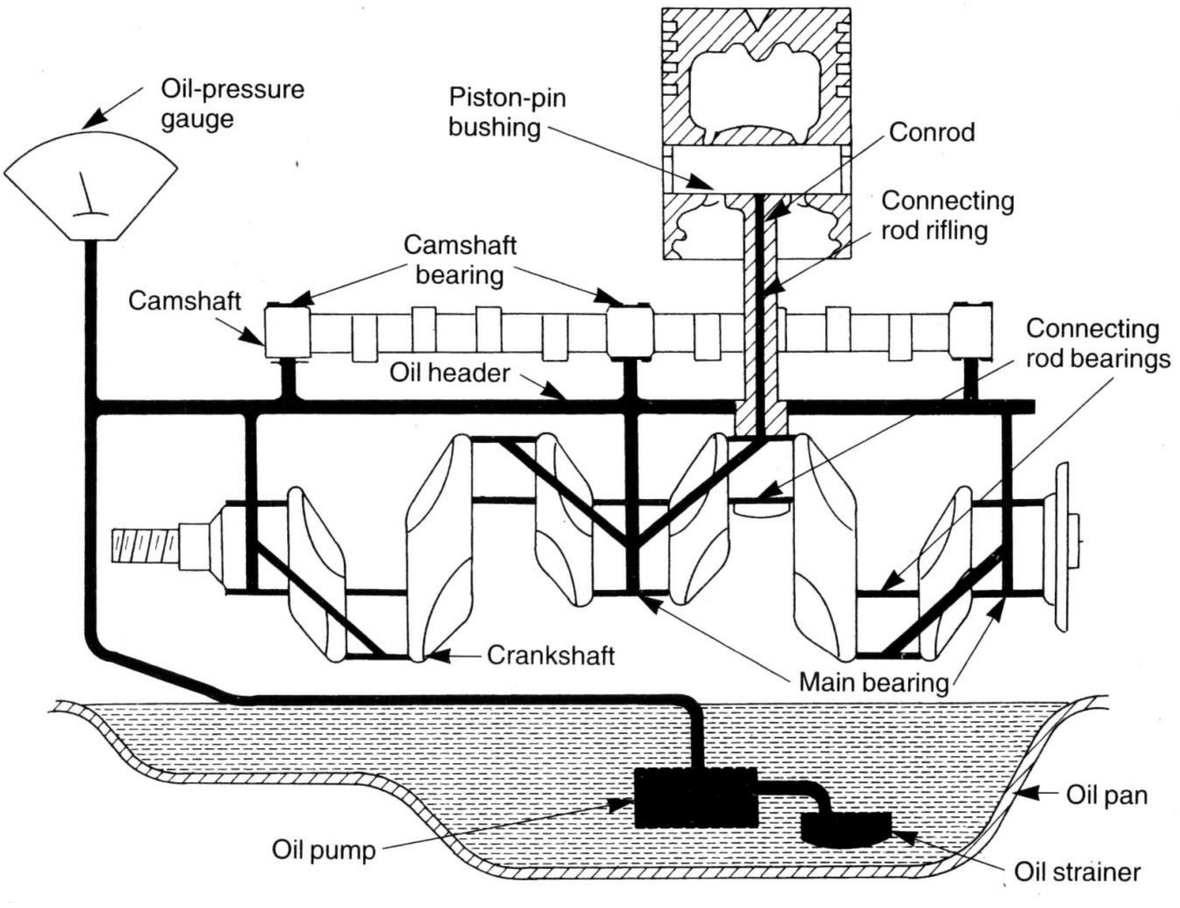


Figure 12.18 Full-pressure lubricating system

12.14 Lubrication of sliding surfaces

The lubrication of machine parts such as engine cross-heads, shaping-machine tables and rams, where the motion is usually of a reciprocal nature, is generally more difficult than that of journals. A method of fulfilling this task is shown in **Figure 12.19**, where the oil is supplied from the sight-feed lubricator.

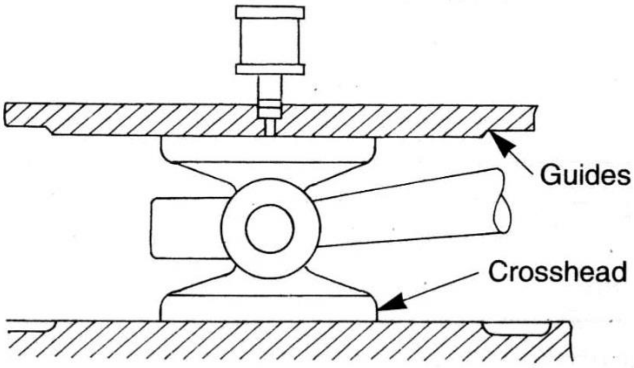


Figure 12.19 Lubricator for reciprocating motion

12.15 Lubrication of reciprocating steam

12.15.1 Steam cylinders

The function of a steam-cylinder lubricant is to form an oil film which will reduce friction and wear of sliding surfaces and prevent leakage of steam past valves, pistons and glades. The normal method of introducing the oil

12.15.2 Lubrication of steam turbines

Steam turbines are provided with pressure-circulating systems. The oil should not only provide adequate and dependable lubrication, but should also serve as a coolant and protect the turbine parts against rust.

Activity 12.1

1. State THREE precautions to keep in mind when selecting the correct lubricant.
2. Give FOUR important aspects to consider before selecting a lubricant for a specific task.
3. Lubricating oil can be divided into three classifications. Give the names of the THREE classifications
4. What do you understand by the following terms?
   a) Cohesion
   b) Adhesion
5. Explain what is meant by *cohesion of oil* and give ONE example of cohesion.
6. What is the purpose of lubricating surfaces?
7. Name THREE types of liquid lubricants.
8. Describe the need for lubrication of the following:
   a) Bearings
   b) Gearboxes (including reduction gearboxes)
   c) Compressors
   d) Internal combustion engines (petrol and diesel engines)
9. Discuss the purpose of oil filtering

10. Explain the working concept and applications of the following lubrication methods:
    a) Lubrication by mixing oil and petrol
    b) Splash lubrication
    c) Siphon wick lubrication
    d) Sight feed lubrication (gravity feed)
    e) Force-feed lubrication
    f) Dry-sump lubrication
    g) Manual feed

Self-Check

I am able to:	**Yes**	**No**
• Describe the need for lubrication of the following:		
o Bearings		
o Gearboxes (including reduction gearboxes)		
o Compressors		
o Internal combustion engines (petrol and diesel engines)		
• Discuss the purpose of oil filtering		
• Explain the working concept and applications of the following lubrication methods:		
o Lubrication by mixing oil and petrol		
o Splash lubrication		
o Siphon wick lubrication		
o Sight feed lubrication (gravity feed)		
o Force-feed lubrication		
o Dry-sump lubrication		
o Manual feed		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 13

Cranes and Lifting Machines

Learning Outcomes
By the end of the module, you should be able to:

- Name and, using plain line sketches, describe the different types of cranes in use
- Name and explain important inspection elements on cranes
- Describe, and using plain line sketches, hand signals used for crane operators in their control operations
- Explain the basic operating principles of a crab or hoist unit
- Describe, and using plain line sketches, an automatic brake used on this type of crane
- Describe what the terms "cross traverse" and "long travel" mean, regarding cranes
- State the main function, and capacity, of wharf cranes
- Name and describe the principle, or main parts of wharf cranes
- Describe slewing and trolley movement of tower cranes (building industry)
- Name the various parts and rules to be observed regarding mobile cranes
- Describe travelling of mobile cranes

13.1 Introduction

For centuries hoisting apparatus has been in use to raise, lower and transport heavy loads over short distances. Today, there are travelling cranes in steel mills and power plants, as well as hammerhead cranes in naval shipyards, all capable of lifting hundreds of tons.

A **crane** may be defined as a device or machine for lifting loads by means of a rope. A **crane** is a multi-purpose machine. Its main use is to move or displace heavy loads and loads that are difficult to handle because of their size.

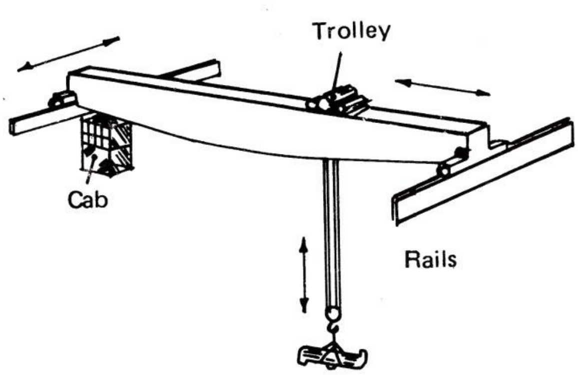
The use of cranes has greatly increased in the construction industry due mainly to the need to raise the large and heavy prefabricated components often used in modern structures.

The range of cranes available is very wide and therefore actual choice must be made on a basis of sound reasoning, overall economics, capabilities of cranes under consideration, prevailing site conditions and the anticipated utilisation of the equipment.

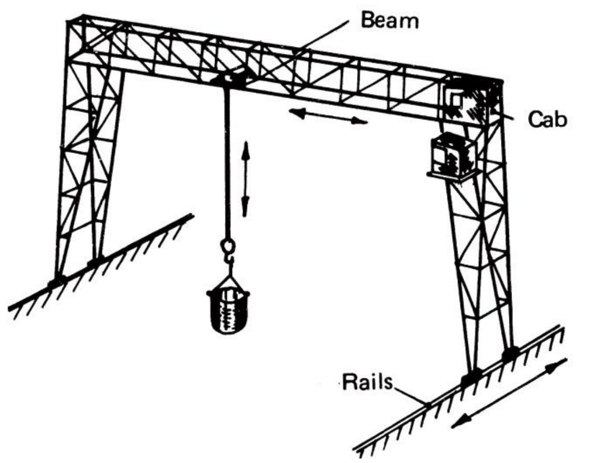
The simplest crane of all consists of a single-grooved wheel, over which the rope is passed, suspended from a scaffold or beams and is called a gin wheel.

The gin wheel is manually operated and always requires more effort than the weight of the load to raise it to the required height. It is only suitable for light loads as, for example, a bucketful of mortar and is normally only used on very small contracts.

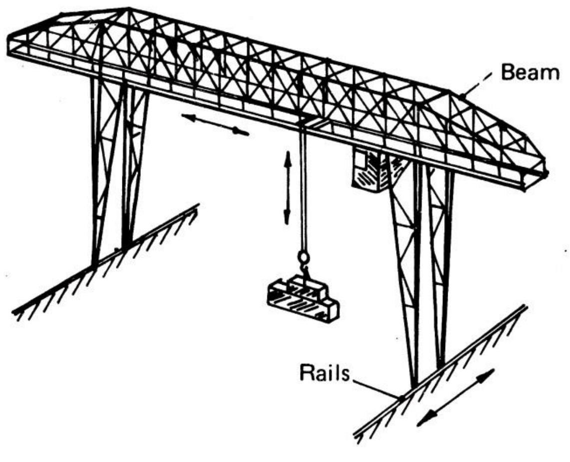
Cranes consist of a variety of designs, some of which are shown in **Figure 13.1**



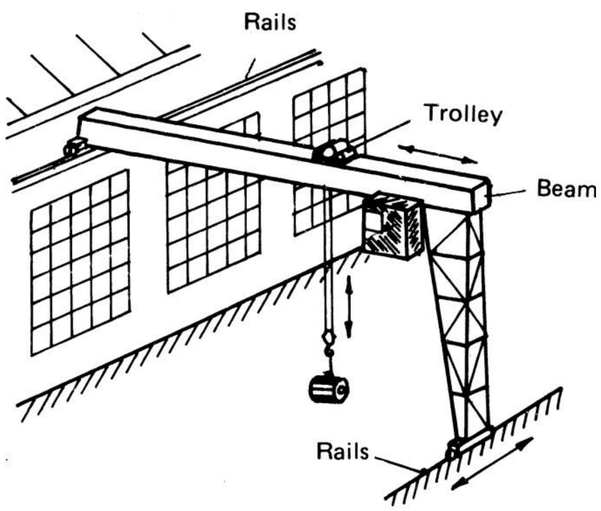
(a) Overhead crane



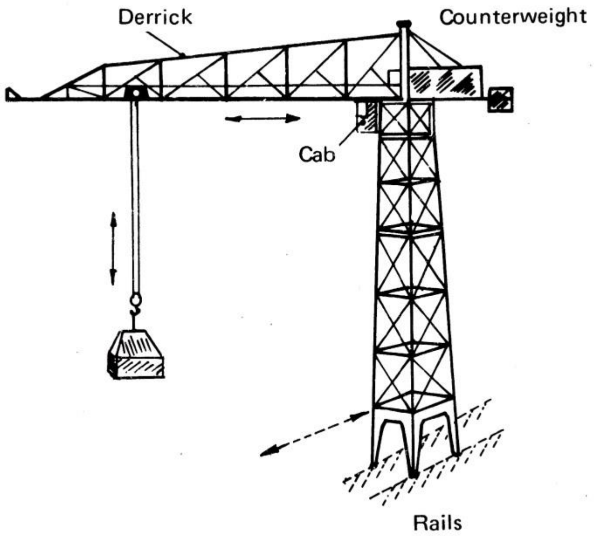
(b) Gantry crane



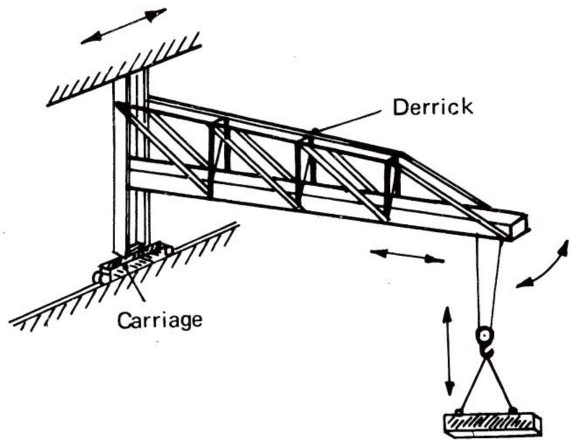
(c) Cantilever gantry crane



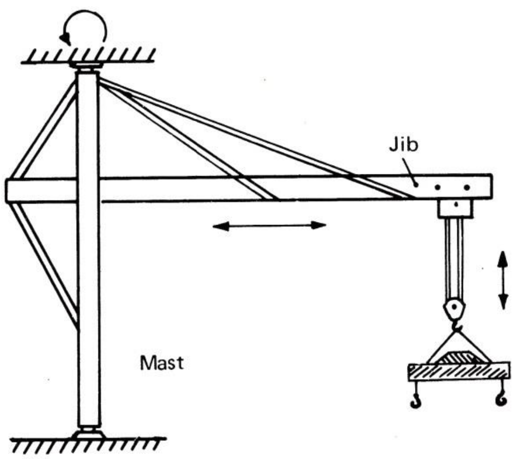
(d) Semi-gantry crane



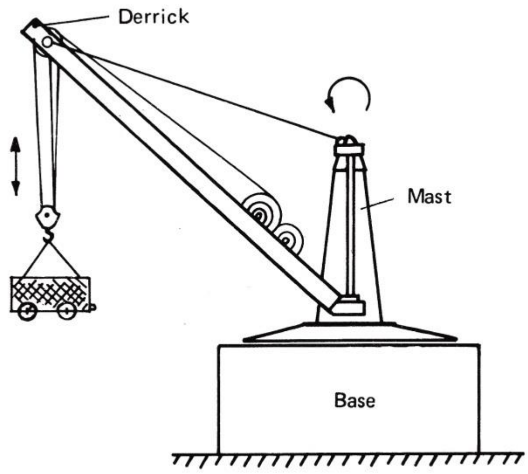
(e) Hammerhead crane



(f) Wall crane



(g) Jib crane



(g) Jib crane

Figure 13.1 Types of cranes

To obtain some mechanical advantage the gin wheel can be replaced by a pulley block which contains more than one pulley or sheave; according to the number and pattern of sheaves used the lesser or greater is the saving in effort required to move any given load.

Another useful but simple crane which can be employed for small, low rise structures is the scaffold crane which consists of a short jib counterbalanced by the small petrol or electric power unit. The crane is fastened to a specially reinforced scaffold standard incorporated within the general scaffold framework with extra bracing to overcome the additional stresses as necessary. The usual maximum lifting capacity of this form of crane is 200 kg.

Apart from these simple cranes for small loads most cranes come in the more recognisable form. Subdivision of crane types can be very wide and varied but one simple method of classification is to consider cranes under THREE general headings:

1. Mobile cranes.
2. Static or stationary cranes.
3. Tower cranes.

13.2 General purpose uses and of cranes

The general purpose and use of cranes are:

- Vertical movement and displacement. A crane can lift a load from the ground to the roof of a building.
- Horizontal movement and displacement. A crane can lift a load from one spot in the workplace and move it to a different spot in the same workplace.
- To transport loads from one site to another.
- To load and unload railway trucks, ships, containers or trucks.

The FOUR types of cranes that we will discuss in this module are:

1. Overhead travelling cranes,
2. Tower cranes,
3. Wharf cranes, and
4. Mobile cranes.

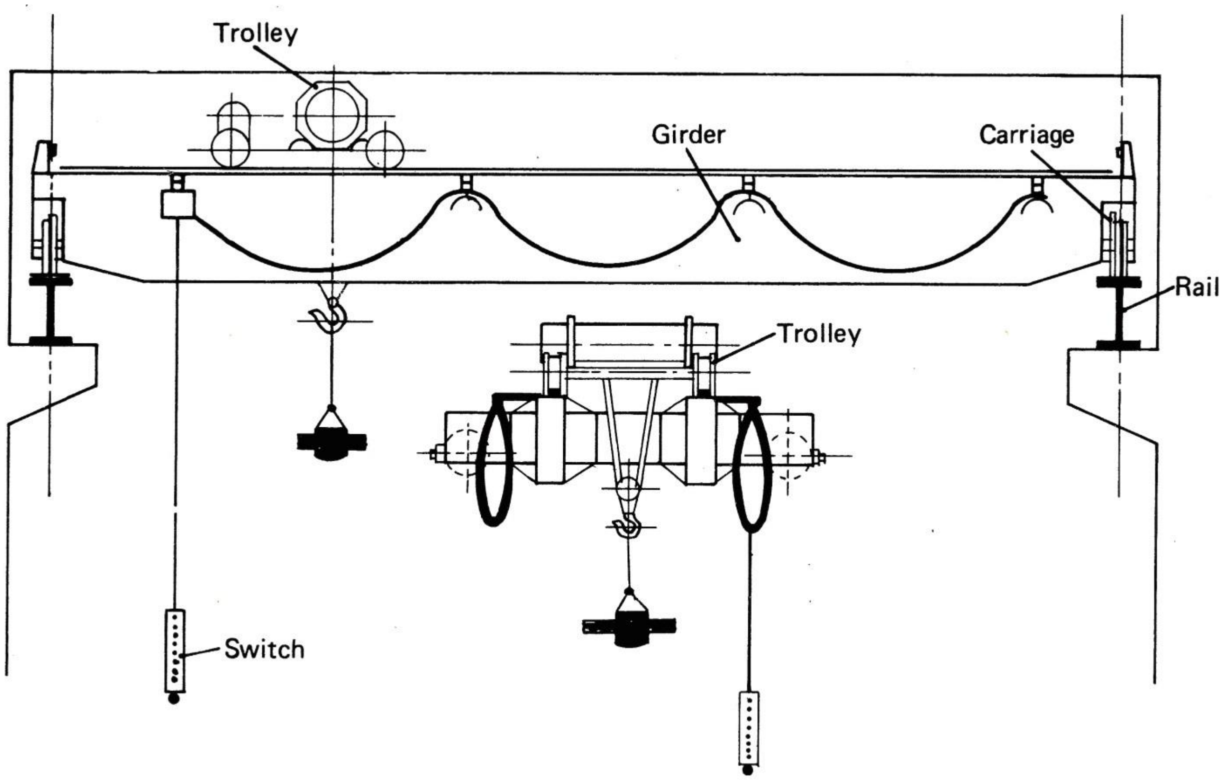
13.3 Overhead travelling cranes

Overhead electric travelling cranes are basically similar in design, all having to perform the same functions. They must be able to hoist a load and travel with it longitudinally or transversely.

These operations are commonly termed:

- Hoisting,
- Long-travel and
- Cross-travel or traverse.

	Hoist motion where the crane lifts or hoists a load. **Long travels** where the crane transports a load longitudinally by moving along its rails or track. The load can thus be transported along the length of the workshop. **Cross travel** where the crane can transport a load in a transverse direction, along the length of the frame of the crane by the trolley.



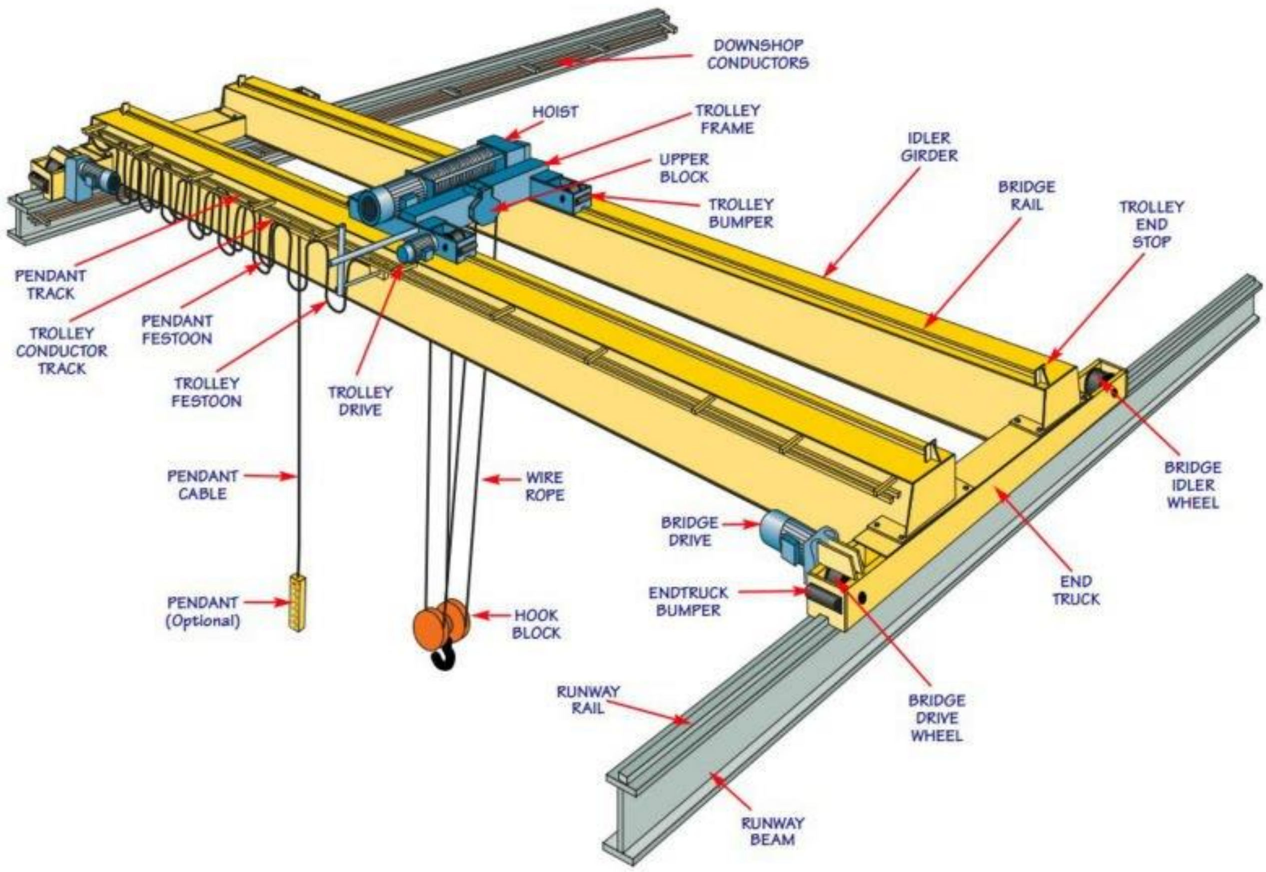


Figure 13.2 Overhead travelling crane

	DID YOU KNOW
	An **overhead crane**, commonly called a bridge crane, is a type of crane found in industrial environments. An overhead crane consists of parallel runways with a traveling bridge spanning the gap. A hoist, the lifting component of a crane, travels along the bridge. If the bridge is rigidly supported on two or more legs running on a fixed rail at ground level, the crane is called a gantry crane.

The advantages and disadvantages of an overhead travelling crane are:

Advantage	Disadvantages
• It is a very versatile type of crane. It can move a load in any direction, up or down, across or along a workshop.	• The working area is limited to the length of the rail or workshop and the span of the crane.
• Overhead travelling cranes can be used to assist in the assembling process of a job.	• We can use the overhead crane only in the workshop or place where it is installed.
• It can be designed to carry extra heavy loads.	• Each overhead travelling crane has a limited load capacity. If a load exceeds this capacity, we cannot bring in a larger travelling crane.
• If we change the number of drops, we can obtain different speed ratios and mechanical advantages.	
• Because of the height of the d river's cabin, the driver has a clear view most of the time.	
• This type of crane can be equipped with a remote control in order to promote safety and productivity.	

13.3.1 Uses of overhead cranes

- The most common overhead crane use is in the steel industry. At every step of the manufacturing process, until it leaves a factory as a finished product, steel is handled by an overhead crane.
- Raw materials are poured into a furnace by crane, hot steel is stored for cooling by an overhead crane, the finished coils are lifted and loaded onto trucks and trains by overhead crane, and the fabricator or stamper uses an overhead crane to handle the steel in his factory.
- The automobile industry uses overhead cranes for handling of raw materials. Smaller workstation cranes handle lighter loads in a work-area, such as CNC mill or saw.

13.4 Tower cranes

In the building industry, tower-lift cranes are used for the handling of material on the building site. Tower cranes may be classified as follows according to the method of mounting: static on a base, on a bogie that runs on rails, or the climbing type.

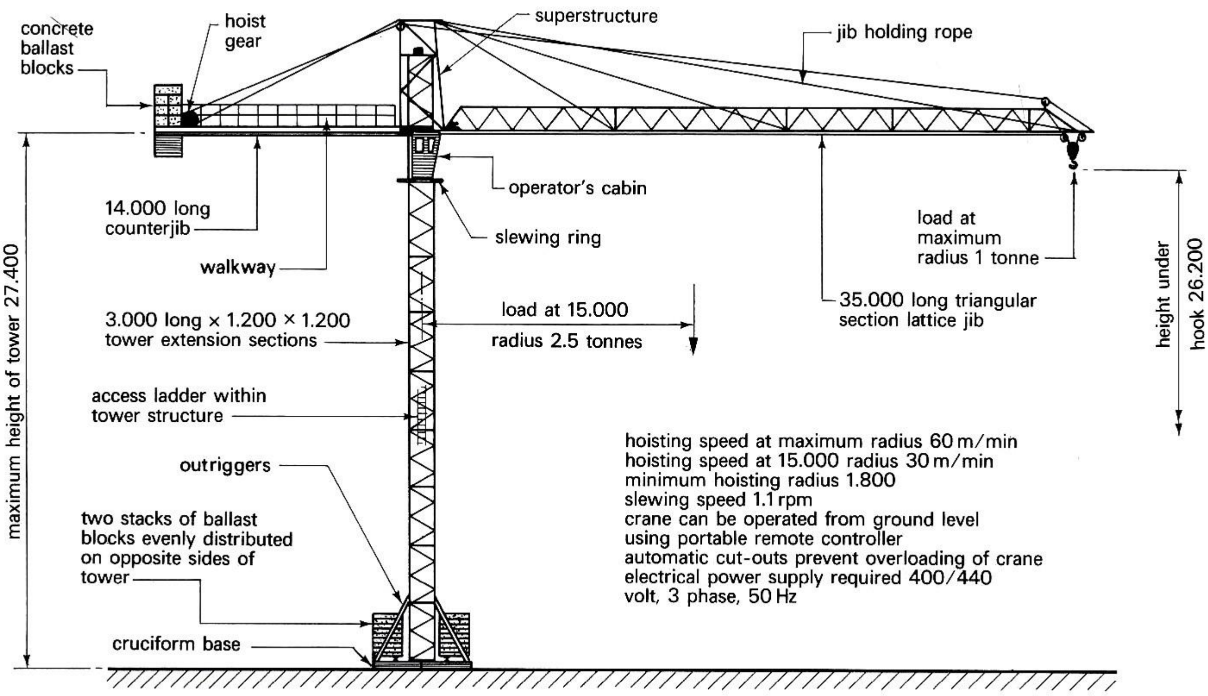


Figure 13.3 Typical self-supporting static tower crane

The advantages and disadvantages of a self-supporting tower crane are:

Advantage	Disadvantages
• The crane occupies a limited area.	• The covering area of the crane is limited because it is fixed in one position.
• It can be set at varying heights up to its maximum free-standing height. By free-standing height we mean the height which the crane can reach without needing support.	• The crane is static and cannot move around while it is in operation.
• It can be extended beyond the free-standing height using the structure it is building to support the crane.	• The crane's capacity decreases as the operating radius increases. • The costs of operation such as erection, dismantling and transport are very high.

