●●●POWER ENGINEERING

Fourth Class

Edition 3.5

Pumps and Compressors

Part B

Unit B-2

PanGlobal
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Published by PanGlobal Training Systems Ltd.
Publishers of Power Engineering Learning Materials

The material in this series is aligned with the SOPEEC Fourth Class Syllabus, dated November 2017, and the IPECC Curriculum, November 2017.
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Printed in Canada
Fourth Class - Part B - Unit B-2 - Pumps and Compressors
Edition 3.5, February 2025

ISBN13: 978-1-77251-265-6 (Part B Paper Set)
ISBN13: 978-1-77251-266-3 (Part B Ebook Set)
ISBN13: 978-1-77251-293-9 (Unit B2 Print)
ISBN13: 978-1-77251-294-6 (Unit B2 Ebook)

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PanGlobal
Partner in Education

1–1339 40 Ave NE
Calgary, Alberta
T2E 8N6

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UNIT B-2

PUMPS AND COMPRESSORS

Unit Introduction

An important consideration in any facility managed by Power Engineers is how to transport fluids: both liquid and gas. In many cases, this action is performed or facilitated by pumps. The use of pumps and pumping systems are widespread in all residential, commercial, institutional, municipal, and industrial sectors.

In most plants, pumps:

- Supply water to the boiler
- Feed chemicals to the deaerator and boiler
- Transfer fuel and lubricants
- Circulate water
- Deliver product

This unit introduces pumps and their use in modern industrial plants.

The air compressor is the heart of the modern power plant. Plant air compressors supply the air required to position dampers, control valves, and other critical final control elements. They are also used to start standby generators, atomize fuel, and to power intrinsically safe tools.

Refrigeration compressors are the heart of compression refrigeration systems. Without the energy added by the compressor, refrigerant would not evaporate, condense, and circulate through the refrigeration system.

The following chapters will familiarize the learner with the types, working principles, and construction of a variety of pumps and compressors. Their operation, maintenance, and troubleshooting will be discussed and illustrated.

Unit Rationale

Although pumps and compressors are typically purchased as individual components, they provide a service only when operating as part of a system. The energy and materials used in a pumping or compressed air will depend on the equipment design, the design of the installation, and the way the system is operated. An understanding of their function is therefore important in optimizing operating and maintenance costs.

Pumps and compressors are integral to a plant's ongoing operation to such a degree that standby units are often specified in a plant's design. Standby units must be available if, and when, the system's primary units fail. The failure of a single pump or a single air compressor can cause an unscheduled plant outage, which can be quite costly to the company. Keeping pumps and compressors running, and making sure that they are operating efficiently is part of the Power Engineer's job. In this way, Power Engineers have a very positive effect on minimizing the occurrence of process disruptions.

CHAPTER 1

Types of Pumps

Learning Outcome

When you complete this chapter you should be able to:

Describe the construction and operating principles of various types of pumps used in plants.

Learning Objectives

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

1. *List common pump applications.*
2. *Define the terms associated with pump performance.*
3. *Describe the common pumps found in plants.*

Chapter Introduction

One of the first pieces of powered machinery to be invented at the dawn of the industrial age was a crude form of pump. Powered by a steam engine, it lifted water out of the coal mines in England. In the 300 years since, pumps have evolved into essential industrial equipment. Pumps are available in an endless variety of types and sizes, and are used for many applications.

A pump moves liquids by adding energy to the liquid. This chapter discusses the theory of pumps, and the types of pumps in common use in commercial buildings and industrial plants.

It is important for Power Engineers to be familiar with the types of pumps commonly used in industry today. By having a good understanding of how a pump works, and its specific applications, a Power Engineer can operate and maintain pumping equipment safely and efficiently.

Objective 1

List common pump applications.

Applications

In industrial plants, pumps are used to move fluids. These fluids can be molten metals at very high temperatures, or cryogenic liquids are at extremely low temperatures. Pumps are used to generate pressures so small as to be barely detectable, or so high that liquid being pumped is capable of cutting through material like a saw. Also, pumps are designed for a very wide range of capacities. They have power requirements from a fraction of a kW to nearly 75 000 kW.

Below are some common types of pumps used in industrial plants.

Boiler feedwater pumps that supply feedwater to the boiler. They must be capable of forcing water against the boiler pressure.

Fuel oil pumps that supply fuel to oil burners.

Lubricating oil pumps that circulate lubricating oil to the bearings of machines such as turbines, internal combustion engines, pumps, and compressors.

Circulating water pumps that continuously move liquid, such as in building heating systems, cooling systems, and thermal fluid systems. They are often called cooling water pumps when used to pump water through heat exchangers, such as a condensers or oil coolers.

Chemical feed pumps that are small capacity units used to inject chemicals into boilers.

Fire pumps that supply water to plant fire suppression systems.

Domestic water pumps that supply potable water from wells or other sources.

Pump Location

Pumps may be small enough to be suspended by the pipework that they are servicing, but are usually anchored to a firm location. Reinforced concrete foundations support large pumps, for stability and vibration control.

Pumps are generally located where they can be easily accessed for monitoring and maintenance. However, some pumps may be on the bottom of a lake, down a well or on the inside of a pipeline or vessel.