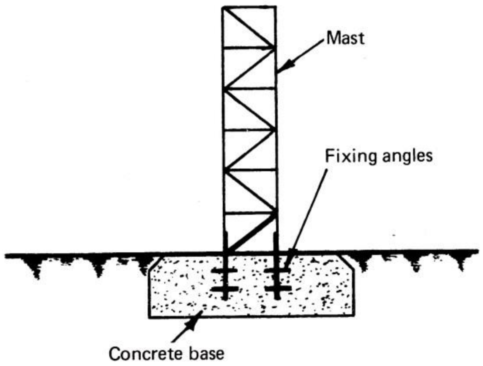


Figure 13.4 Static mounting of a tower crane

Tower cranes are especially designed to handle building materials during the construction of a building. Tower cranes are classified according to the way they are mounted.

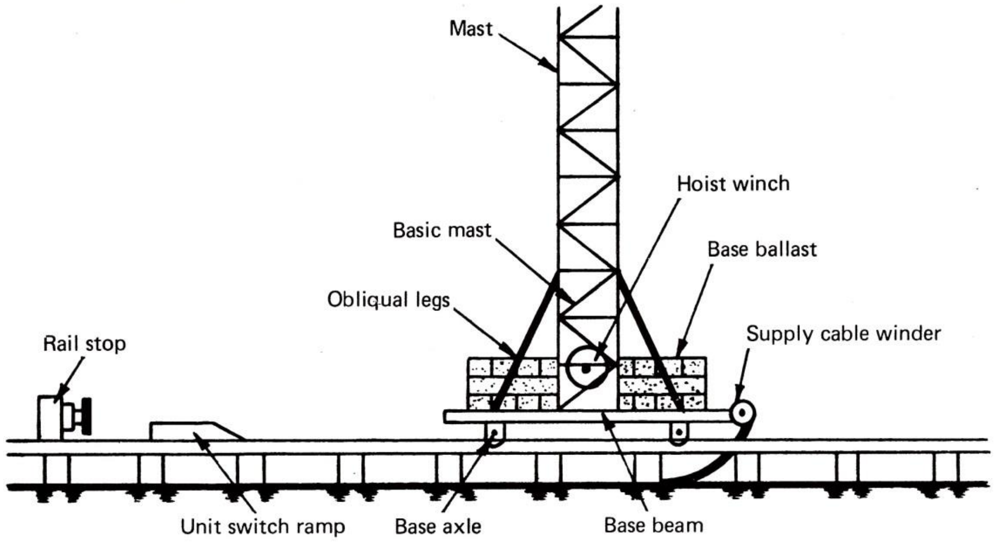


Figure 13.5 Rail mounted tower crane

13.4.1 Travelling tower cranes

To obtain better site coverage with a tower crane a rail-mounted or travelling crane could be used. The crane travels on heavy wheeled bogies mounted on a wide gauge (4.200) rail track with gradients not exceeding 1 in 200 and curves not less than 11.000 radius depending on mast height.

It is essential that the base for the railway track sleepers is accurately prepared, well drained, regularly inspected and maintained if the stability of the crane is to be ensured.

The motive power is electricity, the supply of which should be attached to a spring loaded drum which will draw in the cable as the crane reverses to reduce the risk of the cable becoming cut or trapped by the wheeled bogies.

Travelling cranes can be supplied with similar lifting capacities and jib arrangements as given for static cranes (See **Figure 13.6** for typical example)

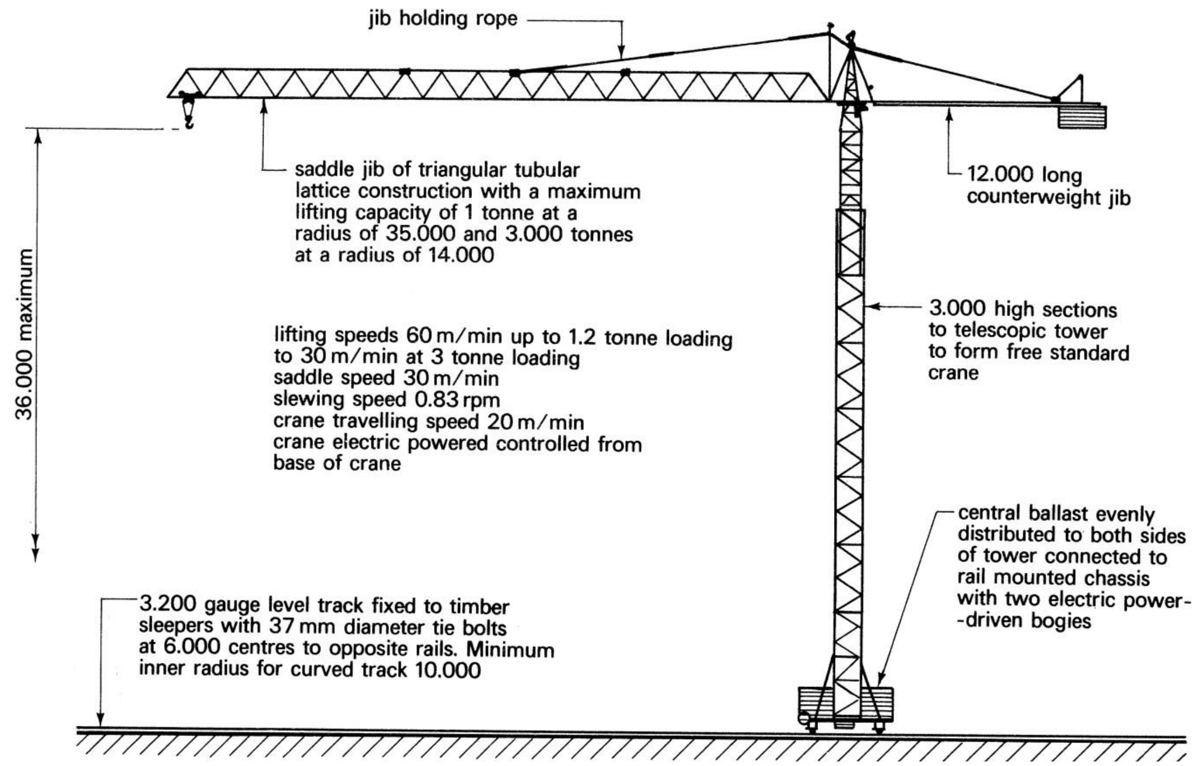


Figure 13.6 Typical travelling tower crane

13.4.2 Climbing cranes

They are designed for tall buildings being located within and supported by the structure under construction. The mast which extends down through several storeys requires only a small (1.500 to 2.000 square) opening in each floor.

Support is given at floor levels by special steel collars, frames and wedges. The raising of the static mast is carried out using a winch which is an integral part of the system.

Generally this form of crane requires a smaller horizontal or luffing jib to cover the construction area than a static or similar tower crane. The jib is made from small, easy-to-handle sections which are lowered down the face of the building, when the crane is no longer required, by means of a special winch attached to one section of the crane. The winch is finally lowered to ground level by hand when the crane has been dismantled (See **Figure 13.7** for typical crane details).

DID YOU KNOW
The climbing-type tower crane is moved upwards with the building as it is built higher and higher. We say that it 'climbs' with the building.

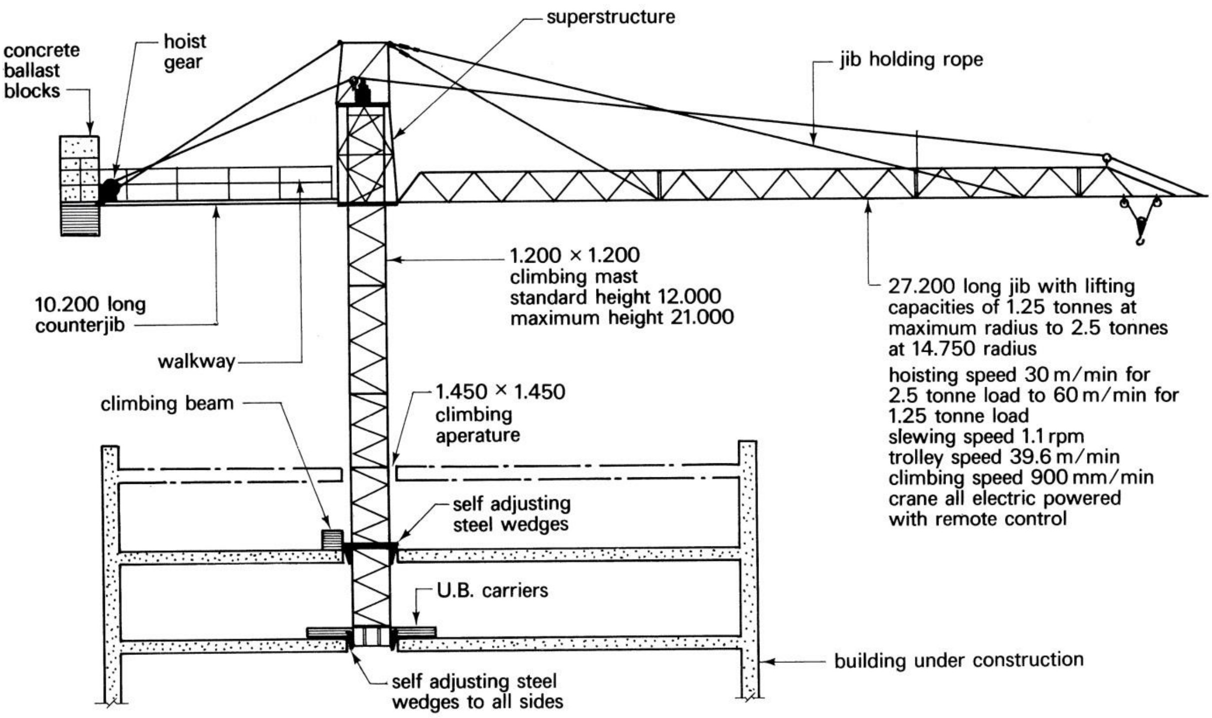


Figure 13.7 Typical climbing tower crane

The advantages and disadvantages of a climbing tower crane are:

Advantage	Disadvantages
• In theory, there is no limit to the height of a building that can be built in this way. The crane is simply moved up floor by floor as the building progresses	• It is a time-consuming process to erect and to dismantle the crane.
• This crane has no effect on the traffic in the surrounding streets or roads.	• The erecting and dismantling processes are very costly.
• The operator of the crane has a clear view of the construction of the floor.	• The cranes are very tall. Lightning and windy conditions may cause a hazard to personnel on the site, the public and the property.
• This crane is used to good advantage when the building structure is high and the side area limited.	• You need more planning than usual when using a climbing-type tower crane because of its structure, foundations and presence on the site.
• The structure of the erected building itself supports the crane.	• The operator at times may be quite far from the point of operation. Under these conditions, misjudgement and misunderstandings can lead to

	serious accidents.
	• The crane cabin is very high. This can cause a dangerous situation for the operator if an accident occurs.
	• If you exceed the load limits, excessive stresses on the whole crane structure occur. This can lead to fatal accidents.
	• In very cold weather structural members can fail suddenly.

13.5 Mobile cranes

Mobile cranes are actually power jib cranes, mounted on a mobile chassis and capable of moving from one place to another under their own power.

The power which actuates both the crane and the vehicle is supplied by an internal combustion engine (petrol or diesel) and the power transmission systems according to which the cranes are classified into THREE types:

- Electric,
- Hydraulic or
- Mechanical.

Figure 13.8 Typical mobile crane

Mobile cranes are built not only to hoist heavy loads, but are also built with jibs with a reach of over 50 metres. The jibs can be fixed or telescopic. Mobile cranes fitted with long jibs are used for lifting loads to great heights.

Because of the length of the jib it also has a longer reach enabling it to reach loads which are far from the crane. Some mobile cranes are designed for easy handling in traffic on streets and also on country roads.

These cranes thus comply with the requirements laid down in the provincial Road Traffic Ordinances.

Jib: The projecting arm of a crane.
Boom: A movable arm of a crane.
Telescopic: Made of parts that slide into one another.

13.5.1 Travelling in mobile cranes

Should doubt exist as to whether the ground over which the crane is to travel will be able to support the mass of the crane, matting must be used. Scrap steel plates or wooden beams may also be used for this purpose.

SAFETY HINTS and PRECAUTIONS for Crane Operators

Have a look at some safety precautions and safety measures:

- Steel plates with sharp or protruding points which are likely to damage the tyres should not be used.
- Crane drivers should never allow themselves to be distracted while operating the crane.
- Cranes should never move closer than approximately 2 metres to any electric overhead conductor.
- Never drag a load sideways when slewing. Any dragging causes abnormal stress on the structure of the crane with possibly serious detrimental results. There have been cases where jibs were torn out of their stays as a result of dragging when slewing.
- If the load is inclined to sway when it is moved, a rope should be fastened to one end of the load to enable a responsible person to control the movement of the load.
- If the jacks are not firmly secured and raised as high as possible, they may be torn off or damaged if they hook on some obstruction accidently.
- Always keep a close watch for persons who are working with you or who may be working in the vicinity.
- It is dangerous to travel in cranes over uneven terrain with the jib luffed out, because it can easily cause the crane to topple over. This applies equally to cranes with strut-type and hydraulic-type jibs. Before moving the crane the hydraulic jib should be drawn in as far as possible and positioned over the crane cabin. In this regard the manufacturer's instructions should be complied with strictly.
- Before travelling in a crane, the lock pin for the slewing motion should be placed in position.

13.5.2 Terms commonly used

Condition of tipping: A crane is in the condition of tipping when it is supporting a load and it is impossible to increase this load by even a small amount without causing the crane to fall over.

Height of lift: This is the vertical distance between the floor level (or datum level) and the lowest point of the throat of the hook when the hook is in the highest working position.

Jib length: This is the shortest distance between the fulcrum of the jib and the centre of the jib head pulley.

Outreach: This is the horizontal distance from the centre line of the lifting hook to the nearest point of the machine other than the jib.

Outrigger (supporting feet): Mobile cranes are equipped with jacks or outriggers on the four corners of the chassis to prevent them from toppling over when lifting heavy loads. The lifting capacity is therefore considerably increased.

Figure 13.8 shows a self-propelled strut jib crane.

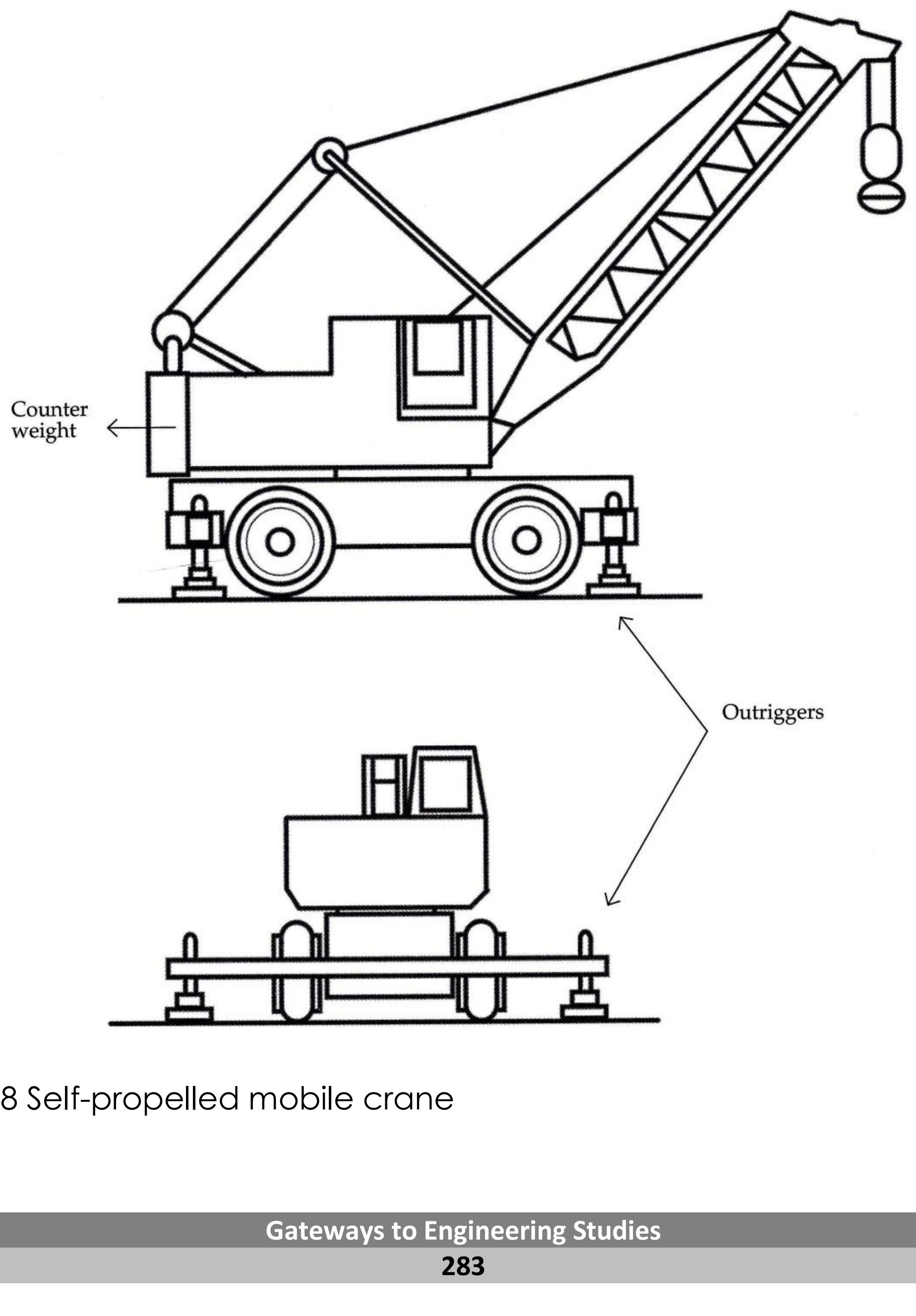


Figure 13.8 Self-propelled mobile crane

13.5.3 Counterweights on mobile cranes

The crane counterweight is critical for ensuring crane stability. A counterweight that is too light for a load and boom configuration will cause the crane to overturn in the direction of the suspended load.

A crane can also fall over backwards due to the effect of the counterweight in situations when:

- the counterweight is too heavy for the boom configuration
- the crane is travelling up a slope with the boom luffed up
- inadequate timbers are placed under the outrigger pads below the counterweight when the crane is positioned on soft ground
- outriggers are not extended or lowered into position.

On most of the smaller mobile cranes, the counterweight is fixed and cannot be easily removed. However, on an increasing number of larger cranes some of the counterweights are designed to be removed for road travel or when smaller boom and lifting configurations are required.

In this situation, it is particularly important to attach the correct type and number of counterweights to the crane for the particular lift to be undertaken.

Counterweights must be secured to the crane in the manner specified by the crane manufacturer. Where counterweights are removable, each counterweight must be clearly and permanently identified with the crane manufacturer's name or trademark and the mass of the counterweight (preferably in tonnes).

Where the crane is fitted with a rated capacity limiter, the data input into the computer must be correct for the counterweight configuration on the crane and related to that shown on the appropriate load chart. This also applies to the boom configuration being used on the crane.

13.5.4 Truck-mounted cantilever jib mobile crane

This crane has a boom that is of a lattice construction and is used as a yard crane. It can travel with bulky loads as the jib is pivoted at a much higher position. **Figure 13.9** shows a truck-mounted cantilever jib crane.

Truck-mounted cranes have a greater mobility on the road, but are less mobile on site. Their primary use is for highly mobile purposes requiring rapid movement from one site to another.

When used for distributing operations in building work it is necessary for the crane to stand some distance away from the building so that the low-mounted jib does not foul the top of the building.

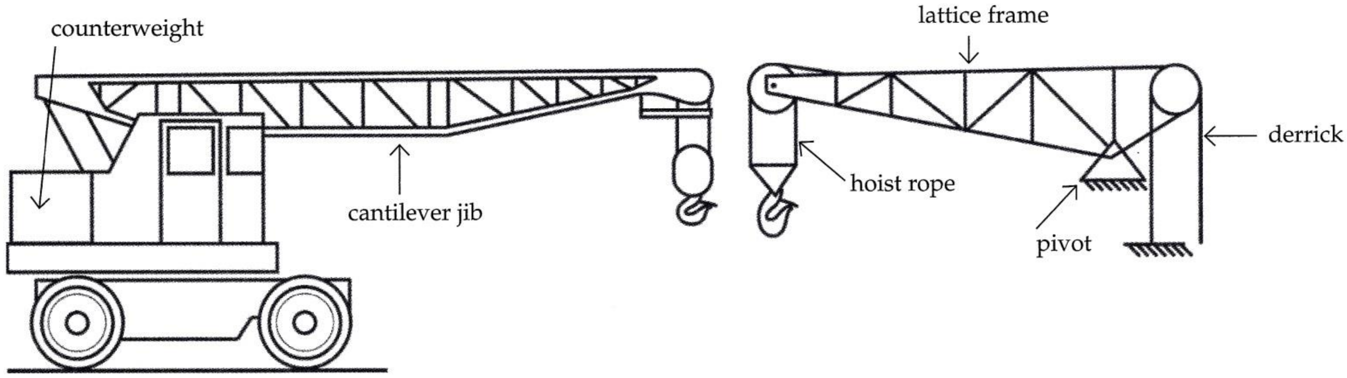


Figure 13.9 Truck mounted cantilever jib mobile crane

13.5.5 Crawler-mounted mobile cranes

These cranes are versatile cranes for site use. They can operate on soft swampy ground and can be converted to grab or drag line.

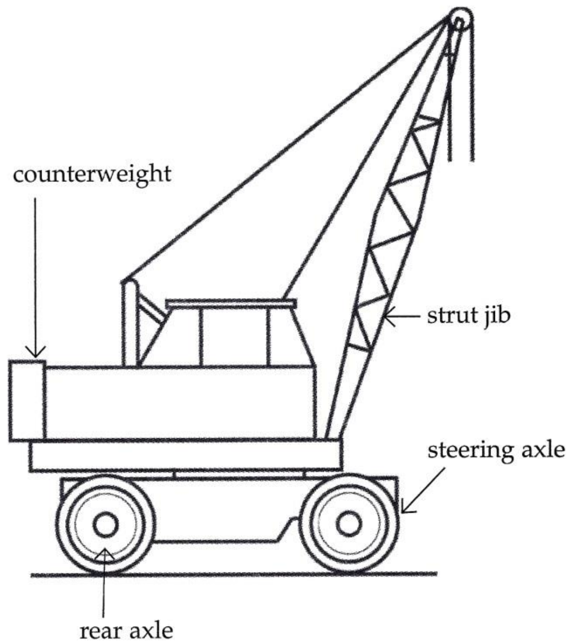


Figure 13.10 Crawler-mounted mobile crane

13.5.6 Selecting a mobile crane

The rated lifting capacity of a crane is the load it can lift with the shortest jib at minimum radius, that is, as close as possible to the crane without riggers fully extended.

When selecting a mobile crane for a job, the size and characteristics of the crane should be assessed against the following criteria:

- The weights, dimensions and lift radii of the heaviest and largest loads to be lifted
- The maximum lift height and radius, and the weight of the loads to be handled at these points

- The number and frequency of lifts to be made
- How long the crane will be required at the workplace
- The type of lifting to be done
- The type of carrier required - this depends on ground conditions and machine capacity in its various operating quadrants
- Whether loads are to be suspended for lengthy periods of time
- The workplace conditions, including the ground on which the crane is to be set up, access roads and ramps it must travel on, space for erection and any obstacles that may prevent access or operation.

13.5.7 Boom selection for cranes

Cantilever jibs

These are suitable for self-propelled and truck-mounted cranes (see **Figure 13.9**).They give greater clearance where headroom is limited, particularly when handling bulky loads.

Lifting capacity is generally lower than for a comparable size strut jib crane because of the need to carry the weight of the cantilever boom. For permanent site-based work, the crawler strut jib crane tends to be more economical for construction work. The cantilever jib is used mainly for stockyards where manoeuvrability and headroom are restricted.

Strut jibs

Strut jibs are used with derricks, crawler cranes and truck-mounted cranes (see **Figure 13.8**). They have a high lifting capacity with long reach but are cumbersome and require dismantling to increase the boom length or to add fly jibs. The strut jib is the preferred boom on the dragline and grabbing crane.

Fly jib

A fly jib may be attached to either a strut jib or a cantilever jib to provide extra reach. It is usually used offset from the main boom for construction work to increase the working radius for a given jib angle. It is also useful for placing concrete, reinforcement and other light loads (see **Figure 13.11**)

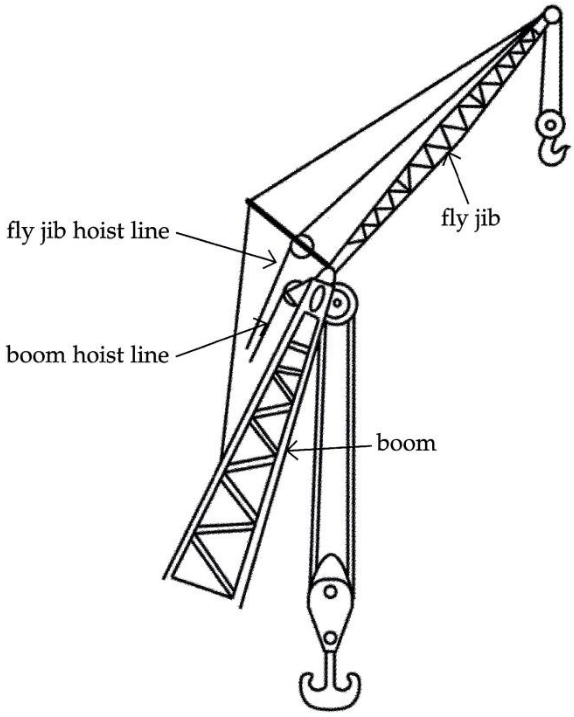


Figure 13.11 Fly jib

Telescopic jib
The telescopic jib is a variation of the cantilever boom. It offers a quickly operational and variable length jib. It is restricted to self-propelled and truck-mounted cranes and cannot handle dragline and grabbing duties.

The weight of the telescoping rams reduces the weight and radius capacity compared to the strut jib, but offers increased manoeuvrability. This is an expensive type of crane.

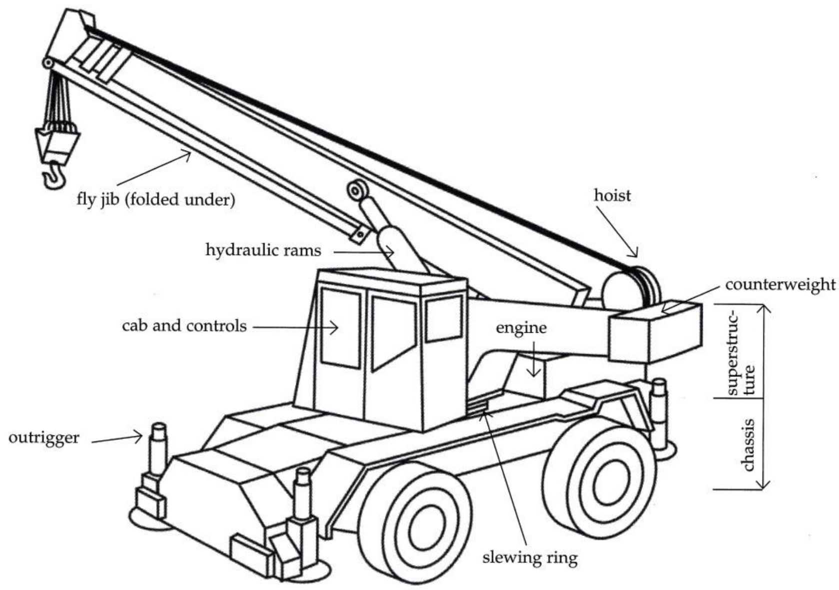


Figure 13.12 Telescopic jib

The advantages and disadvantages of mobile cranes are:

Advantage	Disadvantages
• They can move from point A to point B under their own power while carrying a load.	• If the crane travels over an uneven surface with a heavy load, the crane can topple over.
• Mobile cranes are allowed to move from one stand to another on public roads, as long as they comply with certain traffic regulations.	• A common crane accident occurs when the jib is pulled backwards over the top of the cabin.
• Heavy loads can be lifted to great heights.	• Strong winds can create forces sufficient to topple the jib.
• The crane jib can reach and pick up loads far from the crane.	• The operator's view is often restricted because of the nature or size of the job or operation.
• Because mobile cranes can move forward and backward under their own power, heavy loads can be reached and removed from difficult to reach places.	

13.6 Wharf cranes

A wharf crane is a type of crane designed and adapted to the loading and unloading of ship loads. Although some cranes can handle heavy loads, wharf cranes with a safe lifting capacity of four tons are generally-used.

The Wharf cranes are mounted on rails and can therefore travel along the wharf.
Often several cranes are used next to one another to unload or load cargo on the same ship.

The under frame of wharf cranes is of such a width and height that fully loaded trucks can pass underneath the cranes with ease. Another reason for this is to ensure that the jib will always project at a sufficient height above the sides of large ships.

Wharf cranes are usually driven by electric motors. There is one motor for each movement.

These movements are the following: longitudinal travel, slewing motion, luffing motion, and raising and lowering of the crane hook. Longitudinal travel is when the crane travels along the wharf on its rails to take up position alongside a ship.

A slewing motion occurs when the machine room, driving cabin and jib can swivel on the under frame. It is therefore possible to swivel with a load from a ship in order to place the load on the wharf.

A luffing motion is when the jib which swivels on a heel pin is luffed further out from the centre of the crane, or is luffed in to suit the position of the load being lifted. A hoisting motion is when the crane hook to which all loads are hooked is suspended from a steel cable which is raised or lowered to lift or lower loads as required.

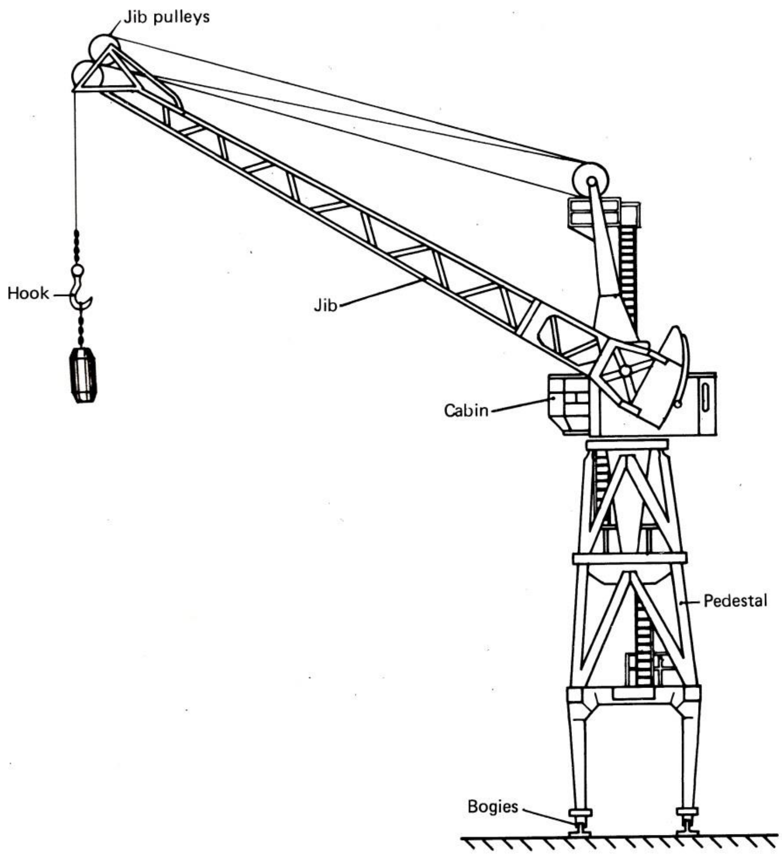


Figure 13.13 Wharf crane

The advantages and disadvantages of Wharf cranes are:

Advantage	Disadvantages
• It can transport loads on a rail between two points alongside the wharf.	• If the Wharf crane travels over an uneven surface with a heavy load, the crane can topple over.
• It can handle very heavy loads as well as very big lighter loads.	• Only used in shipping harbours.
• It does not disturb traffic on the wharf because fully loaded trucks can pass underneath the crane.	• Strong winds can create forces sufficient to topple the jib.

13.7 Lifting attachments for cranes

Figure 13.14 shows the lifting attachments for cranes

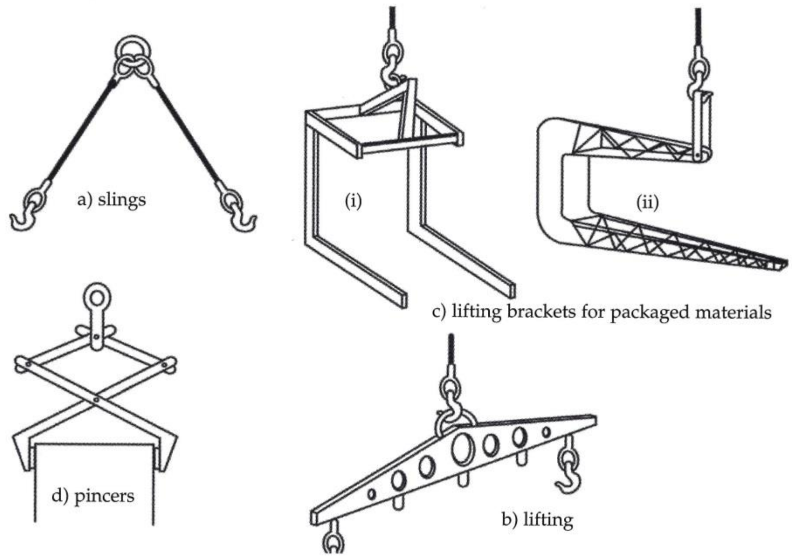


Figure 13.14 Lifting attachments for cranes

13.7.1 Slings

A sling is an assembly that connects the load to the material handling equipment. Slings are used widely for moving bundles of reinforcement, timber, steel and concrete beams and pre-cast concrete units.

The safe working load for two-legged slings is generally quoted at 90°, since the lifting capacity varies with the angle of the legs. For example, a two-leg wire sling of 19 mm diameter will carry 5 280 kg at 60°, 4 300 kg at 90° and 3 050 kg at 120°. The capacity of the equivalent single-leg sling is 3 050 kg.
The two main types of slings are:

- wire rope slings
- chain slings.

13.7.2 Wire rope slings

A wire rope consists of a number of steel strands wound around a core. **Figure 13.15 (a)** shows a steel rope and **Figure 13.15 (b)** shows the construction of a wire rope.

Figure 13.15 (a) Steel rope

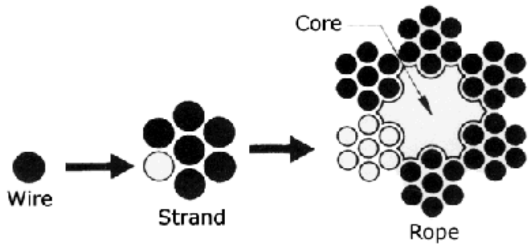


Figure 13.16 (b) Construction of a wire rope

13.7.3 Checking a wire rope or sling

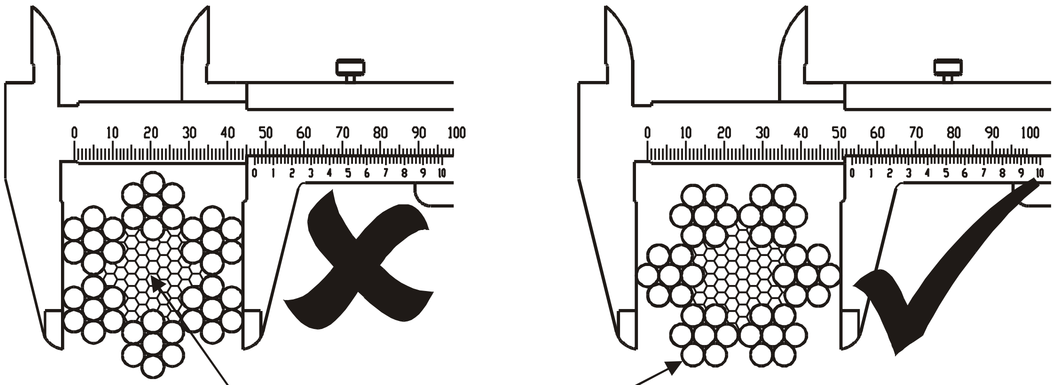
Any rope or sling showing the following defects must be discarded by means of cutting up and disposal.

- **Broken wires**

There must not be more than six broken wires in a sling.

- **Wear**

There's only one right way to measure rope diameter: use a vernier and be sure to measure the widest diameter. The drawing shown in **Figure 13.16** shows the right way with the wrong way.



Correct method of checking a sling diameter

Figure 13.16 Correct and incorrect method of checking a sling's diameter

This method is not only useful for measuring the diameter of a new rope, but also for determining the amount of wear and compression that has occurred while the rope has been in use. Accurate recording of this information is essential in helping to decide when to replace wire rope.

The sling must not be worn by more than 10% of its nominal diameter.

SAFETY HINT
Safe operating practices for selecting slings

1. Determine weight of the load.
2. Select the sling having suitable characteristics for the type of load, hitch and environment. Shock loading must be avoided.
3. Never use a sling that is rated lower than the load being lifted. Slings that appear to be damaged must not be used unless inspected and accepted.
4. Slings with fittings which are used in a choker hitch must be of sufficient length to assure that the choking action is on the webbing and not on a fitting or splice.
5. Slings used in a basket hitch must have the load controlled to prevent slippage.

6. Slings must always be protected from being cut by sharp corners, sharp edges, protrusions or abrasive surfaces with protection sufficient for the intended purpose.
7. Slings must never be twisted or tied into knots, or shorten or joined by knotting.
8. The sling must be hitched in a manner that provides total control of the load.
9. The operator and all other personnel must stand clear of the suspended load. No riding on the load must take place.
10. Place blocks under load prior to setting it down, to allow removal of the sling, if applicable.

13.8 Lifting Equipment

When a load is to be lifted it is usually coupled to the crane hook by wire cables or chain slings. Loads lifted by means of a single sling of wire cables, chain or fibre ropes, should not be heavier than the mass stamped on the sling washer or ferrule. (Each wire cable sling is provided with a sling washer showing the code number of the sling, date of manufacture and safe lifting capacity.)

13.8.1 Simple pulley system

In the pulley system shown in **Figure 13.17**, there are four sections of the rope supporting the load. The load is therefore shared between the four sections of rope.

If the operator were to pull the free end of the rope, the four required would be ¼ of the total load. Of course the force applied by the operator would be more because of friction.

On the other hand if the load were lifted 100 m, each of the four sections of the rope will have to shorten by 100 mm. The operator therefore, will have to pull the free end by 400 mm.

Energy is never created or lost.

There are four main types of chain block, namely, the spur geared, the screw-geared, the differential and the pull-lift types.

The first three types are used for hoisting in a vertical direction, whilst the last type is used primarily for pulling in a horizontal direction.

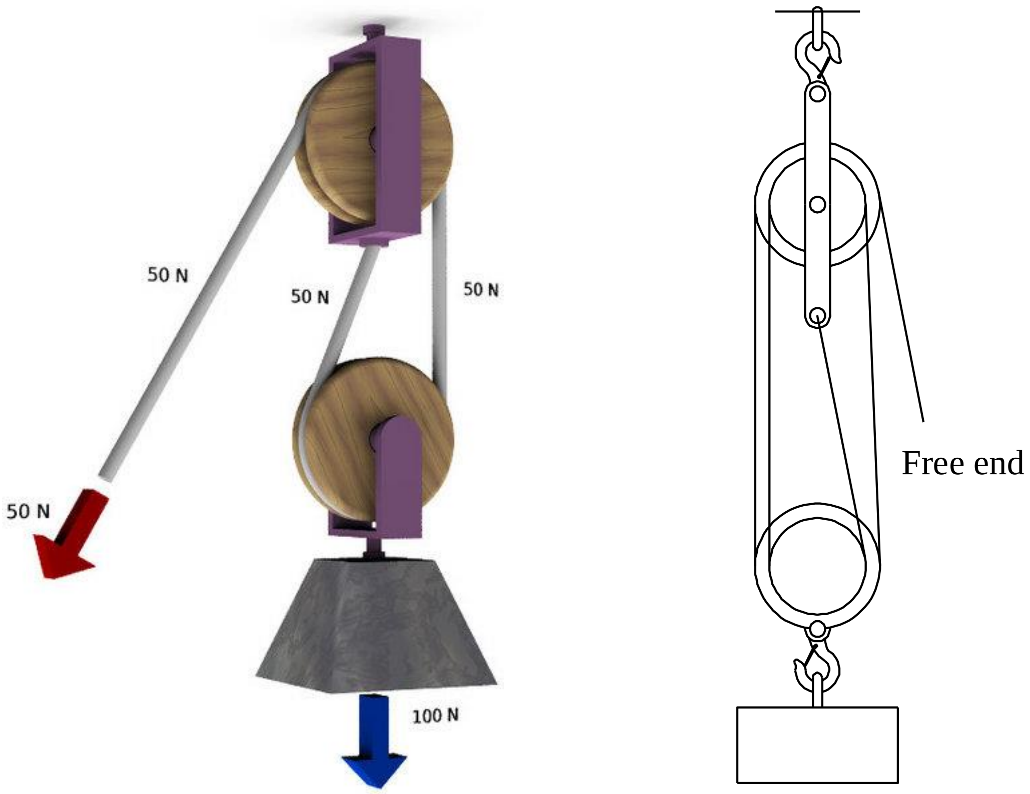


Figure 13.17 Simple pulley system

13.8.2 Differential pulley block

The top block contains two sheaves of different diameters, mounted together so as to form one piece.

The bottom block contains one sheave only. The chain is endless (one piece) and passes first round the larger top sheave, then round the bottom sheave and then round the smaller top sheave.

When raising or lowering the load the loose chain passing from the larger top sheave is pulled.

The chain itself fits into slots which are located in the two top sheaves only.
The load moves up S slots and downs slots.

This is the simplest and least expensive type of chain hoist, with an efficiency of about 30 %.

The mechanical advantage is gained by the two upper sheaves differing by one link slot so that more chain is racked in be the larger wheel to produce a net raising or lowering of the load.

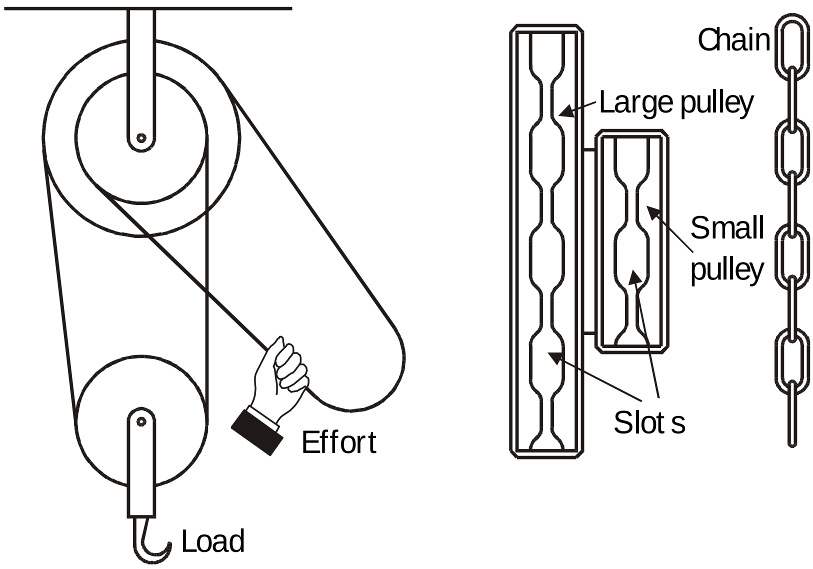


Figure 13.16 Differential pulley block

13.9 Winches

Cranes and some lifting tasks require a winch and rope drum to provide the lifting force. The winch maybe powered by electric motor, compressed air, hydraulic motor or a diesel engine.

The hoisting speed on most winches can be adjusted to accommodate the load being lifted.

For example a winch can handle 4000 kg at a speed of 100 m/min whilst the same winch will hoist a load of 20 000 kg at 20 m/min. **Figure 13.17** shows a typical winch arrangement.

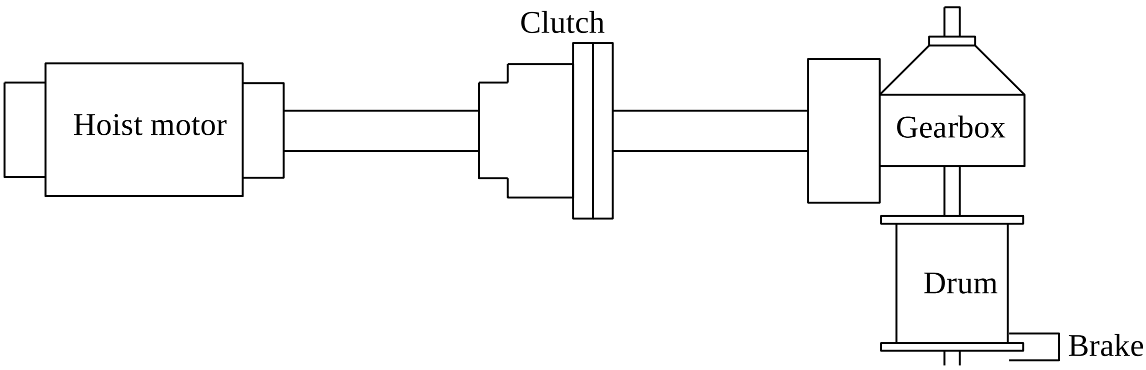


Figure 13.17 Typical winch arrangement

13.10 Rope blocks

To lift light loads a rope block can be used. Rope blocks can be of single or multi-rope type. These can be used to lift heavier hoisting equipment onto high beams so that heavier loads can be hoisted.

13.11 Chain block (block and tackle)

For frequent use and where a minimum of labour is available to operate it, the spur geared hoist is recommended. Although it has an initial high cost it is the most economical to use.

The screw geared and differential hoists have enough internal friction to prevent the load from running away on the lowering motion. Such is not the case with the spur geared hoist, so a load brake is incorporated into it.

The chain block (**Figure 13.19**) is portable, there are two types of chains used on a chain block, namely, the light chain is to operate the chain block and is called the messenger chain, if it is pulled at one end it will lift the load, if the other end is pulled it will lower the load.

Chain blocks are made with the bottom hook as the weakest part and this hook cannot be exchanged with the top hook. The reason that the bottom hook is made weaker is that any overloading will occur at this hook as it will tend to open.

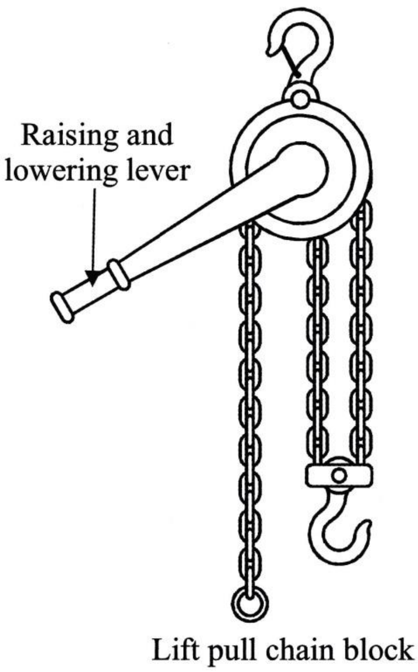


Figure 13.18 Lift pull chain block

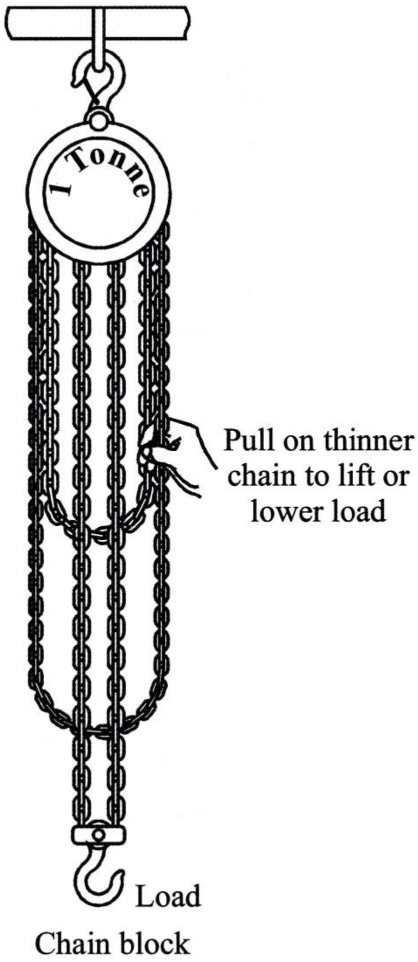


Figure 13.19 Chain block

13.11.1 Lift pull chain block

This type of chain block is portable and lightweight. It can be used to lift load vertically, horizontally or at any angle. This equipment is the riggers most valuable piece of assistance. It can also be used to pull, tension cable stays, and shifting loads.

The lift–pull chain block has a variety of uses:

- Shifting of rail trucks in mines
- Lifting loads on trucks
- Tensioning of stays
- Lifting pipes into manholes
- Construction industry

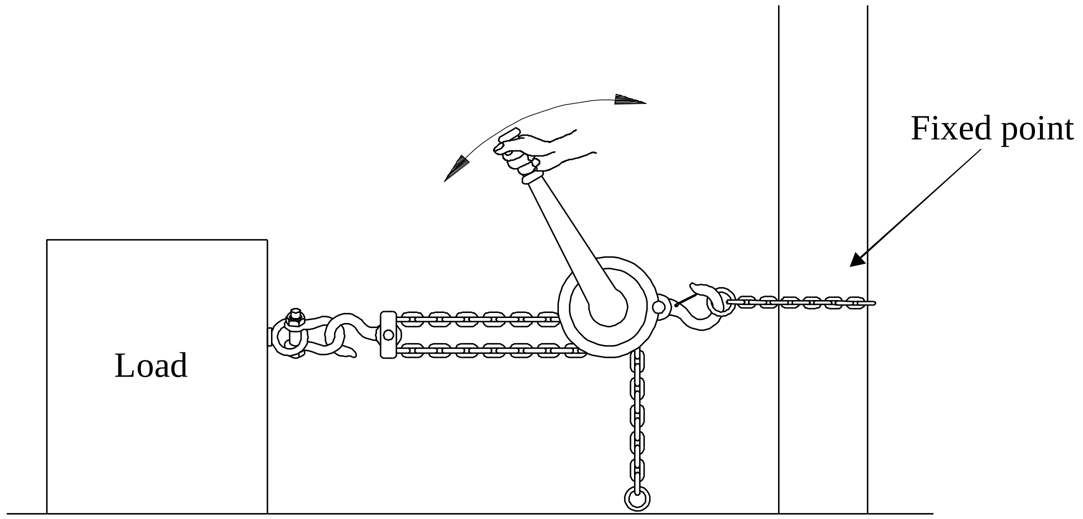


Figure 13.20 Lift pull chain block can be used to lift loads

13.12 Good slinging practice

1. Never work under an unsupported load. Make sure that trestles are used to support the load and not the hoisting equipment (**Figure 13.21**).

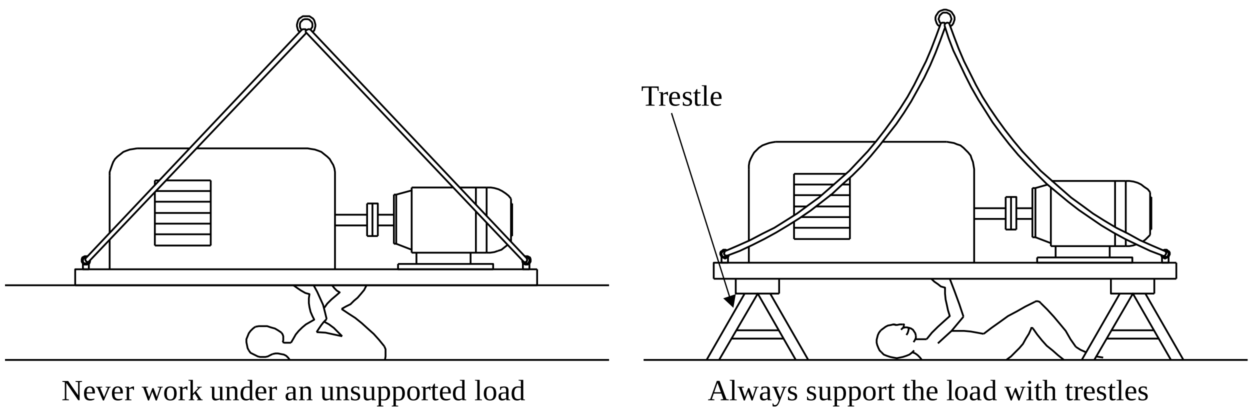


Figure 13.21 When working under a load always support it with trestles

2. Always be ready to land a load onto the site beforehand. Never rest the load on the slings but rather have wooden battens ready if required. This will allow for the easy retrieval of the slings from the load.

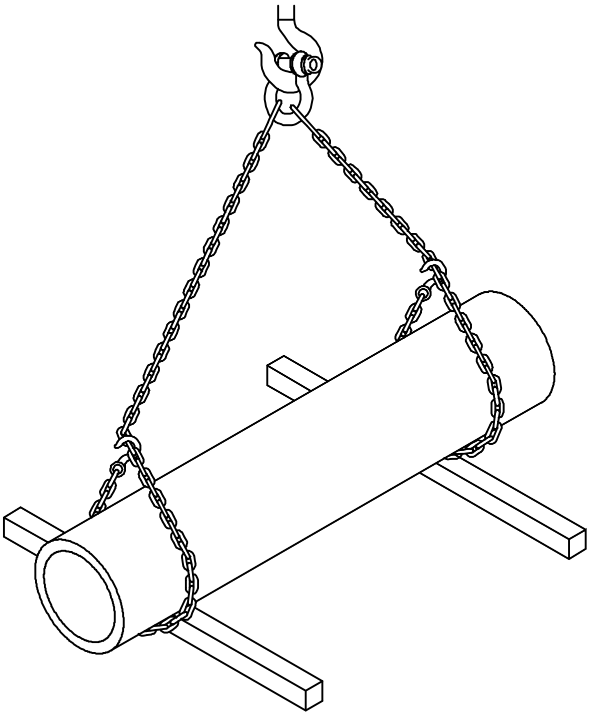


Figure 13.22 Use wooden battens

3. Use blocking or padding to protect hollow vessels (**Figure 13.23**), loose bundles and fragile items from scuffing and bending. Remember that blocking becomes part of the lift, and must be added to total weight on the sling.

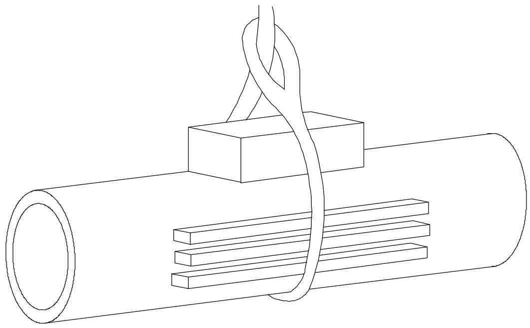


Figure 13.23 Blocking or padding used to protect hollow vessels

4. For long lifting loads use a tag line to control the load (**Figure 13.24**). The tag line is attached to the load and an operator pulls and eases the line as needed to keep the load from rotating etc.

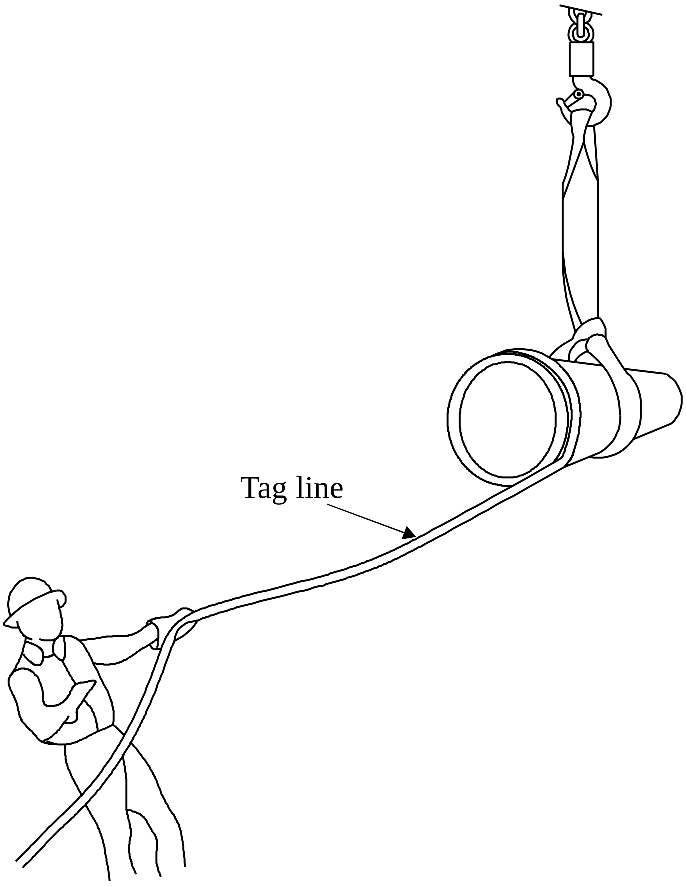


Figure 13.24 a tag line is used to control the load

5. Block loose loads before unhooking.

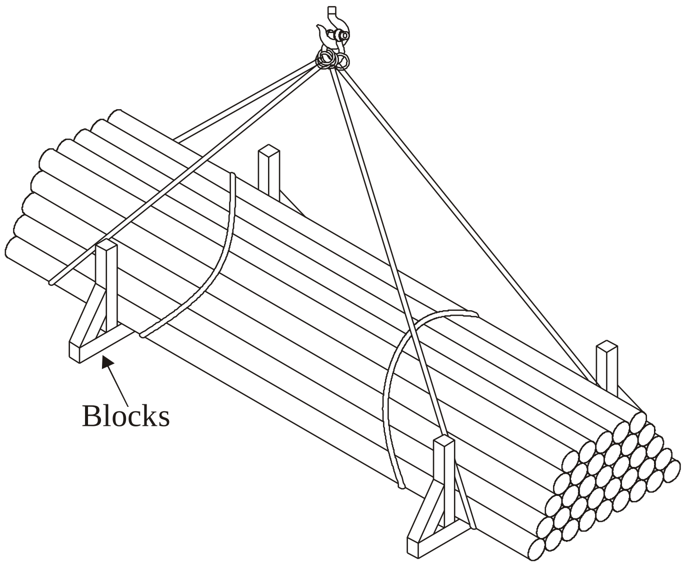


Figure 13.25 Blocks

13.13 Checking the working clearance and the sling length

After the mass and centre of gravity is determined, the clearance between the load and the lifting hook must be checked (also called the head room) to determine the length of the slings to be used and that the correct sling angles been maintained.

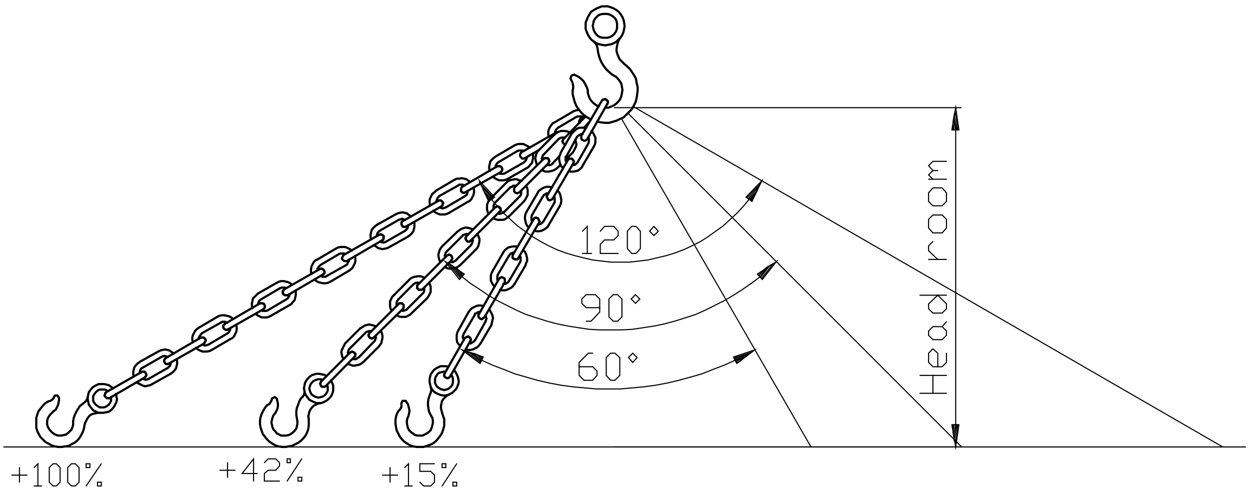
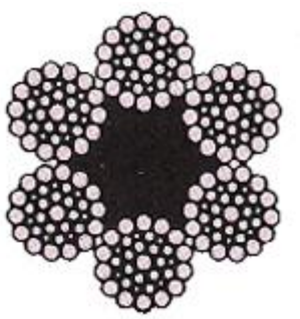


Figure 13.26 determine working clearance and sling length

In relation to the vertical (head room) the length of the sling must be increased by 15% if the included angle is 60°. If the included angle is 90° then the length is increased by 42% in relation to the vertical. If the included angle is 120° then the length is increased by 100% in relation to the vertical.

13.14 Hoist and luffing ropes

We have already mentioned that the hoist and luffing cables are wound around drums to provide the necessary movement. These cables are manufactured from high quality steel, and are excellent for the purpose because of their design.



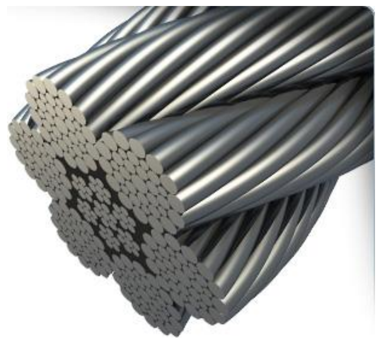


Figure 13.27 Crane wire cable 6 x 36 construction

Various wire cable construction methods are used by manufacturers. The requirements vary, but are mostly complied with by using a 6 x 36 crane wire cable. (These figures refer to: 6 wire strands layed spirally around a fibre core or steel cable core and 36 wires in each strand wound spirally together.)

The core of a steel wire cable consists mostly of fibre. The important function of the core is that by means of the core the cable is internally lubricated. It also serves as a cushion to absorb shocks.

With the necessary care and safe handling, steel wire cables will give long reliable service. However, a steel cable can be damaged very easily if it is not lubricated regularly. Regular lubrication not only supplements the lubricant in the core, but protects the steel cable against rust and wear.

It is always advisable to report any defect in a hoist or luffing cable whether the damage appears to be of a minor nature or not.

Special attention must be given to the following defects: damage to the cable core, corrosion of the inside of the cable, and whether the cable is flattened or twisted so badly that a certain amount of doubt exists as to its suitability for further use.

Figure 13.28 Damaged wire cable

It is extremely dangerous to use other material such as binding wire, electric cables, etc., for handling loads. Crane drivers must ensure that the slings used are only those which have been made for the purpose.

13.15 Rules for crane operators

The crane operator (driver) must:

- Always keep his eyes on the load which is being handled,
- Read the radius indicator to ensure that the load is within the limits of the crane's capacity,
- Always examine the crane ropes and slings at the start of a shift. Should another sling be required during a shift, this sling must also first be examined,
- Always ensure that the tyre pressure of a mobile crane is correct,

- Always test the safety devices of the crane at the start of a shift to ensure that they are in good working order,
- Always ensure that the crane hook is directly above the load which is to be hoisted, i.e. A load should not be dragged to the centre of the jib before it can be lifted,
- Always ensure that the hand brake of the mobile crane is on when a load is being hoisted or lowered

The crane operator (driver) should not:

- Exceed the maximum load limit for a specific luffing position of the arm;
- Allow the load to hang from the crane without proper control from the crane cabin;
- Swing a load over the heads of other staff who are in the vicinity of the crane;
- Leave the crane unattended while the engine is idling and without the hand brake being applied;
- Drag or push loads when the slewing motion of the crane is employed;
- Switch off the machine or allow it to stall with a load in suspension.

13.15 Hand signals

In order to enable the crane operator to carry out his duties efficiently when communication is difficult because of noise or the distance between the rigger and crane operator, hand signals, and in the case of mine hoists bell signals are used.

To reduce to the absolute minimum the number of accidents, hand signals have been established.

The signals should be thoroughly understood by the signalman and operator. Shown are a few of the basic hand signals (see **Figure 13.27**).

13.16 Overhead crane signals

To warn people working underneath and close to an overhead crane, a horn (hooter) will sound. Different sounds will mean different things:

- One horn blast – move off
- Two horn blasts – move the long travel to the right
- Three horn blasts – move the long travel to the left
- One continuous blast – emergency, either fire, brake failure, or load falling etc.

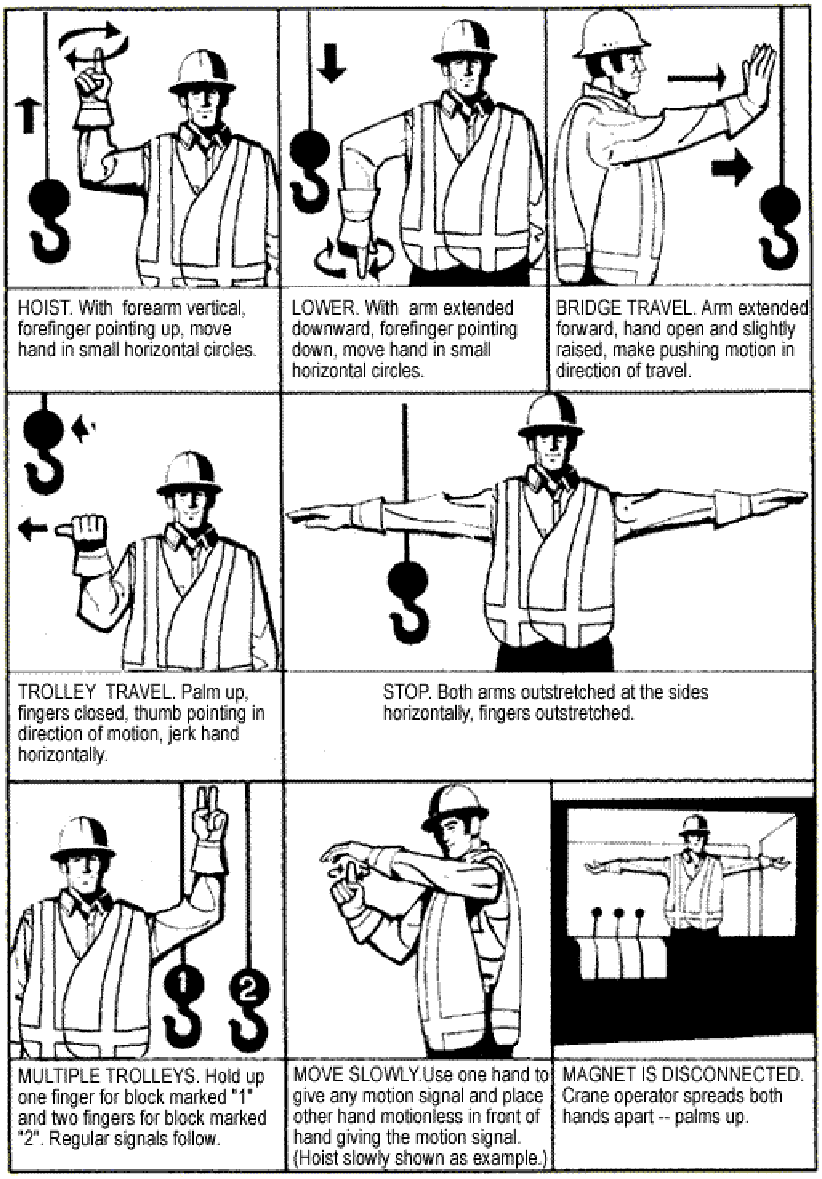


Figure 13.27 Hand signals

Activity 13.1

1. Name four different types of cranes and give one practical example where each type is used.
2. What are the advantages gained by using a mobile crane?
3. Name four precautions to be observed when operating a mobile crane.
4. Name two different types of building cranes in general use and briefly explain how they differ from each other.
5. Two ropes are wound on the hoist drum of most overhead cranes. Give three reasons for this practice.
6. Give short answers to the following questions on hoisting ropes:
   (a) What is meant when referring to the core of the steel wire rope?
   (b) What is its function?
   (c) Why is it important to lubricate steel wire ropes regularly?

7. With the aid of a simple sketch, explain what you understand by referring to a steel wire rope of 6 x 36 construction.
8. (a) Why is it so necessary to make use of hand signals with cranes?
9. (b) Explain with the aid of simple sketches three general hand signals with which you are acquainted.
10. Write a short report (of about 15 lines) on hoist ropes.
11. List THREE different hand signals and make a neat sketch to illustrate your answer.

Self-Check

I am able to:	**Yes**	**No**
• Name and, using plain line sketches, describe the different types of cranes in use		
• Name and explain important inspection elements on cranes		
• Describe, and using plain line sketches, hand signals used for crane operators in their control operations		
• Explain the basic operating principles of a crab or hoist unit		
• Describe, and using plain line sketches, an automatic brake used on this type of crane		
• Describe what the terms "cross traverse" and "long travel" mean, regarding cranes		
• State the main function, and capacity, of wharf cranes		
• Name and describe the principle, or main parts of wharf cranes		
• Describe slewing and trolley movement of tower cranes (building industry)		
• Name the various parts and rules to be observed regarding mobile cranes		
• Describe travelling of mobile cranes		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 14

Industrial Organisation and Planning

Learning Outcomes
By the end of the module, you should be able to:

- Briefly describe effective communication skills in a multi-cultural environment with regard to:
  - Writing and compiling reports and memoranda
  - Verbal and non-verbal skills
  - Application of listening skills
- Discuss organisational communication with respect to the following communication channels:
  - Vertical line
  - Horizontal line
  - Diagonal line
- Briefly describe the basic outlines of the following Acts:
  - Labour Relations Act regarding, grievance - discipline – employment
  - Occupational Health and Safety regarding, incidents -duties - records
- Describe the purpose of an administration system
- Briefly describe the purpose of each of the following documents:
  - Clock cards
  - Job cards
  - Requisition cards
  - Production flow charts
  - Maintenance schedules
- Describe the purpose of budgeting and of controlling expenses
- Describe labour efficiency to improve and increase productivity

14.1 Introduction

In this module we will be looking at the various ways that you can communicate effectively in the industrial environment. Also reviewing the various ACTS that affect the working world of industry.

14.2 Effective communication skills in a multi-cultural environment

Effective communication helps us better understand a person or situation and enables us to resolve differences, build trust and respect, and create environments where creative ideas, problem solving, affection, and caring can flourish. As simple as communication seems, much of what we try to communicate to others—and what others try to communicate to us—gets misunderstood, which can cause conflict and frustration in personal and professional relationships. By learning these effective communication skills, you can better connect with your spouse, kids, friends, and co-workers.

What is effective communication?

In the information age, we have to send, receive, and process huge numbers of messages every day. But effective communication is about more than just exchanging information; it also about understands the emotion behind the information.

Effective communication can improve relationships at home, work, and in social situations by deepening your connections to others and improving teamwork, decision-making, and problem solving.

It enables you to communicate even negative or difficult messages without creating conflict or destroying trust. Effective communication combines a set of skills including nonverbal communication, attentive listening, the ability to manage stress in the moment, and the capacity to recognize and understand your own emotions and those of the person you're communicating with.

While effective communication is a learned skill, it is more effective when it's spontaneous rather than formulaic. A speech that is read, for example, rarely has the same impact as a speech that's delivered (or appears to be delivered) spontaneously.

Of course, it takes time and effort to develop these skills and become an effective communicator. The more effort and practice you put in, the more instinctive and spontaneous your communication skills will become.

Let us briefly describe effective communication skills in a multi-cultural environment with regard to:

- Writing and compiling reports and memoranda
- Verbal and non-verbal skills
- Application of listening skills

What is Communication?
It is the mutual exchange of ideas and the interpretation of messages and signals

14.2.1 Writing and compiling reports and memoranda

People write progress reports to keep interested parties informed about what has been done on a project and about what remains to be done. Often the reader is the writer's supervisor. As a result the tone should be serious and respectful.

Even though progress reports are often in the form of a memo, the writer should be careful to write formal, standard prose.

Progress reports represent not only the writer's work but the writer's organizational and communication skills.

If the progress report is a memo, it should contain the following standard elements:

- Date: Date the memo is sent
- To: Name and position of the reader
- From: Name and position of the writer
- Subject: A clear phrase that focuses the reader's attention on the subject of the memo

Guidelines on writing a good report:

- Be brief and to the point
- State your purpose and be objective
- All information should be accurate
- Use clear and coherent language
- Easy to read
- Keep it simple
- Words to be used economically
- Be open-minded and insightful

The advantages and disadvantages of ***written communication*** are:

Advantages	Disadvantages
• The written word is more accurate than a spoken message	• Although the written word may be more accurate, it takes much longer to produce than a spoken message. It is thus more time-consuming.
• It is tangible, lasting and controllable.	• There is no automatic feedback.
• The message can be kept for an unlimited time	• The fact that a report or memorandum has gone out does not guarantee that it will be read!
• It is particularly suitable for a long correspondence	

14.2.2 Verbal and non-verbal skills

- **Verbal skills**

Verbal communication is communication that uses words, either written or spoken. This is in contrast to non-verbal communication, such as body language.

"Verbal" is sometimes used colloquially in the sense of "spoken", but it is better to use "oral" in that context, to avoid ambiguity.
Verbal communication can be categories into the following:

- o Informal discussions
- o Planned meetings and appointments
- o Telephone or mobile phone calls

Informal discussion and talks
You can work formally with someone or some group and yet not accomplish anything because the rapport and credibility that informal contact brings is missing.

The system works through personalities. You need to talk with people on all levels face to face, not merely through formal channels. People will be more willing to listen and to send information to you because they know you on a first-name basis and feel you understand their views.

Informal communication also helps to:

- o Identify who to talk to
- o Foster an honest atmosphere
- o Gather information
- o Identify problems
- o Develop respect for each other's perspectives
- o Communicate changes
- o Work with participants to solve common problems

Make it a point to provide opportunities for informal discussions. Get core team members involved with other groups on an informal basis. Attend meetings with organizations--people will probably appreciate your efforts. (They may kid you a little, but this also establishes rapport.) Have meals with representatives from different groups or adjourn to a restaurant after a formal meeting.

Planned meetings and appointments
This is where people can discuss feedback from various work projects. At these planned appointments supervisors should be adequately prepared to make such meetings complete and effective by being up to date, providing sufficient information and limiting interruptions.

Regular planned meeting appointments can be scheduled on a daily, weekly or monthly basis for extended projects.

Telephone or mobile phone calls
Phone skills are essential for maintaining a level of confidence with the person on the other end of the line.

They might be a prospective client, co-worker, boss, or current customer, but whoever they are it's going to help your career to carry a phone conversation with the right amount of command.

Figure 14.1 Effective communication using telephone calls

Essentially you need to communicate not only what you are saying clearly, but also that you understand what the other person is saying. In person, this is a lot easier. A head nod or simple grin can do the trick. However, on the phone you are invisible to the other person.

The advantages and disadvantages of ***verbal communication*** are:

Advantages	Disadvantages
• It is concise. • Feedback takes place immediately. • It is possible to determine whether the message was received correctly.	• The disadvantage of verbal communication is that if many people must convey the message, it can lose much of its accuracy.

- **Non-verbal skills**

When we communicate things that we care about, we do so mainly using nonverbal signals. Wordless communication, or body language, includes:

  - Facial expressions,
  - Body movement and gestures,
  - Eye contact,
  - Posture,
  - The tone of your voice, and
  - Even your muscle tension and breathing.

The way you look, listen, move, and react to another person tell them more about how you're feeling than words alone ever can.

Developing the ability to understand and use nonverbal communication can help you connect with others, express what you really mean, navigate challenging situations, and build better relationships at home and work.

  - You can enhance effective communication by using open body language—arms uncrossed, standing with an open stance or sitting on the edge of your seat, and maintaining eye contact with the person you're talking to.
  - You can also use body language to emphasize or enhance your verbal message—patting a friend on the back while complimenting him on his success, for example, or pounding your fists to underline your message.

Tips for improving how you read nonverbal communication

- Practice observing people in public places, such as a shopping mall, bus, train, café, restaurant, or even on a television talk show with the sound muted. Observing how others use body language can teach you how to better receive and use nonverbal signals when conversing with others.

- Notice how people act and react to each other. Try to guess what their relationship is, what they're talking about, and how each feels about what is being said.

- Be aware of individual differences. People from different countries and cultures tend to use different nonverbal communication gestures, so it's important to take age, culture, religion, gender, and emotional state into account when reading body language signals. An American teen, a grieving widow, and an Asian businessman, for example, are likely to use nonverbal signals differently.

- Look at nonverbal communication signals as a group. Don't read too much into a single gesture or nonverbal cue. Consider all of the nonverbal signals you receive, from eye contact to tone of voice to body language.

- Anyone can slip up occasionally and let eye contact slip, for example, or briefly cross their arms without meaning to. Consider the signals as a whole to get a better "read" on a person.

Tips for improving how to deliver nonverbal communication

- Use nonverbal signals that match up with your words. Nonverbal communication should reinforce what is being said, not contradict it. If you say one thing, but your body language says something else, your listener will likely feel you're being dishonest. For example, you can't say "yes" while shaking your head no.

- Adjust your nonverbal signals according to the context. The tone of your voice, for example, should be different when you're addressing a child than when you're addressing a group of adults. Similarly, take into account the emotional state and cultural background of the person you're interacting with.

- Use body language to convey positive feelings even when you're not actually experiencing them. If you're nervous about a situation—a job interview, important presentation, or first date, for example—you can use positive body language to signal confidence, even though you're not feeling it.

- Instead of tentatively entering a room with your head down, eyes averted, and sliding into a chair, try standing tall with your shoulders back, smiling and maintaining eye contact, and delivering a firm handshake. It will make you feel more self-confident and help to put the other person at ease.

14.2.3 Application of listening skills

Listening is one of the most important aspects of effective communication. Successful listening means not just understanding the words or the information being communicated, but also understanding how the speaker feels about what they're communicating.

Effective listening can:

- Make the speaker feel heard and understood which can help build a stronger, deeper connection between you.
- Create an environment where everyone feels safe to express ideas, opinions, and feelings, or plan and problem solve in creative ways.
- Save time by helping clarify information, avoid conflicts and misunderstandings.
- Relieve negative emotions. When emotions are running high, if the speaker feels that he or she has been truly heard, it can help to calm them down, relieve negative feelings, and allow for real understanding or problem solving to begin.

Tips for effective listening

If your goal is to fully understand and connect with the other person, listening effectively will often come naturally. If it doesn't, you can remember the following tips. The more you practice them, the more satisfying and rewarding your interactions with others will become.

- Focus fully on the speaker, his or her body language, and other nonverbal cues. If you're daydreaming, checking text messages, or doodling, you're almost certain to miss nonverbal cues in the conversation. If you find it hard to concentrate on some speakers, try repeating their words over in your head—it'll reinforce their message and help you stay focused.

- Avoid interrupting or trying to redirect the conversation to your concerns, by saying something like, "If you think that's bad, let me tell you what happened to me." Listening is not the same as waiting for your turn to talk. You can't concentrate on what someone's saying if you're forming what you're going to say next. Often, the speaker can read your facial expressions and know that your mind's elsewhere.

- Avoid seeming judgmental. In order to communicate effectively with someone, you don't have to like them or agree with their ideas, values, or opinions. However, you do need to set aside your judgment and withhold blame and criticism in order to fully understand a person. The most difficult communication, when successfully executed, can lead to the most unlikely and profound connection with someone.

- Show your interest in what's being said. Nod occasionally, smile at the person, and make sure your posture is open and inviting. Encourage the speaker to continue with small verbal comments like "yes" or "uh huh."

14.3 Organisational communication

Informal and Formal Communication are used in an organization.

Informal communication, generally associated with interpersonal, horizontal communication, was primarily seen as a potential hindrance to effective organizational performance.

This is no longer the case. Informal communication has become more important to ensuring the effective conduct of work in modern organizations.

We will discuss organisational communication with respect to the following communication channels:

- Vertical line
- Horizontal line
- Diagonal line

Figure 14.2 shows the channels of communication

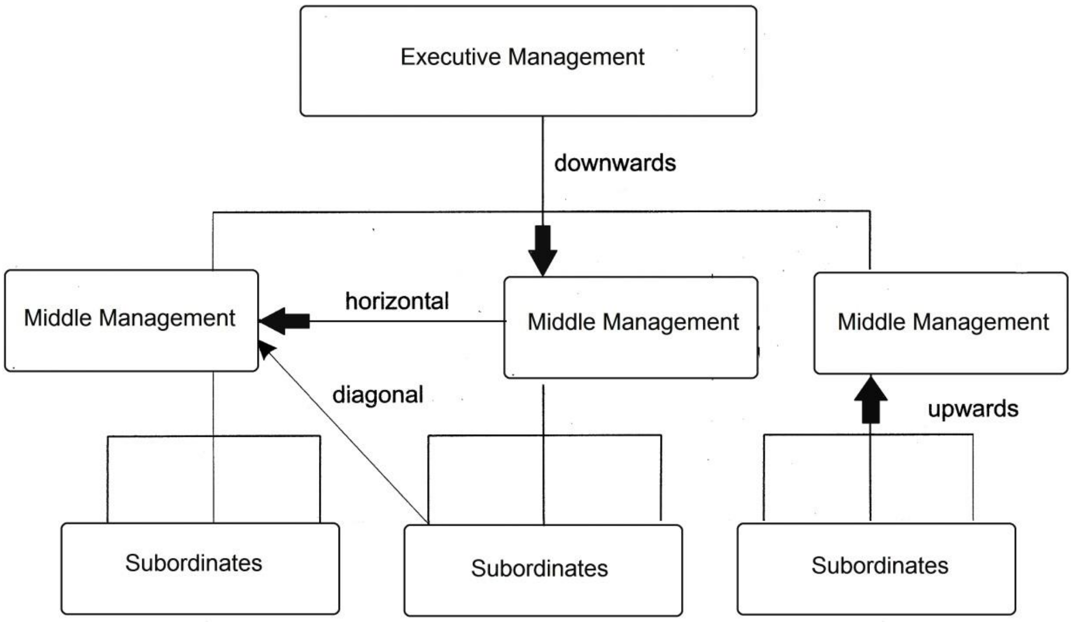


Figure 14.2 Channels of communication

Figure 14.3 shows the flow chart of organization communication

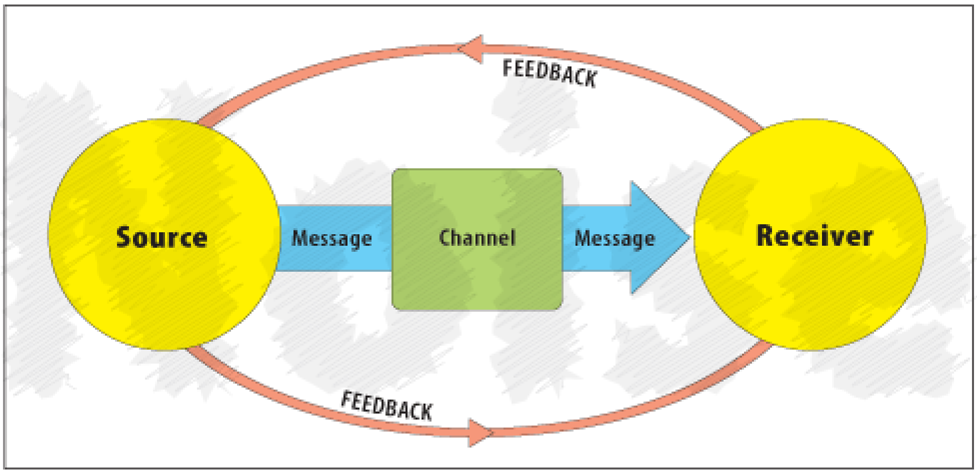


Figure 14.3 Organisational communication

14.4 Labour Relations Act

Many acts have been put into place to protect the rights of employees and employers in the workplace. This section will look at some of these rights and explain why they are in place. This section will also look at business ethics in the workplace.

14.4.1 The Labour Relations Act (No. 66 of 1995)

The reason/purpose for this Act is to advance economic development, social justice, labour peace and the democratisation of the workplace. Certain groups of people are excluded from this Act.

These people include members of the South African National Defence Force, the National Intelligence Agency, and the South African Secret Service. These people are excluded because their work is regarded as essential to the security of the country.

This Act covers various important aspects, such as:

- **Freedom of association**

Employees have the right to form and to join trade unions. In the same way employers have the right to form employer's organisations. These rights are recognised in many labour relations systems and are generally refered to as the right to freedom of association.

- **Organisational rights**

The Act allows trade unions to enter the places of work of the people that they are representing. The Act allows a trade union official to enter an employer's place of work in order to recruit members or to communicate with trade union members.

As long as meetings are held before or after working hours, a union may hold these meetings on an employer's premises. Employees who belong to a trade union may deduct subscriptions or levies payable to that trade union from his/her wages. This is done by authorising the employer, in writing, to do so.

- **Bargaining councils**

One or more trade unions and one and more employer's organisations are allowed to form a bargaining council. The purpose of a bargaining council is to resolve bargaining and dispute problems.

- **Statutory councils**

The purpose of this is to establish a statutory council in a sector in which no bargaining council is registered.

- **The Commission for Conciliation, Mediation and Arbitration (CCMA)**

The CCMA is made up of a director and commissioners. The CCMA does not belong to the state, any political organisation or any other organisation. It is completely independent. The functions of the CCMA are:

  - to resolve, through conciliation, any dispute referred to the CCMAin relation
  - to the Labour Relations Act
  - to arbitrate disputes that remain unresolved by these means

- to help with the establishment of workplace forums
- to compile and publish statistics concerning all its activities.

- **The Labour Court and Labour Appeal Court**

The Labour Appeal Court has the authority to:

- Hear and rule on all appeals against final judgments or final orders of the Labour Court rule on any questions arising from proceedings in the Labour Court.

- **Strikes and lock-outs**

A Strike means the partial or complete refusal to work (in co-operation with others).

A lock-out means the exclusion of workers by an employer from the employer's workplace, for the purpose of compelling the workers to accept a demand in respect of any matter of mutual interest between employer and worker, whether or not the employer breaches those employee's contracts of employment in the course of, or for the purpose of, that exclusion.

- **Collective agreements**

The goal of collective bargaining is to reach agreements. There are two types of agreements:

- Procedural agreements, which regulate how the party will handle the relationship
- Substantive agreements, which handle the content of the relationship and the conditions of service.

- **Unfair dismissals**

These include:

- Dismissal because of participating in legal strike.
- Dismissal because of refusal to do the work of another worker who is participating in protected strike action, unless that work is necessary to prevent actual danger to life, personal safety or health.
- Dismissal because of the worker's pregnancy.
- Dismissal because of unfair discrimination.

Grievance and disciplinary procedures:

- **Grievance procedure**

The definition for grievance is any aspect of the work with which the employees are unhappy, or in respect of which they feel they are being offended.

The advantages of an effective grievance procedure are that:

- It releases tension within the business
- It allows the worker to freely stipulate his/her complaints without fear of retribution or victimization
- It encourages honesty and openness between managers and workers.

- **Disciplinary procedures**

The definition of discipline is an action, on the part of the employer in a social system, which is aimed at stopping the trespasser's behavior because it threatens to disrupt the system from functioning at its best.

- **Disciplinary principles are:**
  - The right of management to take action against a worker who acts in such a way that a conflict of interest arises within the business.
  - The employee's right to a fair procedure.

14.4.2 The Unemployment Insurance Act (No. 30 of 1966)

Certain workers, their employers and the state must contribute to unemployment insurance. If the worker who contributed to this fund loses his/her job and has proved that he/she cannot find another job it is then possible to claim from this fund.

The amount that the worker will receive from the fund and the period for which he or she will receive it depends on the amount he/she contributed to the fund and the period during which he/she contributed.

14.4.3 The Basic Conditions of Employment Act (No. 3 of 1983)

This act regulates certain matters relating to the conditions of employment of certain employees and makes provision for secondary matters.
Matters that receive attention are:

- Working hours for day workers
- Working hours for shift workers
- Payment of overtime
- Payment of work on Sundays and public holidays
- Annual leave
- Sick leave
- Termination of service contracts
- Issuing of service certificates.

14.4.4 The Business Act (No. 71 of 1991)

The goal of this act is to repeal or amend laws regarding the licensing and operating of businesses, and shop hours, in order to make certain new provisions regarding such licensing and operating of businesses, and to provide for related matters.
Businesses that need a license are those that are involved in:

- The sale or provision of meat or perishable foodstuffs

- The provision of certain kinds of health facilities or entertainment.

14.4.5 Ethics in the workplace

Ethics is the term used to define a system of values or a moral system, based on ideas of what is right or wrong.

- **Ethical conduct**

Ethical conduct is conduct that embraces accepted social norms or values. Unethical conduct Unethical conduct is conduct that conflicts with the general social norms and values.

- **Business ethics in the work place**

Business ethics refers to the value system around business and what type of business conduct is right or wrong.

- **Code of conduct in the workplace**

Because people have different views on what is right and wrong it is important for businesses to set up a code of conduct. A code of conduct sets guidelines for ethical behaviour that workers must abide by.
A code of conduct should address the following issues:

- The basis of the code of conduct should be taken from the general social norms and values of the community in which the business operates.
- A code of conduct must be specific.
- Management must make certain that the code of conduct is adhered to.
- Employees who do not abide by the code of conduct should face disciplinary action.
- Remuneration should be based on ethical standards and on upholding these ethical standards.
- Employees should discuss situations with management.

14.4.6 Health issues in the workplace

Health and safety is an important issue in the workplace and many acts are in place to protect the worker from injury caused by accidents and from health issues that may arise at work.

These acts acknowledge the rights of workers and employers alike. This section focuses on certain acts concerned with health and safety, the legal framework relating to HIV/AIDS, the duties of employers and employees in terms of health and safety and first aid in the workplace.

14.5 Occupational Health and Safety Act

The Occupational Health and Safety Act (No. 85 of 1993).The reasons for the Occupational Health and Safety Act are to:

- Allow for the health and safety of persons at work

- Allow for the health and safety of persons in connection with the use of plant and machinery
- Protect persons other than persons at work against threats or hazards to health and safety arising out of or in connection with the activities of persons at work
- Establish an advisory council for the purpose of occupational health and safety
- Provide for issues connected with occupational health and safety.

This act is in place to ensure and protect the rights of employees. It is both the employee's and employer's duty to ensure that these rights are not abused.

14.5.1 The duties of the employer and the employee in terms of health and safety

There are certain responsibilities that both the employee and the employer must be aware of when it comes to maintaining health and safety in the work place.

The duties of employers to their employees:

- Employers should ensure that they provide and maintain systems of work, plant and machinery that are safe and without risks to health.
- Employers should take steps to try and eliminate or reduce hazards or potential hazards to safety or health of employees, before personal protective equipment is needed.
- Employers should make arrangements for ensuring the safety and absence of risks to health in connection with the production, processing, use, handling, storage or transport of articles or substances.
- Employers should provide information, instruction, training, and supervision in order to ensure the health and safety of employees.
- Employers should enforce measures that may be necessary in the interest of health and safety.

The duties of the employee:

- Employees should take reasonable care of his or her own health and safety and the health and safety of any other person/s that may be affected by his/her acts or omissions.
- Employees shall obey the health and safety rules and procedures lay down by the employer or by anyone authorised to do this by the employer, in the interest of health and safety.
- Employees should report any situation that appears to be unsafe or unhealthy to the employer or to the health and safety representative.
- Employees shall not intentionally or recklessly interfere with or misuse anything that is provided in the interest of health and safety.

14.6 Purpose of an administration system

Even a very small business needs a system for managing flows of information. At the very least, an owner-manager needs to know how much she is spending on inputs and other expenses, and how much she is selling, so that she can work out how much profit she is making.

In a large business, managing flows of information becomes a major task, and things can get out of hand quickly if proper administrative systems are not in place. Administrative systems are needed for at least the following:

- Paying suppliers or debtors.
- Keeping an accurate record of costs- direct production costs as well as overheads.
- Management of stock.
- Recording sales and information about customers.
- Invoicing and collecting revenue from customers or creditors.
- The remuneration of staff, including salaries and benefits.

The purpose of an administration system is to run a business effectively that will include:

- Organisation of administrative work
- Bookkeeping
- Costing
- Incoming and outgoing mail

With modern day technology most businesses use a management information system (MIS).

A management information system (MIS) provides information that organizations need to manage themselves efficiently and effectively.

Management information systems are typically computer systems used for managing FIVE primary components:

- Hardware,
- Software,
- Data (information for decision making),
- Procedures (design, development
- Documentation), and
- People (individuals, groups, or organizations).

Management information systems are distinct from other information systems, in that they are used to analyze and facilitate strategic and operational activities.

Figure 14.4: Without proper administrative systems to manage flows of information in a business, there will be chaos

Every business has its own administrative systems. There are many, many different ways of managing information flows in a business efficiently and effectively.

This means that there is no point in teaching or explaining in a textbook the details of a particular system. If you join a business or organisation as an employee, you will learn how their system works. If you start your own business, you will develop your own systems. The important thing to know is that administrative systems are important and deserve attention.

14.7 Production control documents

Within a production controlled environment, budget and budget control will apply to the entire running of the whole organization effectively.

The use of certain documentation is essential for an effective run organization. These include:

- Clock cards
- Job cards
- Requisition cards
- Production flow charts
- Maintenance schedules

The purpose of each document is discussed below:

Production control documents	Purpose
Clock cards	• It serves as a control on an employee's punctuality. • To indicate on which specific job the employee is working.

	• To keep record of the number of hours spent on a specific job. • To assist management to apply budget control
Job cards	• The operator is provided with a job card that specifies the work that must be carried out. • It is normally prepared by the production-control department from the route laid down by the production engineering department and can serve as authorization to the operator to carry out a specific job.
Requisition cards	• The purpose of requisitioning is to provide the correct materials in the correct quantities at the right place at the right time. • Requisitions are made by persons of all functional units in the organization.
Production flow charts	• Production flow charts are also known as route charts. • The operational layout in a production flow chart lists the different elements in the operation. • Most articles are manufactured by a number of separate operations. Production flow charts are used to summarise all the operations in a single reference. • Used to record the complete history of the work, from the initial issue of materials to the approval of the completed and inspected articles and their deposit in the finished-goods store.
Maintenance schedules	• To provide regular services in order to keep the machines in good running condition. • To avoid or minimise breakdown and time-loss periods that lead to a loss of production. • To keep a record of the type or nature of maintenance that has been done in order to establish the running costs of a machine. • To prevent a machine or a piece of equipment from causing an unsafe condition.

14.8 Budgeting and of controlling expenses

A business needs to work out what capital it needs. A capital budget is particularly important for a business that is just starting out, or a business that is expanding. In both situations, working out capital requirements in advance is important.

Expansion, for example, usually requires an investment in extra fixed capital and extra working capital. A cash budget will show the projected cash flows in and out of the business. That will provide the basis for estimating how much extra working capital is needed.

Budgeting and of controlling expenses for an organisation will include:

- A cash budget
- Capital budgets
- Budgeted balance sheets

14.8.1 Cash Budget

The cash budget helps management keep cash balances in reasonable relationship to its needs.

The purpose of a **cash budget** is for cash planning and control that presents expected cash inflow and outflow for a designated time period.

It aids in avoiding idle cash and possible cash shortages. The cash budget typically consists of four major sections:

1. Receipts section, which is the beginning cash balance, cash collections from customers, and other receipts;
2. Disbursement section comprised of all cash payments made by purpose;
3. Cash surplus or deficit section showing the difference between cash receipts and cash payments; and
4. Financing section providing a detailed account of the borrowings and repayments expected during the period

A **cash budget** is extremely important, especially for small businesses, because it allows a company to determine how much credit it can extend to customers before it begins to have liquidity problems.

14.8.2 Capital Budget

Capital budgeting (or investment appraisal) is the planning process used to determine whether an organization's long term investments such as new machinery, replacement machinery, new plants, new products, and research development projects are worth pursuing. It is budget for major capital, or investment and expenditures.

Definition: Capital budget
The process in which a business determines whether projects such as building a new plant or investing in a long-term venture are worth pursuing. Oftentimes, a prospective project's lifetime cash inflows and outflows are assessed in order to determine whether the returns generated meet a sufficient target benchmark.

A capital budget is a long term plan, and is important because capital expenditure will directly influence the ability of the business to be competitive in the long run.

14.8.3 Budgeted balanced sheet

A budgeted balanced sheet is a schedule for expected assets, liabilities, and stockholders' equity. It projects a company's financial position as of the end of the budgeting year. Reasons for preparing a budgeted balance sheet follow:

1. Discloses unfavorable financial condition that management may want to avoid;
2. Serves as a final check on the mathematical accuracy of all other budgets; and
3. Highlights future resources and obligations.

The **budgeted balanced** sheet includes all other budgets. The purpose of the budgeted balance sheet is to give management an indication of what the situation will be at the end of the period, usually a year, in terms of assets, liabilities and the interest of the owners.

This budget can be viewed as a final verification of the planned programmes and activities of the business.

14.9 Labour efficiency to improve and increase productivity

Measuring labour productivity is an important step in identifying the drivers of high and low productivity.

Traditionally, the main drivers of productivity were considered to be outside the control of individual organisations, such as investment in education and training, science and research, and infrastructure.

However, it is increasingly recognised that improvements in labour productivity are also driven by issues that are within the control of individual organisations. These include human capital, organisational infrastructure and investment and use of technology.

Productivity is an average measure of the efficiency of production. Productivity is a ratio of production output to what is required to produce it (inputs of capital, labour, land, energy, materials, etc.). The measure of productivity is defined as a total output per one unit of a total input. We see that as a measure of the average productivity is often difficult to interpret correctly.

14.9.1 Factors determining the efficiency of labour

1. **Personal qualities**: - Some people have some personal qualities and they are suitably built foe certain heavy labour. On other hand some people are very suitable for mental labour. Family background also pays very important role in this regard.

2. **Education**: - It is the basic and essential element which determines the efficiency of labour. Educated labourer is more efficient as compared to the illiterate worker.

3. **Training and skill**: - The modern world requires highly skilled labourers. A labourer with sound technical training will be more effective as compared to a labourer who has no training. It increases the efficiency of the labourer.

4. **Climatic conditions: -** Climates also plays an important role in increasing or decreasing the efficiency. Hot and cold weather has a vital factor for the low efficiency of labour. On other hand cold weather is an important element for increasing the efficiency in labour in U.S.A and Europe.

5. **Wages and benefits: -** If wages, allowances, bonuses and other benefits are given to the workers, then their working efficiency increases. Labourer works very hard if he has attractive salary. On other hand if wages rate is low then efficiency of the labourer will be also low.

6. **Combination of production factors: -** If the other three factors of production combination are ideal then efficiency of labourer will be high otherwise low.

7. **Working hours: -** If working hours of labourer is reasonable then the efficiency will be high. If the working time is very long and without extra payment then efficiency of the worker will be low.

8. **Environment: -** If the working environment is pleasant then efficiency of labourer will be high. It is observed that labourer working in air conditions rooms and healthy conditions are more efficient as compared to others.

9. **Racial qualities: -** By birth some races are very hard working and strong built so they are more efficient as compared to other races.

14.9.2 Factors promoting efficiency of labour

Following are the important factors which promote the efficiency of labour:

1. **Increase in wages: -** Increase in wages and fringe benefits promote the efficiency of labour. When wages and incentives will increase it will make the labourer hard worker and efficient.

2. **Technical education: -** Vocational, technical and commercial colleges, should be opened to provide technical skill to the people. Modern industry, agriculture, banking, transport and commerce require highly skilled persons. Such type of training and skill is provided in the colleges and universities.

3. **Care of health: -** Health facilities should be provided to the labourers. A healthy worker can work more efficiently as compared to sick worker. All the factory owners should opened the health clinics in their factories and regular medical check-up should be compulsory.

4. **Increases in allowances: -** Various types of allowances like dearness and bonus must be increased. Special allowances should be given to the efficient workers.

5. **Labour laws: -** Government should also frame the strict labour laws. In case of accident special compensation should be given. In case of industrial dispute courts should be established. This step will provide the security to the labourers and they will work with full concentration.

6. **Special stores: -** To provide the goods on lower rates to the labourer's special stores should be opened for the workers.

7. **Establishment of the canteen: -** Lunch and dinner facility should be provided to the workers. On the lower rates food should be provided during the working interval. In this way time of the workers will be saved and their efficiency will increase.

Activity 14.1

1. Briefly describe effective communication skills in a multi-cultural environment with regard to:
   a) Writing and compiling reports and memoranda
   b) Verbal and non-verbal skills
   c) Application of listening skills

2. List the advantages and disadvantages for:
   a) Written communication
   b) Non-verbal communication
   c) Verbal communication

3. Discuss by means of a flow chart the organisational communication with respect to the following communication channels:
   a) Vertical line
   b) Horizontal line
   c) Diagonal line
4. Briefly describe the basic outlines of the following Acts:
   a) Labour Relations Act regarding:
      i. Grievance
      ii. Discipline
      iii. Employment
   b) Occupational Health and Safety regarding:
      i. Incidents
      ii. Duties
      iii. Records
5. Describe the purpose of an administration system.
6. Briefly describe the purpose of each of the following documents:
   a) Clock cards
   b) Job cards
   c) Requisition cards
   d) Production flow charts
   e) Maintenance schedules
7. Describe the purpose of budgeting and of controlling expenses.
8. Describe labour efficiency to improve and increase productivity.
9. Discuss the factors determining the efficiency of labour.
10. Discuss the factors promoting efficiency of labour.

Self-Check

I am able to:	**Yes**	**No**
• Briefly describe effective communication skills in a multi-cultural environment with regard to:		
o Writing and compiling reports and memoranda		
o Verbal and non-verbal skills		
o Application of listening skills		
• Discuss organisational communication with respect to the following communication channels:		
o Vertical line		
o Horizontal line		
o Diagonal line		
• Briefly describe the basic outlines of the following Acts:		
o Labour Relations Act regarding, grievance - discipline – employment		
o Occupational Health and Safety regarding, incidents - duties - records		
• Describe the purpose of an administration system		

• Briefly describe the purpose of each of the following documents:		
o Clock cards		
o Job cards		
o Requisition cards		
o Production flow charts		
o Maintenance schedules		
• Describe the purpose of budgeting and of controlling expenses		
• Describe labour efficiency to improve and increase productivity		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 15

Entrepreneurship

Learning Outcomes
By the end of the module, you should be able to:

- Explain in basic terms the concepts:
  - Entrepreneurship
  - Small business enterprise
- Name and briefly describe five characteristics of an entrepreneur and complete a self-analysis
- Name and explain the process of generating ideas for establishing a small business
- Describe the general resources necessary for the small business entrepreneur
- Name and briefly describe the factors that will influence the location of a small business enterprise

15.1 Introduction

Entrepreneurship is seen as the driving force behind economies today. Small, medium and micro-enterprises (SMMEs) play an important role in addressing the problems of job creation, poverty and sustainable economic growth.

15.2 Entrepreneurship

Much research has been conducted into answering questions like these:

- Who is an entrepreneur?
- Can we identify particular characteristics and qualities common to successful entrepreneurs?
- Are you born an entrepreneur or can you learn to be one?

In general, the results of the research show that entrepreneurs possess a range of identifiable characteristics and qualities. There is also evidence to suggest that entrepreneurial skills can be learnt and applied successfully.

There are many different definitions of an entrepreneur:

- An entrepreneur is a person who recognizes business opportunities, has the courage to seize them, and has the ability to manage them.
- An entrepreneur is a person who produces a good or service which he then sells in order to make money.
- An entrepreneur is a person with the ability to identify business opportunities and the courage to utilize and manage these opportunities so as to make a profit.
- An entrepreneur is a person with the knowledge and the skills to combine and co-ordinate the factors of production in such a way as to make a profit.

- An entrepreneur is a person who recognizes new business opportunities, invents new methods of production, successfully establishes new markets and initiates growth by providing new job opportunities.
- An entrepreneur is an individual who organises, owns, manages and assumes the risks of a business.

15.3 Characteristics of an entrepreneur

Just as there is no universal list of traits and characteristics to describe every entrepreneur, there is not a universal list of characteristics that makes for success in business.

The skills and characteristics required for success will vary from one type of business to another. Nevertheless, five characteristics have been identified as having primary importance for entrepreneurial success. Although not all-inclusive, most successful small business owners possess the following traits:

- **High achievement drive:** Successful entrepreneurs are high achievers. They both want and need to get things done. They are action-oriented people who enjoy and strive for success in everything that they do.
- **Creativity:** Another characteristic of successful entrepreneurs is their ability to be creative. Creativity can be defined as the ability to think of new, original and meaningful ideas. The successful entrepreneur needs to be able to think creatively so that he or she can solve problems and generate innovative ideas and products.
- **Business know-how:** Successful entrepreneurs need the business know-how skills. They need to know how to manage and run a business. The entrepreneur uses business know-how to develop competitive strategies and organise his or her business efficiently. The entrepreneur must understand accounting, marketing, psychology, advertising, management, law, and economics, if he or she hopes to make a success of the business.
- **Human relationship skills:** Successful entrepreneurs have good human relationship skills- that are; they know how to get along with others, including their employees, business associates, suppliers, and customers. In particular, they know how to communicate, motivate, and lead.
- **Technical competence**: The characteristic most important for success in small business is technical competence- entrepreneurs need to know what

they are doing. A computer salesman who knows nothing about computers, a motor mechanic who tunes cars badly, and a landscape architect, who designs eyesores, will soon find themselves out of business. The first thing that an entrepreneur must know is the 'how-to-do-it' side of the job.

15.4 Profile of the typical entrepreneur

No two people are exactly alike and entrepreneurs are no exception. Nevertheless, certain characteristics are so common among those who start their own business that it is possible for us to identify a profile of the typical entrepreneur.

- Entrepreneurs are usually self-confident individuals.
- Entrepreneurs tend to be action-orientated, emotionally charged, energetic people.
- Many entrepreneurs have no university degree.
- Entrepreneurs usually have high standards and cannot tolerate mediocrity. They tend to judge themselves and their employees harshly when they make mistakes.
- Entrepreneurs like to be in control.
- Entrepreneurs are goal-orientated and they cannot tolerate failure. Success is the only result acceptable to them and they often become workaholics in their quest for success.
- Entrepreneurs are impatient and tend to get bored with the planning and administrative aspects of their work.
- Entrepreneurs tend to believe that they are always right, and it is difficult for them to take advice.
- Entrepreneurs are calculated risk takers.
- Entrepreneurs are good communicators who can generate enthusiasm in others.
- Many entrepreneurs are not strong in money matters. They do not see the point in carefully monitoring the flow of money in and out of their business.
- Many entrepreneurs are so focused on their products that, left to their own
- devices, they would manufacture enough widgets to fill an entire warehouse before they realised that they need to market their product.
- Above all else, entrepreneurs are visionaries. They see a vision of the future, and they strive to make their vision a reality.

15.5 Small business enterprise

What constitutes a small business varies widely around the world. Small businesses are normally privately owned corporations, partnerships, or sole proprietorships. What constitutes "small" in terms of government support and tax policy varies by country and by industry, ranging from fewer than 15 employees to 50 employees. Small businesses can also be classified according to other methods such as sales, assets, or net profits.

Small businesses are common in many countries, depending on the economic system in operation. Typical examples include: convenience stores, other small shops (such as a bakery or delicatessen), hairdressers, tradesmen, lawyers, accountants, restaurants, guest houses, photographers, small-scale manufacturing, and online business, such as web design and programming, etc.

15.6 General resources necessary for the small business entrepreneur

As an entrepreneur you will need resources necessary to succeed in a small business. The following THREE general resources will be needed:

- Finance
- Contacts
- Knowledge and skills

Let us discuss briefly some basic and general resources needed:

1. Finance

Before you set up a small business it is essential for you to know how much capital will be required to fund the start-up, and from where these funds will be obtained.

2. Contacts

You will need to build up a data base of contacts. So to get to know the right people in the right places is important. Clients or customers are vital to any small business. The customer is the person or organisation that pays for the goods or services the business produces. These contacts can also bring along other contacts and even assist with advice.

3. Knowledge and skills

When starting up a small business an entrepreneur should have some knowledge and skills in the type of product or business that he or she intends running. Knowledge of the product and how it works is of utmost importance so that your employees that are doing the work in the business will be benefiting the business. So then to start with something that you are very knowledgeable and have the technical skills is a must.

15.7 Process of generating ideas for establishing a small business

Not all potential business ideas are good ideas. Some potential ideas are impossible to implement, others are illegal while others involve work that may not appeal to the entrepreneur. Good business ideas are ideas which satisfy the following conditions:

- The product or service is something which consumers want.
- The work involved is something that you like doing.

- The work involved is something that you can do.
- You are able to acquire the necessary skills and knowledge to do the work.
- The product or service is better than or different from, existing products and services. If it is different, the difference must be important and of value to some people.
- The market must not be saturated. There should not be too many businesses already offering a similar product or service in the area that you wish to set up your business.

Before starting a business you would need to do market research. Let us discuss this briefly.

15.7.1 Market research

Entrepreneurs use market research to collect information about a product or service. Market research is used to find out what consumers think about a product or service, how much they are prepared to pay for a product or service and how the product or service can be improved. The information obtained from the market research is then used to make business decisions.

Before starting a new business it is advisable to do market research in order to discover:

- What consumers think about your product or service?
- Whether there are other products or services that may be in competition with you.
- Whether consumers will be willing to purchase the product or service.
- How much of the product or service consumers will be prepared to pay for the product or service.
- How much of the product or service they are willing and able to purchase.

Whenever an individual does research of this nature there is a real danger that they only hear what they want to hear and they will thus 'force' the research to confirm their initial ideas.

This tendency to interpret data to confirm your own ideas is known as research bias. When doing your initial market research try to avoid research bias by being objective.

If the feedback from people is negative, or if the competitions' products are very good, you should ask yourself honestly whether your idea is a good one.

Sometimes entrepreneurs do market research by means of focus groups. A focus group is made up of a number of potential consumers who are asked to discuss various aspects of the product or service.

The content of this discussion is then recorded and analysed to make business decisions. Focus groups are not the only way to collect market data.

Questionnaires and surveys can also be used to collect valuable information from consumers.

Before starting a business you would need to do also do a SWOT analysis. Let us discuss this briefly.

15.7.2 SWOT analysis

SWOT analysis is a teb1nique that is used to evaluate a situation from different perspectives in order to make strategic decisions. This technique is used to identify the strengths, weaknesses, opportunities and threats of a particular situation, product or service.

A SWOT analysis can be done in any situation but it is particularly useful in evaluating a new potential business idea.

In order to do a SWOT analysis of a business you need to identify:

- Possible internal strengths
- Possible internal weaknesses
- External opportunities
- External threats.

Identification of factors in each of the categories is best done by means of brainstorming.

Thoughts and perceptions are merely listed and suggestions are consolidated without stopping to discuss them.

Once an extensive list of strengths, weaknesses, opportunities and threats have been identified, the factors can be discussed, evaluated and refined. At this stage, factors which are not applicable can be deleted from the list.

When evaluating the factors identified, the following questions should be considered:

- Which of the weaknesses have the greatest debilitating effect on the strengths?
- Which of the strengths will best enable us to overcome the weaknesses?
- Which of the weaknesses have the greatest effect on the realisation of the opportunities?
- Which of the strengths will best enable us to realise the opportunities?
- Which of the weaknesses have the greatest effect on the ability to deal with external threats?
- Which threats constitute the most serious problem to the organisation?
- Which opportunities present the greatest possibility for success?

The information gained from doing a SWOT analysis will help an entrepreneur reject potential business ideas which are unsuitable for implementation.

A SWOT analysis can also to identify how a potential business idea can be refined and improved.

What about the financial viability? Let us discuss this briefly.

15.7.3 Financial viability

Research the feasibility of your business. To do this you need to take a look at the following things:

1. **Determine all costs**. Fixed and variable costs (including setting up costs, operating costs once-off annual costs such as audit fees), need to be accurately determined.
2. **Prepare a cash flow projection**.
3. **Determine your business' break-even point**. Will you be able to produce and sell big enough quantities to get beyond the break-even point?

- **Fixed costs**

Fixed costs are those business costs that are not directly related to the level of production or output. In other words, whether the business has zero output or high output, the level of fixed costs will remain broadly the same.

Examples of fixed costs:

- rent and rates
- research and development
- administration costs
- depreciation
- marketing costs (non-revenue related)

- **Variable Costs**

Variable costs are those costs which vary directly with the level of output. They represent payment for output- related inputs such as raw materials, direct labour, energy (e.g. petrol) and revenue-related costs such as commission.

A distinction is often made between ' direct' variable costs and ' indirect' variable costs.

Direct variable costs are those which can be directly attributed to the production of a, particular product or service and allocated to a particular cost centre. Raw materials and the wages of those working on the production line are good examples.

Indirect variable costs cannot be directly attributed to production but they do vary with output. These include some types of depreciation (where it is calculated related to output e.g. machine hours), maintenance and certain labour costs.

Break-even analysis is a technique widely used by production management and management accountants. It is based on categorising production costs between those which are ' variable' (costs that change when the volume of production changes) and those that are 'fixed' (costs not directly related to the volume of production).

Total variable and fixed costs are compared with sales revenue in order to determine the level of sales volume, sales value or production volume at which the business makes neither a profit nor a loss (the 'break-even point').

15.8 Factors that will influence the location of a small business enterprise

Regardless of the type of business you have, there are some general factors that will influence the location of your business. The most important of these factors are:

- **Personal factors**. One of the most important factors in determining the location for your business are your personal preferences and values. Where do you want to live? Do you have a preference for a small town or a big city? Do you want to be near your relatives or far from them? Do you prefer a warm climate or a cold one? All of these personal factors will influence your decision about where to locate your business.

- **Economic factors**. The purchasing power of the community will also influence your decision about where to locate your business. The number of people employed in the area, total family income, bank deposits, per capita retail sales, and the number and value of homes in the area. These statistics indicate whether the community is thriving economically, or just getting by.

- **The existence of competition**. The existence of competition can be a good or bad thing, depending on whether the business thrives on it or is destroyed by it.

  Retail shops that are located in shopping centres usually do quite well if there is competition in the same shopping centre. Since there is a large volume of traffic the retailer just needs to ensure that he or she gets a 'fair share' of this business.

  Manufacturers who are not dependent on the local market also do well in an environment with healthy competition. On the other hand, some businesses (for example, small grocery wholesalers) can be severely hurt by competition.

- **Geographical factors**. Another area of concern in locating a business is geographical considerations. Such factors like 'nearness to the market' are important. Some goods must be located near to where they are sold. For example, bricks require production close to their market because they are heavy and it is thus expensive and difficult to transport them long distances.

  Likewise manufacturing and processing plants must be located in areas where they have' easy access to their inputs and raw materials. The availability and supply of labour is another important geographical consideration.

  Sometimes the specific location of a business is determined by where adequate labour can be found. If people with a particular skill live in a certain area, then that is where the business must be established.

- **Legal factors**. Various codes, ordinances, by-laws, regulations, restrictions and laws will influence and determine the location of a business. The entrepreneur needs to analyse these laws and regulations before deciding on a location.

  For example, zoning regulations dictate where and under what conditions a business may operate. In addition, building, electrical, plumbing, fire, health, labour and other codes require that the operation of a business meet certain standards in order to protect the public's health and safety.

15.8.1 Specific factors in selecting a location

In addition to the general factors discussed above, there are specific factors which influence the location decisions of different businesses. We will examine some of the specific factors that determine the location of a retail business and the specific factors pertaining to a manufacturing business.

15.8.2 Factors influencing location of an engineering retail outlet

Retail businesses have location problems that are different from those of other small enterprises. The following factors are among the most important considerations for the owners of retail businesses:

- **Size of the town**. Small towns are often a good location for small retail businesses. Many large retail chains have minimum size requirements for towns in which they locate.

  As a result, the retailers in small towns need not be concerned about competition from these large retail giants. This does not mean that small business cannot survive in large cities. For example, variety stores, lunch counters and bottle-stores appear to do equally well in big or small communities.

However, some types of business require a large number of customers and are thus not likely to do well in small towns. Examples include delicatessens, optical shops and speciality stores for the sale of such products as office and school supplies, cameras, books and cigars.

- **Availability of parking**. Availability of parking is a very important consideration for the owner of a retail store. People like to park in safe places that are not far away from the shops they are going to. For this reason, retail stores need to be located close to suitable parking.

- **Crime**. People like to know that they will be safe while doing their shopping. In addition, entrepreneurs need to know that their business is not going to be robbed. For these reasons the level of crime in the area is an important factor in determining the location of a retail business.
- **Accessibility and visibility**. Retail businesses generally need to be located in areas where they are clearly visible to consumers. They should also be in positions where customers have easy access to the shop. It may be useful for the entrepreneur to locate the business somewhere where he or she can put up a large signboard or advertisement.

15.7.3 Factors influencing location of a manufacturing business

The biggest problem facing the owner of a small manufacturing business is that once the building is built and the equipment in place, the cost of moving may be prohibitive. Thus, it often makes sense to rent facilities rather than build them. Keeping this in mind, the entrepreneur needs to seek a location at which the combined cost of production and distribution are minimised. Some of the factors that will influence the overall decision about where to locate the factory include:

- Proximity to markets
- Proximity to suppliers
- Adequacy and cost of labour
- Government and local regulations and taxes
- Transportation services and costs (accessibility to harbours, railways and airports if needed)
- Cost of land and building or the level of rent.

15.7.4 General points to remember about location

In addition to the factors identified and discussed above, it is also important to consider the following when deciding on the location of a business:

- Study and evaluate the selected area carefully.
- Avoid areas of traffic congestion.
- Check on the ownership of vacant lots and attempt to determine future building plans. The image of the area may be a key factor.
- Check the success and failure record of nearby businesses- they provide a track record for the area.

- Evaluate daily, weekly and evening traffic patterns in the area.
- Be careful of highly polluted areas.

Activity 15.1

1. Explain in basic terms the concepts:
   a) Entrepreneurship
   b) Small business enterprise
2. Name and briefly describe FIVE characteristics of an entrepreneur and complete a self-analysis
3. Name and explain the process of generating ideas for establishing a small business
4. Describe the general resources necessary for the small business entrepreneur
5. Name and briefly describe the factors that will influence the location of a small business enterprise

Self-Check

I am able to:	Yes	No
• Explain in basic terms the concepts:		
o Entrepreneurship		
o Small business enterprise		
• Name and briefly describe five characteristics of an entrepreneur and complete a self-analysis		
• Name and explain the process of generating ideas for establishing a small business		
• Describe the general resources necessary for the small business entrepreneur		
• Name and briefly describe the factors that will influence the location of a small business enterprise		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Past Examination Papers

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

AUGUST 2011

NATIONAL CERTIFICATE

MECHANOTEHNOLOGY N3

(**8190373**)

22 July (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Calculators may be used.

This question paper consists of 9 pages, 2 table sheets and a formula sheet.

TIME: 3 HOURS
MARKS: 100

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. ALL the drawings must be large, clear, neat and in good proportion.
4. Keep questions and subsections of questions together.
5. Number the answers correctly according to the numbering system used in this question paper.
6. Write neatly and legibly.

QUESTION 1: POWER TRANSMISSION

1.1 A hammer mill is driven by an electrical motor for a duty period of six hours per day. The designed power of the electric motor is 15 kW and the speed is 1 440 r/min.

The recorded information for this wedge belt power transmission is as follows:

Power increment per belt:	0,7kW
Duty operation type:	'heavy duty'
Speed ratio:	1,69: 1
Diameter of hammer mill shaft:	100mm
Type of start:	'heavy'
Belt length:	± 2300mm

Refer to the attached TABLE 1 and TABLE 2.

1.1.1 Determine the correction factor for this drive. (1)
1.1.2 Determine the pitch diameter for the driver. (1)
1.1.3 Determine the basic power per belt (assume there is no power loss). (1)
1.1.4 Calculate the corrected power per belt. (3)
1.1.5 Calculate the number of belts that can be used for this drive. (3)

1.2 Refer to FIGURE 1 below and answer the questions that follow.

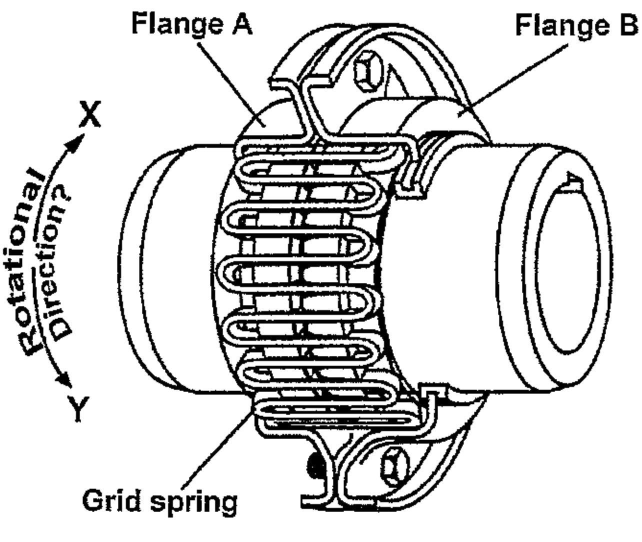


FIGURE 1

1.2.1 Name the type of coupling. (1)
1.2.2 What type of load can this coupling transmit? (1)
1.2.3 Name the types of speeds that this coupling can transmit. (1)
1.2.4 Will the drive direction be towards X or towards Y or, towards both X and Y? (1)

1.3 Refer to FIGURE 2 of the gear system below and answer the questions that follow.

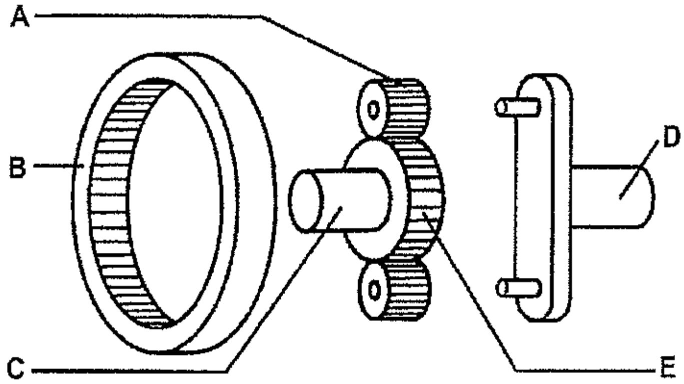


FIGURE 2

1.3.1 Name the type of gear system shown. (1)

1.3.2 Label the different parts (A - E) as indicated. Write the answers below one another in the ANSWER BOOK. (5)

[19]

QUESTION 2: BRAKES

2.1 State **TWO** disadvantages of the hydraulic braking system. (2)

2.2 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (2.2.1 - 2.2.3) in the ANSWER BOOK.

2.2.1 The brake shoes around the drum of the electromagnetic braking system will disengage (release) in the case of a power failure, thus causing the load to fall. (1)

2.2.2 A disadvantage of the disc brake system is that water and dust are not thrown off easily by the centrifugal force and enters the friction surface easily and thereby causing excessive wear on the friction surfaces. (1)

2.2.3 The smaller the angle of the wedge with the axis on the cone brake system, the smaller the axial force needed to operate this brake. (1)

[5]

QUESTION 3: BEARINGS

3.1 Refer to FIGURE 3 below of the anti-friction bearing and answer the questions that follow.

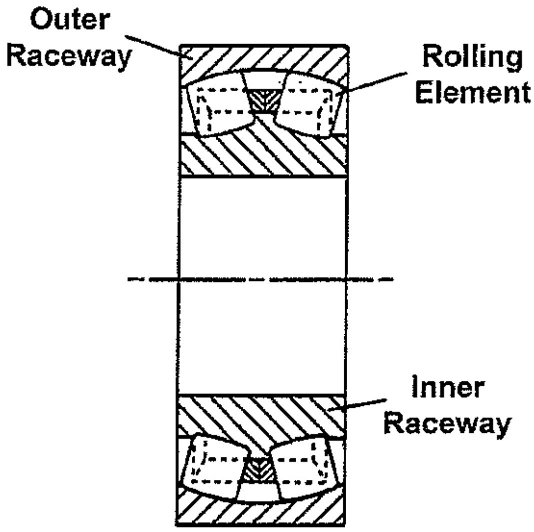


FIGURE 3

3.1.1 Name the type of bearing shown. (1)
3.1.2 What types of loads can the bearing carry? (2)
3.1.3 Briefly describe the main advantage of the bearing. (1)

3.2 Name the **FIVE** main categories into which friction bearings can be classified. (5)

3.3 A bearing must be chosen to fit onto a 95 mm diameter shaft. The radial space available is 180 mm and the axial space available is 45 mm. The bearing must be able to carry a static load of approximately 34 350 N. Refer to TABLE 3 below and choose the applicable bearing. (1)

Principal Dimensions in millimetres			Basic load ratings in Newton		Bearing Number
d	D	B	Dynamic (N)	Static (N)	
95	170	32	34 500	24 000	1209
95	170	43	83 200	34 500	2219
95	200	45	133 000	51 000	1319
95	200	67	165 000	64 000	2319

TABLE 3

[10]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 Briefly describe **THREE** advantages of the external stuffing box as applicable to plunger pumps. (3)

4.2 Describe, with regard to lubrication, **FOUR** reasons for the purpose of oil filtering. (4)

4.3 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (4.3.1 - 4.3.2) in the ANSWER BOOK.

4.3.1 The manometric head is the vertical distance or height at which a pump can deliver fluids under perfect conditions. (1)

4.3.2 The heat exchanger consists of a bundle of tubes and a shell and. the water circulating around the tubes, and is often referred to as 'saturated water'. (1)

4.4 Refer to FIGURE 4 below and answer the questions that follow.

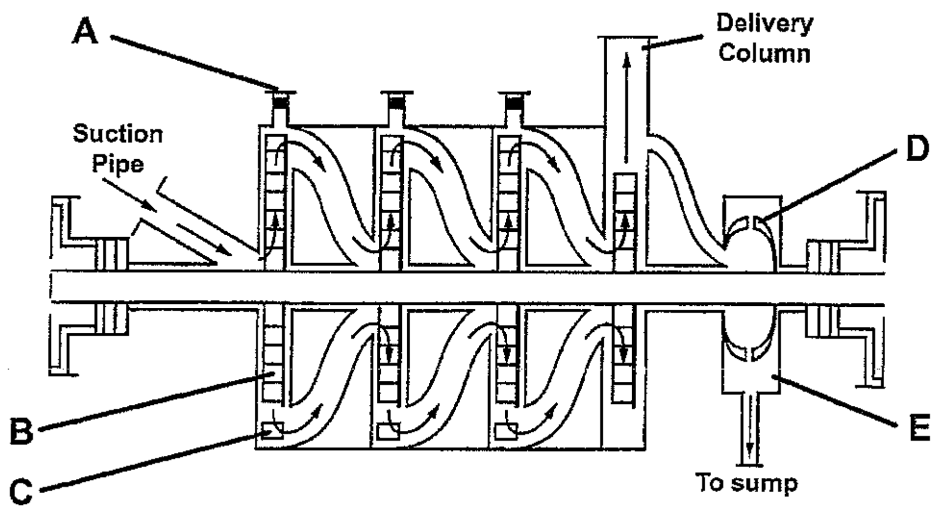


FIGURE 4

4.4.1 Name the type of water pump. (1)
4.4.2 Label different parts (A - E) as indicated. Write the answers below one another in the ANSWER BOOK. (5)

[15]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1 The volume of a hydraulic cylinder is 10 000 cm^3 and during the operation process the plunger moves a distance of 5 mm when a pressure of 450 kPa is applied to it.

Use $\pi = 3{,}1416$

Calculate the following:

5.1.1 The cross sectional area of the plunger. Express the answer in m^2 (1)
5.1.2 The force applied during the operation. Express the answer in kN (3)

5.1.3 The work done during the process if the plunger moved a distance of 80 mm. Express the answer in Joule (2)

5.2 Briefly describe **THREE** negative results when the viscosity of hydraulic oil is too high when used in a hydraulic system. (3)

5.3 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (5.3.1 and 5.3.2) in the ANSWER BOOK.

5.3.1 The working operation of hydraulic systems is slower when compared to that of pneumatic systems due to changes in fluid viscosity. (1)

5.3.2 The overall efficiency of compressors and pneumatic actuators is higher in contrast· to that of hydraulic pumps and hydraulic actuators. (1)

[11]

QUESTION 6: INTERNAL COMBUSTION ENGINES

Briefly describe the induction stroke of the four-stroke diesel engine.

[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1 Briefly describe **FIVE** advantages of a crane on a bogie on a rail. (5)

7.2 Briefly describe **THREE** advantages of the infrared signal remote control when comparing it to the driver's cabin on the overhead crane. (3)

[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1 Briefly explain what a *non-ferrous metal* is and give an example of it. (4)

8.2 Metals are identified according to their colour codes in the industry. Give the identifying colour codes for the following metals as standardised by the SABS:

8.2.1 High carbon steel (1)
8.2.2 Structural steel (1)
8.2.3 Cast steel (1)

[7]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 Describe the purpose of a grievance procedure. (4)

9.2 Name **FOUR** listening skills that can improve the effectiveness of the communication process. (4)

9.3 A written communication is a report that is intended to convey information to colleagues. State **FOUR** characteristics of a good report. (4)

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 Briefly describe the term *service business* as a business opportunity for a small business enterprise. (4)

10.2 As a proprietor or entrepreneur, you should be able to work with and manage your own book keeping. A proprietor makes an extra profit of R5 200.00 this month. (4)

On advice, he was told to pay off his debt and allocate some of the money to each company where he still has an outstanding balance.

It was proposed that he allocates the profit according to the ratio that he owes these companies. This action was only to reduce his existing outstanding debt partially.

Calculate the amount of the extra profit for this month which the proprietor will allocate to each company.

Company:	**Outstanding Debt:**
Company A	R4 500,00
CompanyB	R2 500,00
Company C	R6 000,00

[8]

TOTAL: 100

TABLE 1

BASIC POWER PER BELT (kW) – SPB WEDGE BELTS

r/min of faster shaft	Rated power (kW) per belt for small pulley pitch diameter (mm)													Belt Speed (m/s)
	140	150	160	170	180	190	200	212	224	236	250	280	315	
500	2,52	2,93	3,35	3,76	4,17	4,58	4,99	5,47	5,96	6,44	6,99	8,18	9,53	
600	2,92	3,41	3,90	4,39	4,87	5,36	5,83	6,41	6,97	7,54	8,19	9,58	11,17	
720	3,38	3,96	4,54	5,11	5,68	6,25	6,81	7,49	8,15	8,82	9,58	11,21	13,06	10
960	4,23	4,99	5,73	6,47	7,21	7,94	8,66	9,52	10,38	11,23	12,20	14,26	16,60	
1200	5,02	5,93	6,83	7,73	8,62	9,50	10,38	11,41	12,44	13,45	14,61	17,05	19,70	
1440	5,73	6,80	7,85	8,89	9,93	10,95	11,95	13,15	14,32	15,48	16,80	19,55	22,57	20
1800	6,68	7,96	9,21	10,45	11,68	12,88	14,06	15,45	16,81	18,13	19,64	22,70	25,96	
2100	7,36	8,80	10,19	11,58	12,93	14,26	15,55	17,07	18,53	19,95	21,54	24,71	27,96	30

TABLE 2

CENTRE DISTANCES FOR 16N SPB WEDGE BELT DRIVES

Combined arc and belt length Correction factor					0,8			0,85			0,9				1,05			
Speed Ratio	Pitch diameter of pulleys		Power per belt kW		BELT LENGTH													
	Driver	Driven	960 r/min	1 440 r/min	1 260	1 340	1 410	1 590	1 800	1 900	2 020	2 150	2 280	2 400	4 560	4 820	5 070	5 380
1,69	236	400	11,94	16,56	-	-	-	-	392	443	504	570	635	696	1 779	1 909	2 034	2 189
1,75	160	280	6,45	8,92	278	319	355	446	551	602	662	727	792	852	-	-	-	-
1,75	180	315	7,92	11,00	-	273	309	401	507	557	618	683	748	809	-	-	-	-
1,78	200	355	9,38	13,03	-	-	-	351	458	508	569	635	700	760	1 843	1 973	2 098	-
1,79	140	250	4,95	6,80	319	360	395	486	591	641	702	767	832	892	-	-	-	-
1,79	224	400	11,10	15,41	-	-	-	-	400	452	513	578	644	705	1 788	1 918	2 043	2 198

FORMULA SHEET

1.	Design Power	= *Power (electrical motor)* x *service factor*
2.	Corrected power per belt	= *(basic power per belt + power increment per belt)* x *correction factor*
3.	Belt length (L)	= *[(Pitch diameter of larger pulley + Pitch diameter of smaller pulley)* x *1,57] + (2* x *Centre Distance)*
4.	Force (F)	= *Pressure (P)* x *Area (A)*
5.	Work done (W)	= *Force (F)* x *Distance (s)*
6.	Volume (V)	= *Area of base (A)* x *perpendicular height* ($\perp h$)

Marking Guidelines

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

AUGUST 2011

NATIONAL CERTIFICATE

MECHANOTECHNOLOGY N3

(8190373)

QUESTION 1: POWER TRANSMISSION

1.1

1.1.1 **For Correction Factor {CF}:** (1)

Consider:
Belt length = use 2280 mm
($\pm$2300 mm)

Read from TABLE 2
The correction factor (CF) as **0,9**→

1.1.2 **For Pitch Diameter of Driver (P_d)** (1)

Consider:
Speed Ratio = 1,69 (given)

Read from TABLE 2 in column of pitch pulley diameters
The P_d as **236 mm**→

1.1.3 **For Basic Power per Belt (Pb):** (1)

Consider:
Pitch diameter of driver = 236 mm
Speed of shaft = 1440 r/min

Read from TABLE 1

At the point of intersection of 236 mm and 1400 r/min, read the Basic Power (Pb) as **15,48 kW**→

(16,56 kW in TABLE 3 cannot be used due to the speed of 1440 r/min, which is for the driven pulley- motor is the driver)

1.1.4 **For the corrected power per belt (CP):** (3)

$$\begin{aligned} \mathrm{CP} &= (\mathrm{Pb} + \mathrm{lncr.P}) \times \mathrm{CF} \\ \mathrm{CP} &= (15{,}48 + 0{,}7) \times 0{,}9 \\ &= \mathbf{14{,}562\ kW/belt} \rightarrow \end{aligned}$$

1.1.5 **For Number of Belts:** (3)

$$\begin{aligned} \therefore N^O\ of\ Belts &= \frac{Design\ Power}{Corrected\ power/belt} \\ &= \frac{15}{14{,}562} \\ &= 1{,}03\ \text{belts} \\ &= \textbf{use 2 belts} \rightarrow \end{aligned}$$

1.2 **Questions regarding FIGURE 1:**

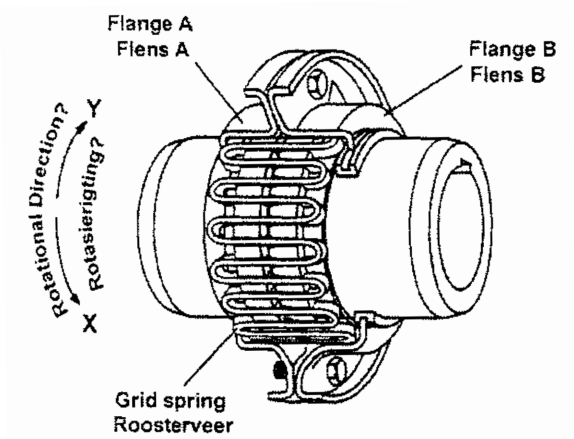
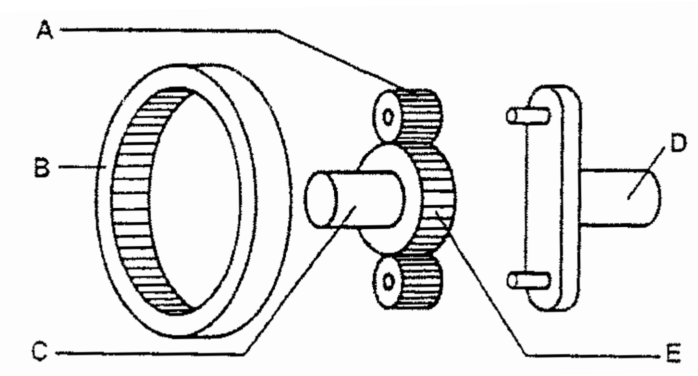


FIGURE 1

1.2.1 Bibby Flexible coupling/Steel-Grid Coupling (1)
1.2.2 Heavy loads (1)
1.2.3 High and low speeds (1)
1.2.4 Towards 'X andY' (1)

1.3

FIGURE 2



1.3.1 **Type of gear system:** (1)

Planet gear system

1.3.2 **Gear parts of Figure 2:** (5)

A - Planet gear
B - Internal ring gear
C - Input shaft
D - Output shaft
E - Sun gear

[19]

QUESTION 2: BRAKES

2.1 **TWO disadvantages of hydraulic braking system:** (2)

1. Air in the system will make the brakes feel spongy - if so, bleed the system.
2. Fluid leaks in the system can cause brakes to fail.

2.2 **Statements of 'TRUE' or 'FALSE':**

2.2.1 False (1)
2.2.2 False (1)
2.2.3 True (1)

[5]

QUESTION 3: BEARINGS

3.1 **Questions w.r.t. FIGURE 1:**

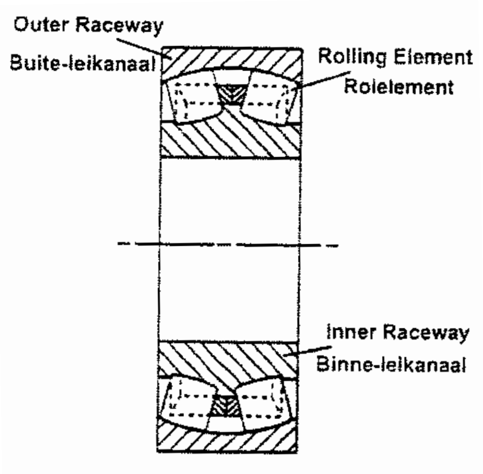


FIGURE 3

3.1.1 **Type of Bearing:** (1)

Spherical Roller Bearing

3.1.2 **Type of loads carried by this bearing:** (2)

- Very High Radial loads
- Moderate Axial loads

3.1.3 **Main advantage of this bearing:** (1)

Self-aligning

3.2 **FIVE Categories of Friction Bearings:** (5)

1. Solid bearings.
2. Part bearings.
3. Split bearings.
4. Thrust bearings.

5. Guide bearings.

3.3 **Refer to TABLE 3:** (1)

Determining of suitable bearing according to table 3

Suitable Bearing $\mathrm{N^O}: 2219$

[10]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 **THREE Advantages of the External Stuffing Box- plunger pumps:** (3)

1. Worn parts can be replaced quickly.
2. The packing can be replaced or adjusted without opening the pump.
3. Leaks can be spotted immediately.

4.2 **FOUR reasons for oil filtering:** (4)

1. Prevent excessive wear of moving parts.
2. Prevent clogging and sticking of control valves and pistons.
3. Extend oil life.
4. Removing of oil-deterioration products and thus preventing sluggish operation.

4.3

4.3.1 True (1)
4.3.2 False (1)

4.4 **Questions with regard to FIGURE 4:**

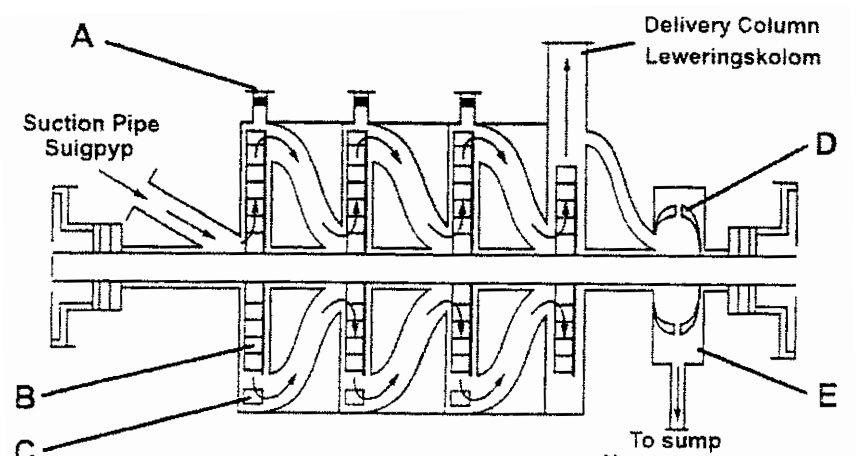


FIGURE 4

4.4.1 **Type of Water Pump:** (1)

Multi Stage centrifugal pump

4.4.2 **Parts as Indicated:** (5)

A - Pet cocks
B - Impeller
C - Deflector Plate
D - Movable Balance Disk
E - End Thrust Chamber

[15]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1

5.1.1 **For Cross-sectional area (A):** (1)

$$Volume = Area\ (A) \times Distance\ (s)$$
$$\therefore Area\ (A) = \frac{Volume}{\perp Distance}$$
$$A = \frac{0{,}01}{0{,}005}$$
$$A = 2m^2 \rightarrow$$

5.1.2 **For the Force applied (F):** (3)

$$Force\ (F) = Pressure(\rho) \times Area\ (A)$$
$$F = 450 \times 2$$
$$F = 900\ KN \rightarrow$$

5.1.3 **For Work Done by plunger (W):** (2)

Work done (W) = Force (F) × distance (s)

$$W = F \times s$$
$$\therefore W = 900 \times 0{,}08$$
$$\therefore W = 72\ kJ$$
$$OR = 72\,000\ J \rightarrow$$

5.2 **THREE Negative results if Viscosity is too high - Hydraulic oil:** (3)

1. Increase of fluid temperature - thick fluid will retain heat longer.
2. Sluggish valve action - sticky valves.
3. Poor mechanical efficiency - parts do not move freely.

5.3 **Statements of 'TRUE' or 'FALSE':**

5.3.1 True (1)

5.3.2 False (1)

[11]

QUESTION 6: INTERNAL COMBUSTION ENGINES

Induction stroke of Four-stroke Diesel Engine:

1. Intake valve opens just before piston reaches TDC.
2. Piston moves past the TDC to the bottom of cylinder.
3. The downward movement of the piston creates a vacuum in the cylinder.
4. Clean air is sucked into the cylinder.
5. The exhaust valve is closed.

[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1 **FIVE advantages of a Crane on a Bogie on a Rail:** (5)

1. It has a maximum coverage with a minimum site space.
2. The crane can move alongside the site and position itself to perform a specific function.
3. The bogie can be mounted on a mobile chassis, which moves under its own power.
4. Mobility gives it a larger coverage area compared to the static or climbing cranes.
5. It is better adapted to travel with a load.

7.2 **THREE Advantages of the Infrared Signal Remote Control:** (3)

1. Operators can walk safely behind the load. They can choose safe vantage points with the best visibility to do the job.
2. There is greater productivity. Operators can carry out other floor-based tasks while waiting for the next hoisting job.
3. The handling of loads is faster. Operators are not tied to the crane and they are closer to the load to see what they have to do.

[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1 **Non-Ferrous metals with an example:** (4)

1. Contains no iron.
2. Non-magnetic.
3. Corrosion resistant.

One example:
Tin /lead **/** copper **/** zinc **/** antimony **/** aluminum/

(**ANY 1**)

8.2 **Standardised colour codes for materials according to SABS:**

8.2.1 High carbon steel - Brown (1)
8.2.2 Structural steel - Red (1)
8.2.3 Cast steel - Blue (1)

[7]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 **PURPOSE of a grievance procedure:** (4)

1. To remove workers' grievances - between employers themselves and/or management.
2. To prevent tension or conflict- this can be manifested in different ways.
3. Conflict is dangerous for the organisation and it can cause the organisation to close down.
4. It is an effort to maintain, to preserve and to restore good labour relations.

9.2 **FOUR Listening skills to improve the effectiveness of communication:** (4)

1. Don't assume anything. Don't let the speaker think or feel that you know what s/he is going to say
2. Don't interrupt the speaker.
3. Don't react too quickly.
4. Don't jump to conclusions.
5. Pay full attention.
6. Don't get upset with inappropriate words being used.
ANY 4

9.3 **FOUR Characteristics of a Good Report:** (4)

1. Brief.
2. Open-minded and insightful.
3. Objective.
4. Accurate.
5. Clear.

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 **TERM for 'Service Business**': (4)

1. Do not require special office or premises.
2. The entrepreneur visits the premises of the customer.
3. Can operate from own premises or from a site that has low rental costs.

4. Examples: Plumbers; Garden Services; Insurance Brokers; Electricians; etc.

10.2 **Distribution of Extra Profit:** (4)

Ratio is = 4,5 : 2,5 : 6 = 13

$$1. \therefore \text{Company A gets } = \frac{4,5}{13} \times 5200 = R1800.00$$

$$2. \therefore \text{Company B gets } = \frac{2,5}{13} \times 5200 = R1000.00$$

$$3. \therefore \text{Company C gets } = \frac{6}{13} \times 5200 = R2400.00$$

[8]

TOTAL: 100

Past Examination Papers

higher education & training

Department: Higher Education and Training
REPUBLIC OF SOUTH AFRICA

APRIL 2011

NATIONAL CERTIFICATE

MECHANOTECHNOLOGY N3

(**8190373**)

1 April (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Calculators may be used.
This question paper consists of 9 pages, 2 tables and a 1-page formula sheet.

TIME: 3 HOURS
MARKS: 100

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers correctly according to the numbering system used in this question paper.

4. ALL the drawing must be large, clear, neat and in good proportion.

5. Keep questions and subsections of questions together.

6. Write neatly and legibly.

QUESTION 1: POWER TRANSMISSION

1.1 1.1 A 16 N SPB wedge belt is fitted between an electrical motor and a hammer mill.

The following information is available:

Design power of electric motor	50kW
Basic power per belt	21,14 kW
Power increment (additional power) per belt	1,95 kW
Type of start	'soft'
Duty operation type	'medium'
Duty hours per day	9 (nine) hours
Speed of the pulley on electric motor	1 400 r/min
Service factor	1,2
Correction factor	0,85

Calculate the following:

1.1.1 The power of electric motor (1)
1.1.2 The corrected power per belt in kW (3)
1.1.3 The number of belts (3)

1.2 Briefly discuss the following terms with regard to belt drives:

1.2.1 Basic power per belt (1)
1.2.2 Additional power (1)
1.2.3 Corrected power per belt (1)

1.3 Refer to FIGURE 1 of a section of a gear and label the different parts (A- E) as indicated. Write the answer below one another in the ANSWER BOOK. (5)

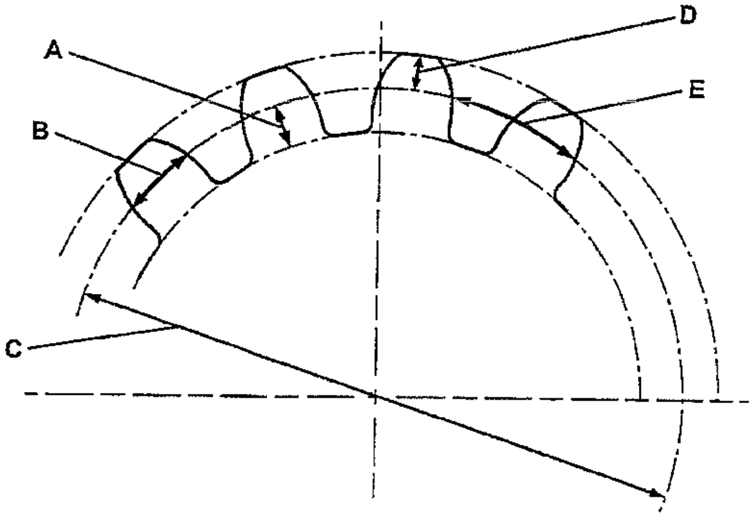


FIGURE 1

1.4 Refer to the flexible coupling in FIGURE 2 below and label the different parts (A - C) as indicated. Write the answers below one another in the ANSWER BOOK. (3)

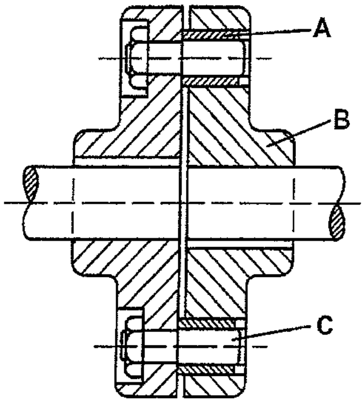


FIGURE 2

1.5 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (1.5.1 - 1.5.2) in the ANSWER BOOK.

1.5.1 A spiral claw clutch can be used to transmit energy from one shaft to another. This can be in both directions of rotation. (1)

1.5.2 There is more reinforcement materials in a V-belt to make it stronger when compared to a wedge belt. (1)

[20]

QUESTION 2: BRAKES

Refer to FIGURE 3 of the electromagnetic brake below and briefly explain the activating and de-activating action of this brake.

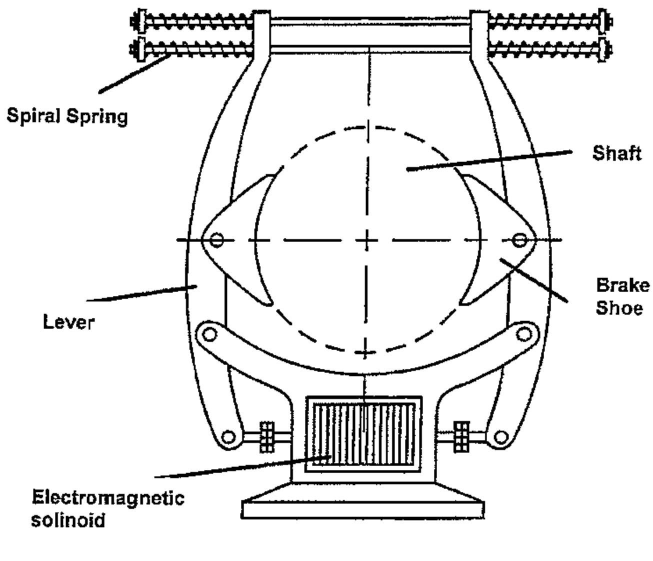


FIGURE 3

[4]

QUESTION 3: BEARINGS

3.1 Each anti-friction bearing has an identification number. The basic bearing number consists of three numbers. Explain the meaning of each of these three numbers in the following order: (3)

3.1.1 First number
3.1.2 Second number
3.1.3 Third number

3.2 There is a limit to the speed at which anti-friction bearings can operate due to the heat generated from the speed. State FOUR factors that would influence the permissible speed at which an anti-friction bearing can operate. (4)

3.3 Refer to FIGURE 4 below and name the different types of bearing loads (AC) as indicated. Write the answers below one another in the ANSWER BOOK. (3)

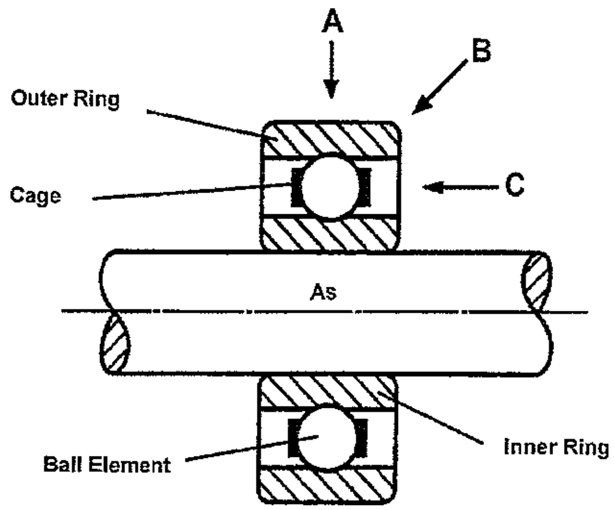


FIGURE 4

HINT: A= Vertical load; B =Diagonal load and C = Horizontal load

[10]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 Lubricants can be classified in three main groups. Name the **THREE** groups and give **ONE** example of each. (3)

4.2 Briefly explain **THREE** reasons for the necessity of welding machines to be cooled. (3)

4.3 Pump slip can be defined as the difference between the theoretical and real flow rate. Briefly explain **FIVE** reasons for this. (5)

4.4 Refer to FIGURE 5 below, that is applicable to the operation of centrifugal pumps and name the different curves A, B, C and point D as indicated. Write the answers below one another in the ANSWER BOOK. (4)

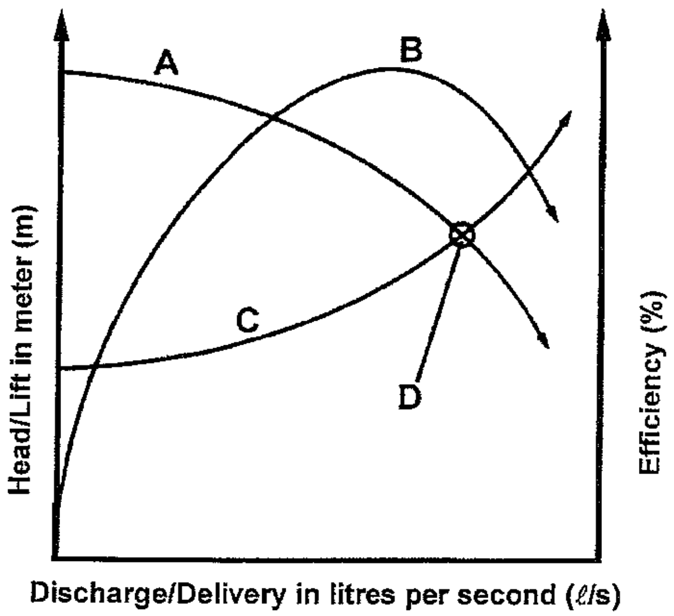


FIGURE 5

[15]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1 Briefly describe **FIVE** functions of control valves in a hydraulic system. (5)

5.2 The volume of a hydraulic cylinder is $6{,}13672 \times 10^{-5}$ cubic metres (m^3).

Use π = 3,142

Calculate the following:

5.2.1 The cross sectional area of the cylinder if the length of the cylinder is 125 mm. Express the answer in mm2 (1)

5.2.2 The diameter of the cylinder in millimetres (mm) (2)

5.2.3 The pressure in the cylinder if the force in the cylinder is 35 kN. Express the answer in kPa (2)

[10]

QUESTION 6: INTERNAL COMBUSTION ENGINES

Refer to FIGURE 6 of the two-stroke petrol engine below and answer the following questions:

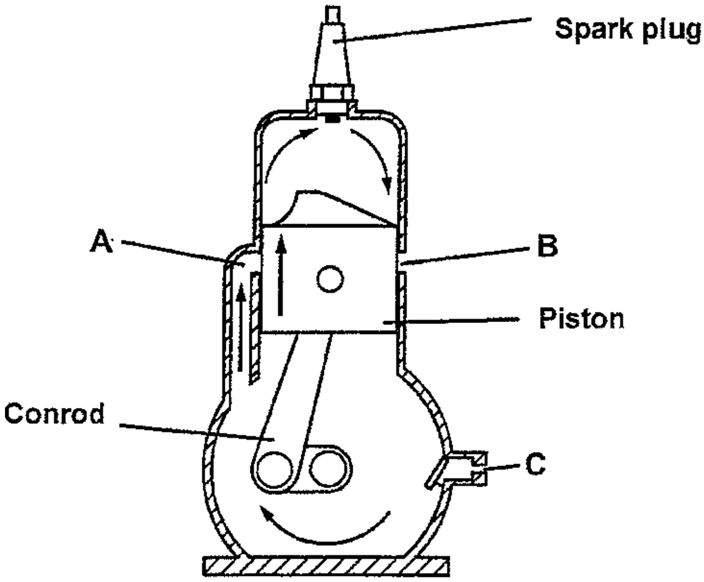


FIGURE 6

6.1 Which **TWO** strokes are shown? (2)

6.2 Label the different ports (A - C) as indicated. Write the answers below one another in the ANSWER BOOK. (3)

[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1 State **FOUR** functions of the fibre core in a steel rope. (4)

7.2 Langs-Jay refers to the weaving method of a steel rope. Briefly state **FOUR** advantages of this weaving method in contrast to the cross-Jay weaving method. (4)

[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1 Briefly describe the basic characteristics from non-laboratory tests with reference to the hardness of the following polymers:

8.1.1 Perspex (1)
8.1.2 Nylon (1)
8.1.3 Bakelite (1)

8.2 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true' or 'false' next to the question number (8.2.1 - 8.2.4) in the ANSWER BOOK.

8.2.1 Plasticity, as a property of a metal, is the ability of a metal to be deformed (1) under load and then return to its original shape.

8.2.2 Elasticity, as a property of a metal, is the ability of a metal to be deformed under load and then retain its new shape. (1)

8.2.3 Durability can be considered as a characteristic of thermosetting Plastics. (1)

8.2.4 Ductility is the property of a metal to withstand elongation under tension before breaking apart. (1)

[7]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 Name **FIVE** documents that form part of the production process and assist in managing the budget of an organisation. (4)

9.2 State **THREE** disadvantages of written communication. (4)

9.3 Communication has certain aims within a business. State **FOUR** of these aims. (4)

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 Briefly explain the term *entrepreneurship.* (4)

10.2 As a spare part dealer, you sold an item for R146,21 *to* a customer. A markup value of thirty five percent (35%) and VAT of fourteen percent (14%) was included in the selling price. (5)

Calculate the cost price of the spare part.

[9]

TOTAL: 100

ANNEXURE A

TABLE 1

SERVICE FACTORS FOR THE SELECTION OF WEDGE BELTS

	TYPE OF PRIME MOVERS					
	'Soft' starts			'Heavy' starts		
TYPES OF DRIVEN MACHINES	Hours per day duty			Hours per day duty		
	10 and under	Over 10 to 16	Over 16	10 and under	Over 10 to 16	Over 16
Class 1 – Light duty Blowers and fans Centrifugal compressors and pumps Belt conveyors (uniformly loaded)	1,0	1,1	1,2	1,1	1,2	1,3
Class 2 – Medium duty Blowers and fans Rotary compressors and pumps Belt conveyors (not uniformly loaded) Generators	1,1	1,2	1,3	1,2	1,3	1,4
Class 3 – Heavy duty Brick machinery Compressors and pumps (reciprocating) Conveyors (heavy duty) Hammer mills Punches and presses	1,2	1,3	1,4	1,4	1,5	1,6
Class 4 – Extra heavy duty Crushers Mills	1,3	1,4	1,5	1,5	1,6	1,8

TABLE 2

CENTRE DISTANCES FOR 16 N SPB WEDGE BELT DRIVES

Combined arc and belt length Correction factor					0,8			0,85			0,9				1,05			
Speed Ratio	Pitch diameter of pulleys		Power per belt kW		BELT LENGTH													
	Driver	Driven	960 r/min	1 440 r/min	1 260	1 340	1 410	1 590	1 800	1 900	2 020	2 150	2 280	2 400	4 560	4 820	5 070	5 380
1,69	236	400	11,94	16,56	-	-	-	-	392	443	504	570	635	696	1 779	1 909	2 034	2 189
1,75	160	280	6,45	8,92	278	319	355	446	551	602	662	727	792	852	-	-	-	-
1,75	180	315	7,92	11,00	-	273	309	401	507	557	618	683	748	809	-	-	-	-
1,78	200	355	9,38	13,03	-	-	-	351	458	508	569	635	700	760	1 843	1 973	2 098	-
1,79	140	250	4,95	6,80	319	360	395	486	591	641	702	767	832	892	-	-	-	-
1,79	224	400	11,10	15,41	-	-	-	-	400	452	513	578	644	705	1 788	1 918	2 043	2 198

FORMULA SHEET

1.	Design Power	= *Power (electrical motor)* x *service factor*
2.	Corrected power per belt	= *(basic power per belt + power increment per belt)* x *correction factor*
3.	Belt length (L)	= *[(Pitch diameter of larger pulley + Pitch diameter of smaller pulley)* x *1,57] + (2* x *Centre Distance)*
4.	Force (F)	= *Pressure (P)* x *Area (A)*
5.	Work done (W)	= *Force (F)* x *Distance (s)*
6.	Volume (V)	= *Area of base (A)* x *perpendicular height* ($\perp h$)

Marking Guidelines

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

APRIL 2011

NATIONAL CERTIFICATE

MECHANOTECHNOLOGY N3

(8190373)

QUESTION 1: POWER TRANSMISSION

1.1

1.1.1 **For the Power of the Electr. Motor {P):** (1)

$$Design\ Power = Power \times Safety\ Factor$$
$$\therefore \text{ Power (P)} = \frac{\text{Design Power}}{\text{Safety Factor}}$$
$$= \frac{50}{1{,}2}$$
$$\therefore \mathbf{P = 42kW} \rightarrow$$

1.1.2 **For Corrected Power/Belt (P_{cor}):** (3)

$$Corrected\ Power/Belt = (Basic\ Power/belt + Power\ Increment/Belt) \times Safety\ Factor$$

$$P_{cor} = (21{,}14 + 1{,}95) \times 0{,}85$$
$$\therefore \boldsymbol{P_{cor} = 19,627\ kW\ per\ belt} \rightarrow$$

1.1.3 **For the Number of Belts (n}:** (3)

$$\therefore n = \frac{Design\ Power}{Corrected\ Power/Belt}$$
$$= \frac{50}{19{,}627}$$
$$\therefore n = 2{,}547\ belts$$
$$\therefore \boldsymbol{Use\ 3\ belts} \rightarrow$$

1.2 **Brief descriptions of terms w.r.t .Belt**

1.2.1 **Basic Power per Belt:** (1)
No power losses have been taken into account- ideal conditions.

1.2.2 **Additional Power:** (1)
Due to the speed ratio, there is a power loss in the drive.

1.2.3 **Corrected power per belt:** (1)
Power needed for power losses per belt.

(**NB:** All above-mentioned obtainable and compensated from applicable tables)
Award a bonus point If candidate mentions this

1.3 **Gear tooth terms of Figure 1:** (5)

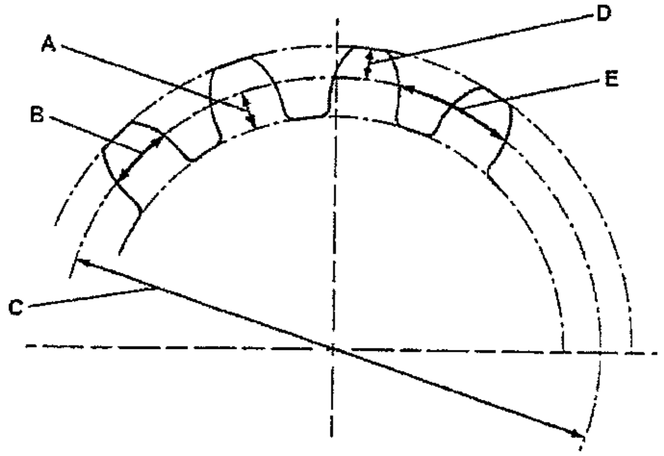


FIGURE 1

A - Dedendum
B - Circular tooth thickness
C - Pitch Circular Diameter (PCD)
D - Addendum
E - Circular Pitch

1.4 **Parts of Flexible Coupling in Figure 2:** (3)

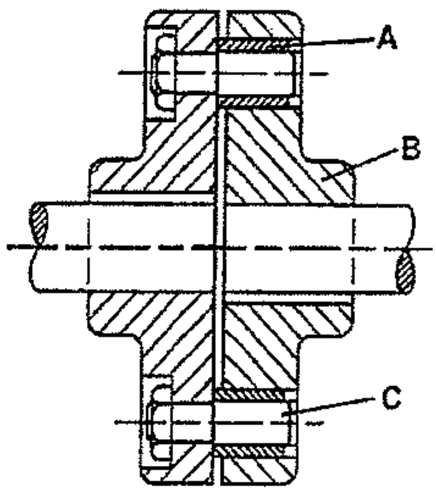


FIGURE 2

A - Rubber band/-ring
B - Flange
C - Pin

1.5 **Statements of 'TRUE' or 'FALSE':**

1.5.1 False (1)
1.5.2 False (1)

[20]

QUESTION 2: BRAKES

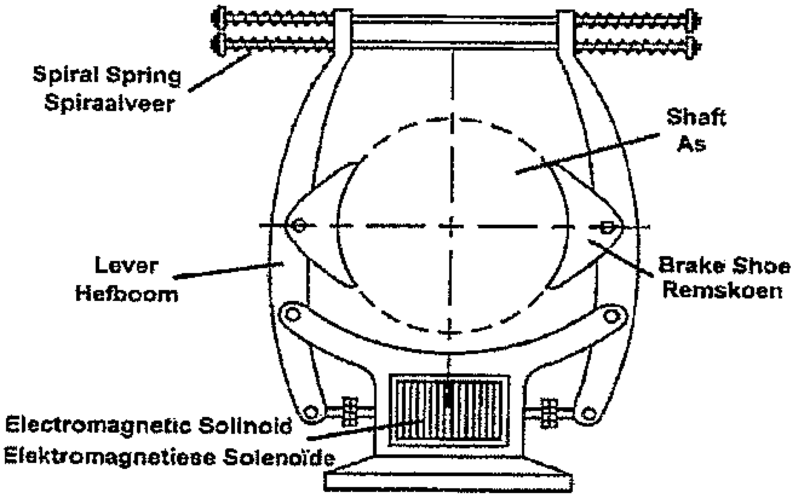


FIGURE 3

Activating and De-activating of the Brake in FIGURE 3:

1. The electromagnetiic solenoid is activated as soon as there is a current flow.

2. The electromagnetic solenoid will pull the levers in and the brake shoes will be pulled away from the shaft- shaft is free to turn.

3. When the current flow is cut-off, the electromagnetic solenoid will release the levers.

4. The spiral springs will push the levers, with the brake shoes, towards/against the shaft - braking the shaft.

[4]

QUESTION 3: BEARINGS

3.1 **Meaning of Identification Number on Anti-friction Bearings:** (3)

3.1.1 1st Number: Type of bearing
3.1.2 2nd Number: Width of bearing
3.1.3 3rd Number: Diameter of bearing

3.2 **FOUR** Factors that will influence the Speed limit due to heat generated (Anti-Friction Bearings): (4)

1. The frictional heat generated as well as the external heat.
2. The amount of heat transported away from bearing.
3. The bearing type and size.
4. The magnitude of the load.
5. The lubrication and cooling conditions.

6. The design of the cage.
7. The internal clearance.
8. The accuracy of the installation.
   (**ANY 4**)

3.3 **Bearing loads of Figure 4:** (3)

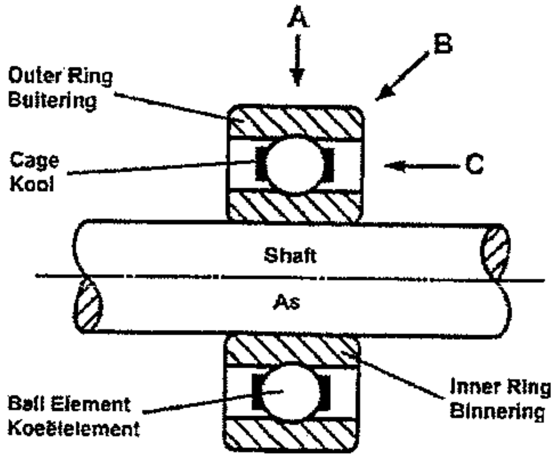


FIGURE 4

A - Radial - / Perpendicular load (Not Vertical load! – hint given)
B - Combined - / Angular load (Not Diagonal load! - hint given)
c - Axial - / Thrust load (Not Horizontal load! - hint given)

[10]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 **THREE** main groups of lubricants - and example of each: (3)

1. Liquid - oil.
2. Semi - solid grease
3. Solid graphite. white lead

4.2 **THREE** reasons for Welding machines to be cooled: (3)

1. Prevents insulation material from crumbling or disintegrating.
2. The resistance will increase - results in poor power transmission.
3. At high temperatures - short circuit may occur and lead to an electric shock.

4.3 **FIVE** reasons for Pump slip: (5)

1. Worn external packing - air slips in and destroys the vacuum.
2. Worn internal packing - allows the fluid to slip past from one chamber to another.
3. The strainer is exposed above the fluid level -air slips into the pump.

4. A faulty foot valve - allows fluid to slip back into the suction chamber.
5. Faulty or loose flanges - allows fluid to slip in during the suction stroke and to slip out during the delivery stroke.
6. The seat or spring of a valve is weak or faulty.

4.4 **Name different Curves & Point:** (4)

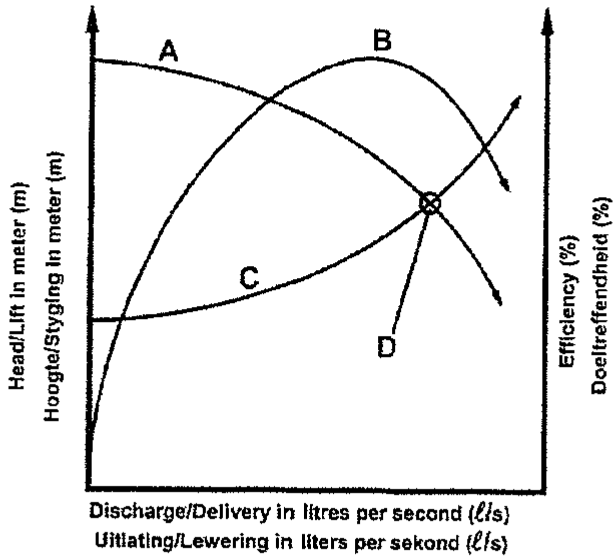


FIGURE 5

A - Head available curve
B - Efficiency curve
C - Head required curve
D - Operation point

[15]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1 **FIVE Functions of control valves in a hydraulic system:** (5)

1. To regulate the pressure in the circuit.
2. To determine how much fluid will flow in the different parts of the system:
3. To direct the fluid into specific directions or lines.
4. To connect and disconnect the different lines in the system (cross linkage between connections).
5. To influence the direction of the effect of pressure and volumetric flow and to control motion in the system.

5.2

5.2.1 **For the Cross Sectional Area of the cylinder [A):** (1)

$$Volume = Area\ x\ \perp\ height$$
$$0{,}0000613672 = A \times 0{,}125$$

$$A = \frac{0{,}0000613672}{0{,}125}$$
$$\therefore \text{Area (A)} = 0{,}000490938\ m^2$$
$$\therefore \boldsymbol{A = 490{,}9mm^2} \rightarrow$$

5.2.2 **For the diameter of the cylinder (d):** (2)

$$Area = \frac{\pi \times d^2}{4}$$
$$0{,}000490938 = \frac{\pi \times d^2}{4}$$
$$\therefore d = \sqrt{\frac{0{,}000490938 \times 4}{3{,}142}}$$
$$\therefore d = \sqrt{0{,}000625}$$
$$\therefore d = 0{,}025\text{m}$$
$$\therefore \boldsymbol{d = 25\ mm} \rightarrow$$

5.2.3 **For the pressure in the Cylinder (P):** (2)

$$Pressure\ (P) = \frac{Force}{Area}$$
$$\therefore P = \frac{35}{0{,}000490938}$$
$$\therefore \boldsymbol{P = 71292{,}1\ \text{kPa}} \rightarrow$$

[10]

QUESTION 6: INTERNAL COMBUSTION ENGINES

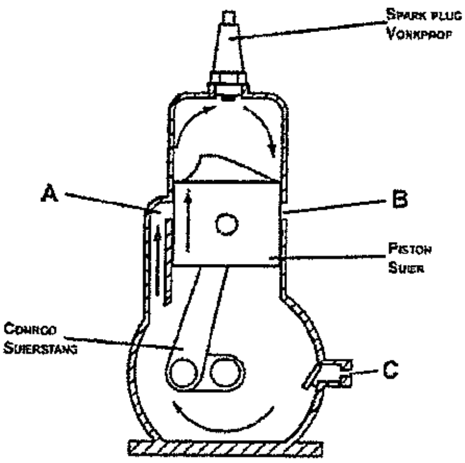


FIGURE 6

6.1 **Which TWO strokes are shown in Figure 6:** (2)

1. Induction stroke
2. Compression stroke

6.2 **Ports in Figure 2:** (3)

A -Transfer port
B - Exhaust port
C - Intake port

[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1 **FOUR functions of the fibre core:** (4)

1. It supports the strands and keeps them from jamming against each other.
2. It lubricates the inside of the cable and thus prevents wear.
3. The lubrication helps prevent corrosion on the inside.
4. It provides a cushion effect to absorb shocks.

7.2 **THREE advantages of Langs-Lay method:** (4)

1. Wear takes place more evenly-due to windings weaved in same direction.
2. A Langs-Lay has a better resistance to fatigue.
3. It is more flexible.
4. It has a dense and smooth outside surface.

[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1 **Hardness Properties of Polymers:**

8.1.1 **Perspex:** (1)
Rigid

8.1.2 **Nylon:** (1)
Stiff

8.1.3 **Bakelite:** (1)
Rigid

8.2 **Statements of 'TRUE' or 'FALSE':**

8.2.1 False (1)
8.2.2 False (1)
8.2.3 True (1)
8.2.4 True (1)

[7]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 **FIVE Documents that form part of the production process:** (4)

1. Clock cards.
2. Production flow charts.
3. Job cards.
4. Requisition cards.
5. Maintenance schedules.

9.2 **THREE Disadvantages of a Written Communication:** (4)

1. It takes much longer to prepare if compared to a verbal message.
2. There is no automatic feedback.
3. There is no guarantee that it will be read

9.3 **Aims of communication:** (4)

1. To inform
2. To remind
3. To bring about a certain reaction
4. To persuade
5. To understand
6. To educate
7. To stimulate action
8. To socialise
9. To entertain
10. To command

(**ANY 4**)

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 **TERM for entrepreneurship refers to:** (4)

1. A person who creates a new business
2. In the face of risk and uncertainty
3. For the purpose of achieving profit and growth
4. Identifying opportunities
5. Assemble the necessary resources and capitalise on these opportunities

(**ANY 4**)

10.2 **For cost price of Item ICP):** (5)

$CP = Cost\ Price\ of\ item$

Equation:

$$Price\ from\ W/Saler + 35\%\ of\ Price + (14\% \times Cost\ Price) = R146.21$$

$$CP + (35\% \times CP) + (14\% \times CP) = R146.21$$
$$\therefore CP + 0{,}35CP + (0{,}14 \times 1{,}35\ CP) = R146.21$$
$$\therefore 1{,}35\ CP + (0{,}189\ CP) = R146.21$$
$$1{,}539\ CP = R146.21$$
$$Cost\ Price = \frac{146.21}{1.539} = R95.00$$

[9]

TOTAL: 100

Past Examination Papers

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2010

NATIONAL CERTIFICATE

MECHANOTECHNOLOGY N3

(**8190373**)

12 November (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Calculators may be used.

This question paper consists of 7 pages, 2 annexures and a 1-page formula sheet.

TIME: 3 HOURS
MARKS: 100

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers correctly according to the numbering system used in this question paper.

4. ALL the drawings must be large, clear, neat and in good proportion.

5. Keep questions and subsections of questions together.

6. Write neatly and legibly.

QUESTION 1: POWER TRANSMISSION

1.1 A 16 N SPB wedge belt is installed between a compressor and a 15 kW electric motor with a speed ratio of 1,79:1. The speed of the pulley on the compressor is 700 r/min and that of the electrical motor is 1 440 r/min. The approximate centre distance between the drive is ±767 mm. The service factor is 1,1. Use the following information to partially design the belt drive:

Refer to TABLE 1 and TABLE 2.

1.1.1 Determine the correction factor. (1)
1.1.2 Calculate the design power. (1)
1.1.3 Determine the pitch diameters of both pulleys. (2)
1.1.4 Calculate the belt length. (3)

1.2 Refer to FIGURE 1 below of the cross sectional view of a V-belt: (5)

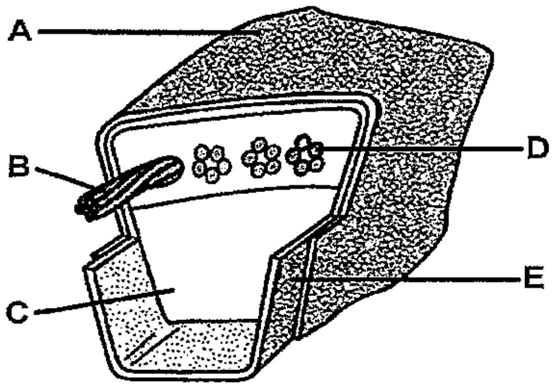


FIGURE 1

Label the different parts (A - E) as indicated above. Write only the answer next to the letter (A - E) in the ANSWER BOOK.

1.3 Name the **FOUR** main categories that clutches can be grouped in. (4)

1.4 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true' or 'false' next to the question number (1.4.1 - 1.4.4) in the ANSWER BOOK.

1.4.1 The module of a gear is the ratio between the circular pitch and the number of teeth on the gear and is measured in millimetres. (1)

1.4.2 The dedendum of a gear tooth is the radial height of the tooth above the circular pitch. (1)

1.4.3 The brake shoes around the drum of the electromagnetic braking system will disengage (release) in the case of a power failure, thus causing the load to fall. (1)

1.4.4 A disadvantage of the disc brake system is that water and dust are not thrown off easily by the centrifugal force and they enter the friction surface easily and thereby cause excessive wear on the friction surfaces. (1)

[20]

QUESTION 2: BRAKES

Briefly describe **FIVE** disadvantages of the disc brake system.

[5]

QUESTION 3: BEARINGS

3.1 Give **FIVE** reasons that may cause vibration and might have a harmful effect on an anti-friction bearing. (5)

3.2 Refer to FIGURE 2 of the bearing.

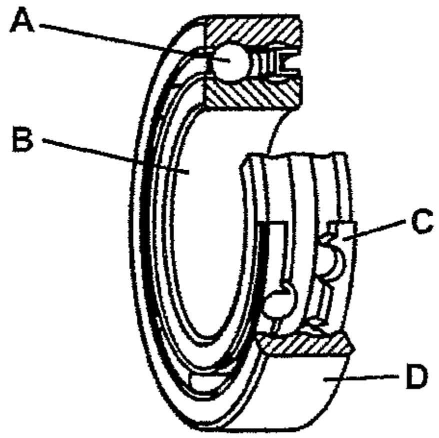


FIGURE 2

3.2.1 What type of bearing is shown? (1)

3.2.2 What type of load can this bearing carry? (1)

3.2.3 Name the parts (A- D) as indicated. Write only the answer next to the letter (A- D) in the ANSWER BOOK. (4)

[11]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 Define the following terms:

4.1.1 Manometric head (2)
4.1.2 Required head (2)

4.2 Except from applying lubrication with an oil can or grease pot, name **FIVE** OTHER main methods to apply lubrication to machine components or moving parts. (5)

4.3 Briefly describe **TWO** main reasons why it is necessary for compressors to be cooled. (2)

4.4 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true' or 'false' next to the question number (4.4.1 - 4.4.3) in the ANSWER BOOK.

4.4.1 The manometric head is the vertical distance or height at which a pump can deliver fluids under perfect conditions. (1)

4.4.2 In an indirect cooling system the heat is transferred from the engine to the water which flows around it. (1)

4.4.3 The heat exchanger that consists of a bundle of tubes and a shell and the water circulating around the tubes, is often referred to as 'saturated water'. (1)

[14]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1 The diameter of a plunger in a hydraulic cylinder is 45 mm and the length of the cylinder is 120 mm. During operation a pressure of 340 kPa is exerted on the plunger.

Calculate the following:

5.1.1 The cross sectional area of the plunger (express the answer in m^2) (1)

5.1.2 The force on the plunger (express the answer in newton) (1)

5.1.3 The work done by the plunger, if the plunger moved a distance of 80 mm (express the answer in joule) (1)

5.2 State **THREE** functions of the accumulator in a hydraulic system. (3)

5.3 Make neat drawings of the ISO symbols as applicable to pneumatic systems of the following:

5.3.1 A compressor (1)
5.3.2 A lubricator (1)
5.3.3 A pressure relief valve (2)

[10]

QUESTION 6: INTERNAL COMBUSTION ENGINES

Refer to FIGURE 3 of a two-stroke diesel engine:

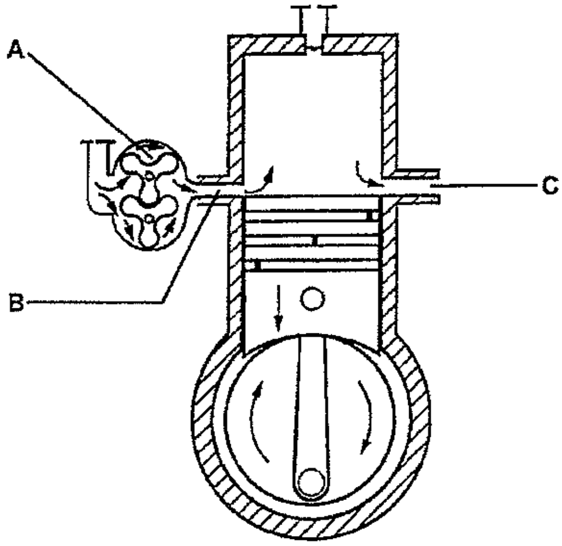


FIGURE 3

6.1	Name the parts (A- C) as indicated. Write only the answer next to the letter (A - C) in the ANSWER BOOK.	(3)
6.2	Name the **TWO** phases during the downward stroke of the piston.	(2)
		[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1	Briefly describe **FIVE** disadvantages of static tower cranes.	(5)
7.2	Briefly describe **THREE** advantages of the infrared signal remote control when comparing it to the driver's cabin on the overhead crane.	(3)
		[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1	Describe **FOUR** results of annealing as a heat treatment process.	(4)
8.2	When adding an alloy in various proportions to iron, specific properties of metals can be obtained. Name **FOUR** of these specific properties of metals.	(4)
		[8]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 Briefly describe the purpose of the Occupational Health and Safety Act, 1993 (Act No 85 of 1993). (4)

9.2 Define the term *capital budget.* (5)

9.3 Briefly describe **THREE** methods to improve horizontal communication, as part of the communication channels, in an Organisation. (3)

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 Briefly explain the term *SWOT analysis* that will be utilized in the erecting of a prospective business. (4)

10.2 Name **THREE** pre-established basic principles that an entrepreneur will have in mind before starting a successful financial project. (3)

[7]

TOTAL:100

TABLE 1

SERVICE FACTORS FOR THE SELECTION OF WEDGE BELTS

TYPES OF DRIVEN MACHINES	TYPE OF PRIME MOVERS					
	'Soft' starts			'Heavy' starts		
	Hours per day duty			Hours per day duty		
	10 and under	Over 10 to 16	Over 16	10 and under	Over 10 to 16	Over 16
Class 1 – Light duty Blowers and fans Centrifugal compressors and pumps Belt conveyors (uniformly loaded)	1,0	1,1	1,2	1,1	1,2	1,3
Class 2 – Medium duty Blowers and fans Rotary compressors and pumps Belt conveyors (not uniformly loaded) Generators	1,1	1,2	1,3	1,2	1,3	1,4
Class 3 – Heavy duty Brick machinery Compressors and pumps (reciprocating) Conveyors (heavy duty) Hammer mills Punches and presses	1,2	1,3	1,4	1,4	1,5	1,6
Class 4 – Extra heavy duty Crushers Mills	1,3	1,4	1,5	1,5	1,6	1,8

TABLE 2

CENTRE DISTANCES FOR 16 N SPB WEDGE BELT DRIVES

Combined arc and belt length Correction factor					0,8			0,85			0,9				1,05			
Speed Ratio	Pitch diameter of pulleys		Power per belt kW		BELT LENGTH													
	Driver	Driven	960 r/min	1 440 r/min	1 260	1 340	1 410	1 590	1 800	1 900	2 020	2 150	2 280	2 400	4 560	4 820	5 070	5 380
1,69	236	400	11,94	16,56	-	-	-	-	392	443	504	570	635	696	1 779	1 909	2 034	2 189
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1,75	180	315	7,92	11,00	-	273	309	401	507	557	618	683	748	809	-	-	-	-
1,78	200	355	9,38	13,03	-	-	-	351	458	508	569	635	700	760	1 843	1 973	2 098	-
1,79	140	250	4,95	6,80	319	360	395	486	591	641	702	767	832	892	-	-	-	-
1,79	224	400	11,10	15,41	-	-	-	-	400	452	513	578	644	705	1 788	1 918	2 043	2 198

FORMULA SHEET

1.	Design Power	= *Power (electrical motor)* x *service factor*
2.	Corrected power per belt	= *(basic power per belt + power increment per belt)* x *correction factor*
3.	Belt length (L)	= *[(Pitch diameter of larger pulley + Pitch diameter of smaller pulley)* x *1,57] + (2* x *Centre Distance)*
4.	Force (F)	= *Pressure (P)* x *Area (A)*
5.	Work done (W)	= *Force (F)* x *Distance (s)*
6.	Volume (V)	= *Area of base (A)* x *perpendicular height* ($\perp h$)

Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2010

NATIONAL CERTIFICATE

MECHANOTECHNOLOGY N3

(8190373)

QUESTION 1: POWER TRANSMISSION

1.1

1.1.1 **For Correction Factor (CF):** (1)

Consider:
$Speed\ Ratio\ =\ 1{,}79\ (given)$
$Centre\ Distance\ =\ \pm 767\ mm$

Read from TABLE 2
$The\ correction\ factor\ (CF)\ as\ \mathbf{0,9} \rightarrow$

1.1.2 **For the Design Power (P_D):** (1)

$P_D = P_{Motor} \times 1{,}1$
$\therefore P_D = 15 \times 1{,}1$
$\therefore \boldsymbol{P_D = 16{,}5kW} \rightarrow$

1.1.3 **For Pitch Diameter of Pulleys (D & d):** (2)

Consider:
$Speed\ Ratio\ =\ 1{,}79:1$
$\&\ Centre\ Dis. = \pm 767\ mm$

Read from TABLE 2 in column of pitch pulley diameters:
$D = \mathbf{250mm} \rightarrow$
$d = \mathbf{140\ mm} \rightarrow$

1.1.4 **For the Belt Length (L):** (3)

$L = [(D + d) \times 1{,}57] + (2 \times CD)$
$L = [(250 + 140) \times 1{,}57] + (2\ X\ 767)$
$= 612{,}3 + 1\ 534$
$= 2\ 146{,}3$
$= \mathbf{2146\ mm} \rightarrow$

1.2 **Parts: Construction of wedge belt:** (5)

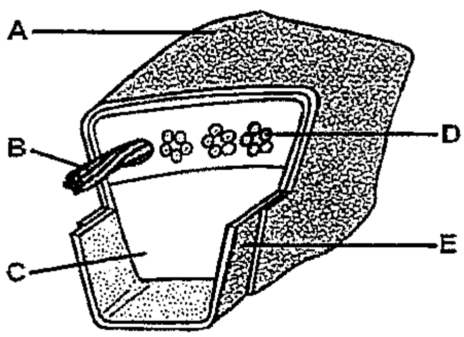


FIGURE 1

A. Heat and oil resistant cover.
B. Polyester, nylon or rayon cord.
C. Fibre base.
D. Cord support.
E. Double cover.

1.3 **FOUR Main groups of clutches:** (4)

1. Positive clutches.
2. Friction clutches.
3. Centrifugal clutches.
4. Hydraulic clutches.

1.4 **Statements of 'TRUE' or 'FALSE':**

1.4.1 False (1)
1.4.2 False (1)
1.4.3 False (1)
1.4.4 False (1)

[20]

QUESTION 2: BRAKES

FIVE Disadvantages - Disc brake system:

1. Brakes wear quicker because of the smaller friction surface.
2. The brakes must be removed when the wheel bearings must be replaced.
3. Brake noise is sometimes a problem.
4. Higher operating forces are required. This complicates the design of the hand brake mechanism.
5. A booster is necessary to increase the applied force because disc brakes have no self-servo action.

[5]

QUESTION 3: BEARINGS

3.1 **FIVE reasons for vibrations and harmful effects on an anti-friction bearing:** (5)

1. Insufficient lubrication
2. A flattened roller or ball
3. A variation in the sizes of the rollers or balls
4. An indent of raceways due to incorrect handling or assembly or because of shock loads
5. Contamination or pollution
6. The bearing slipping on the shaft or in the housing
7. The shaft is not round
8. Races turning

9. Excessive clearance between the shaft and the bearing or between the housing and the bearing
(**ANY 5**)

3.2 **Questions with regard to FIGURE 2:**

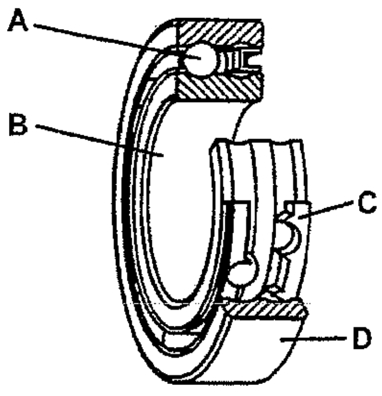


FIGURE 2

3.2.1 **Type of Bearing:** (1)
Double Row Deep Groove Ball Bearing

3.2.2 **Type of Load:** (1)
Radial loads

3.2.3 **Parts as Indicated:** (4)

A - Ball element
B - Inner ring
C - Cage
D - Outer ring

[11]

QUESTION 4: WATER PUMPS, COOLING AND LUBRICATION

4.1 **Define terms for:**

4.1.1 **Manometric head:** (2)

1. It is the vertical distance or height at which the pump can deliver fluids under perfect conditions and;
2. it is measured in m.

4.1.2 **Required head:** (2)

1. It is the friction head distance at suction and delivery side height, plus
2. the available head distance

4.2 **FIVE types of lubrication methods:** (5)

1. Splash lubrication
2. Syphon/Siphon wick lubrication
3. Sight feed lubrication
4. Force feed lubrication
5. Dry sump lubrication
6. Oil and fuel mixture- two stroke engines
7. Brush/Manual

(**ANY 5**)

4.3 **TWO Main Reasons for Compressors to be cooled:** (2)

1. The volume of the compressed air reduces when cooled down. That makes it possible that more air can be compressed and stored
2. Prevention of explosions

4.4 **Statements of 'TRUE' or 'FALSE':**

4.4.1 True (1)

4.4.2 True (1)

4.4.3 False (1)

[14]

QUESTION 5: HYDRAULICS AND PNEUMATICS

5.1 **For the Cross Sect. Area of the plunger (A):**

5.1.1 (1)

$$A = \frac{\pi \times d^2}{4}$$
$$= \frac{3{,}142 \times 0{,}045^2}{4}$$
$$\therefore A = 0{,}0015906 \text{ m}^2 \rightarrow$$

5.1.2 **For the Force on the Plunger (F):** (1)

$$F = Pressure\ (P) \times Area\ (A)$$
$$= 340 \times 0{,}0015906$$
$$= 0{,}540818\ kN$$
$$\therefore F = 540{,}818\ N \rightarrow$$

5.1.3 **For the Work done by the Plunger (W):** (1)

$$W = Force\ (F) \times Distance\ (s)$$
$$= 540{,}818 \times 0{,}08$$

$$\therefore F = 43{,}2653\ J \rightarrow$$

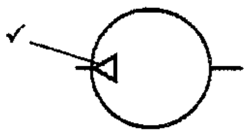
5.2 **THREE Functions of an Accumulator:** (3)

1. Stores or accumulate oil under pressure to operate an actuator by itself (To supplement pump delivery).
2. Absorbs and cushion shocks or surges in the system.
3. Supply smooth operation to systems.

5.3 **Drawings sketches of ISO Symbols in Pneumatic Systems:**

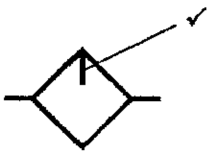
(Marks only for correctness and not line work)

5.3.1 (1)



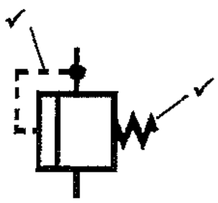
Compressor

5.3.2 (1)



Lubricator

5.3.3 (2)



Pressure Relieve valve

[10]

QUESTION 6: INTERNAL COMBUSTION ENGINES

6.1 **Different parts:** (3)

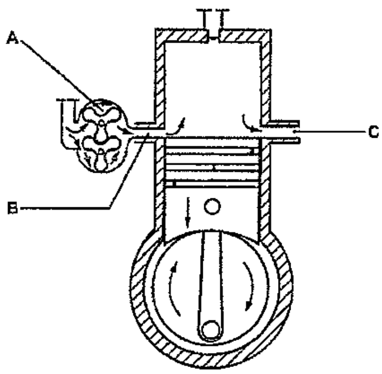


FIGURE 2

A - Blower
B - Intake port
C - Exhaust port

6.2 **TWO phases of FIGURE 1:** (2)

Induction phase
Exhaust phase

[5]

QUESTION 7: CRANES AND LIFTING MACHINES

7.1 **Five disadvantages of Static Tower Cranes:** (5)

1. The covering area of the crane is limited due to the fixed base.
2. Crane is static and cannot move around.
3. Load capacity decreases when the operating radius increases.
4. Costs w.r.t. erection, dismantling, transport, etc. are very high.
5. Limited operating area

7.2 **THREE Advantages of the Infrared Signal Remote Control:** (3)

1. Operators can walk safely behind the load. They can choose safe vantage points with the best visibility to do the job.
2. There is greater productivity. Operators can carry out other floor-based tasks while waiting for the next hoisting job.
3. The handling of loads is faster. Operators are not tied to the crane and they are closer to the load to see what they have to do.

[8]

QUESTION 8: MATERIAL AND MATERIAL PROCESSES

8.1 **FOUR Purposes for Annealing as a heat treatment process:** (4)

1. To soften carbon steel for machinability.
2. To release internal stresses.
3. To refine the grain structure.
4. To reduce brittleness.

8.2 **THREE Properties of metals when adding an alloy to metal:** (4)

1. It gives resistance to heat, wear and corrosion.
2. It gives improved machinability properties.
3. It can make the metal softer or harder.
4. It gives increased compressive or tensile strength.
5. It gives improved elasticity, ductility malleability and toughness.
   (**ANY 4**)

[8]

QUESTION 9: INDUSTRIAL ORGANISATION AND PLANNING

9.1 **PURPOSE of Occupational Health and Safety Act (No. 85 of 1993):** (4)

1. To provide for the health and safety of persons at work.
2. To provide for the health and safety of persons with the use of plant and machinery
3. To protect others against hazards to health and safety- from others at work.
4. To establish an advisory council for occupational health and safety
5. To provide for matters connected with occupational health and safety (**ANY 4**)

9.2 **Capital budget:** (5)
It is a plan for investment in:

1. property
2. equipment
3. other physical facilities
4. maintaining or expanding existing production
5. A long-term plan

9.3 **THREE methods to improve horizontal communication:** (3)

1. Interdepartmental meetings - to discuss the functioning of each department.
2. Co-operation incentives - such as bonuses can be created.
3. Social meetings - to promote interpersonal relations.

[12]

QUESTION 10: ENTREPRENEURSHIP

10.1 **The term "SWOT":** (4)

S - Strengths of your business
W - Weaknesses of your business
O - Opportunities that may arise
T - Threats that can influence the sales of the business

10.2 **FOUR pre-established basic principles that an entrepreneur will have in mind before starting a successful financial project:** (3)

1. A business idea.
2. A business plan.
3. Appropriate financing.
4. Appropriate premises.

[7]
TOTAL: 100

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