Pump Drives

A pump can be driven by a variety of power sources. These include:

- Electric motors
- Gas or diesel internal combustion engines
- Gas, water, or steam turbines
- Steam engines

Small pumps can be operated:

- By hand or foot
- With air pressure or hydraulic pressure

Objective 2

Define the terms associated with pump performance.

Theory of Pressure

All matter has mass. Therefore, all matter is subject to the force of gravity. Liquids are no exception. Knowing that force = mass × acceleration, it is possible to calculate the force of gravity exerted on a mass of liquid (or its "weight"). One litre of pure water at 4°C has a mass of 1 kg. This litre, then, has a "weight" of 1 kg × 9.81 m/s^2 = 9.81 N.

Pressure is force exerted over a unit area. For example, a pascal is a force of one newton over an area of one square metre. A force of 9.81 newtons over an area of one square metre will exert a pressure of 9.81 Pa. So, a litre of water, spread evenly over the base of a container with an area of one square metre, will exert a pressure of 9.81 Pa on the bottom of the container. That same litre of water could be placed in a milk carton, with a base area of 0.0049 m^2. In this case, the pressure exerted at the base of the container by the same kilogram of water will be:

$$\begin{aligned} P &= \text{force} \div \text{area} \\ &= 9.81\ \text{N} \div 0.0049\ \text{m}^2 \\ &= 2002\ \text{Pa} \end{aligned}$$

So, the pressure exerted at the base of a column of liquid depends on the height of the liquid.

The pressure exerted at the base of a column of liquid is also dependent on the density of the liquid. For example, mercury has a density 13.6 times that of water. One litre of mercury, if put in the same milk carton, would exert a pressure of 2002 × 13.6 = 27228 Pa on the base of the carton!

The relationship between pressure, density, acceleration due to gravity and height of liquid is summarized in the following formula:

$$P = \rho g h$$

Where:

- P = pressure in Pascals
- ρ = density of the liquid, in kg/m^3
- g = gravitational constant (9.81 m/s^2)
- h = height of liquid, in m

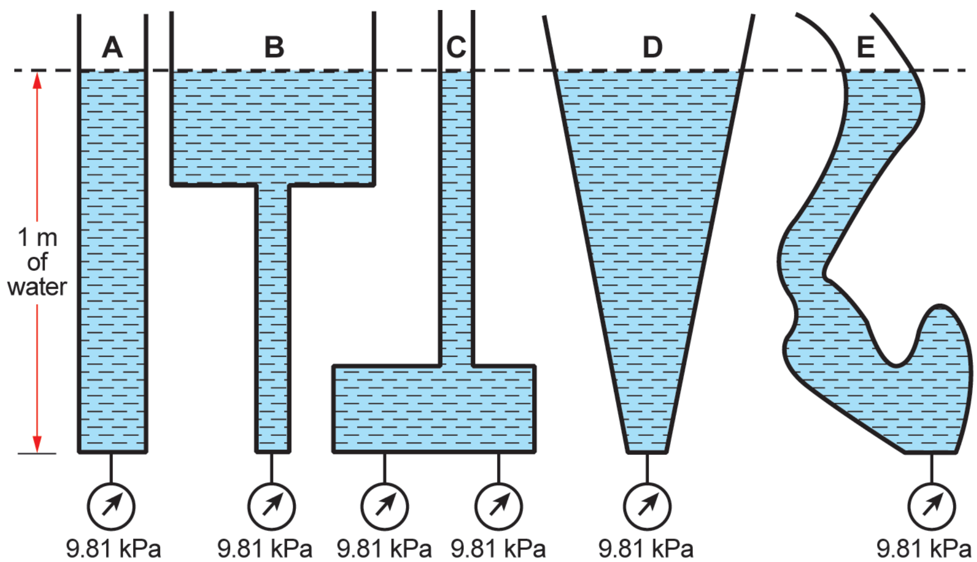
If several open containers hold the same fluid to the same height, the pressure at the base of the fluid in each container will be the same, regardless of its shape. This is known as **Pascal's Paradox**. Consider a conical vessel filled one metre deep with water. It does not matter which end of the vessel is pointed downward. As long as the water measures 1 m from the bottom, the pressure at the base of the vessel will be the same.

Figure 1 demonstrates Pascal's paradox. Here, several open containers with different shapes are filled with water at a temperature of 4°C, to a depth of one metre. Despite containing different masses, each container has a pressure of 9.81 kPa at its base. Note that the vessel shape has no effect on the pressure at the base of the column of water.

Pumps are designed to produce adequate pressure to move liquids from one elevation to another. However, the pressure a pump develops depends on the density of the liquid being pumped. For example, a pump rated at 10 metres of head of the relative fluid can elevate water, glycol, fuel oil, or mercury to a height of 10 metres. The pressure measured at the base of the piping system will vary depending on which of these fluids is being pumped. The shape of the piping system has no effect on the pressure at its base.

Therefore, in pumping theory, all pressures are translated into its equivalent head in metres.

Figure 1 – Pascal's Paradox



HEAD

Head can be used to refer to many different pumping configurations. Moving liquid from one elevation to another involves a change in vertical distance. Therefore, knowing the head requirements of a pumping system helps designers select the correct pump, motor, and piping system to move the fluid.

Static Head

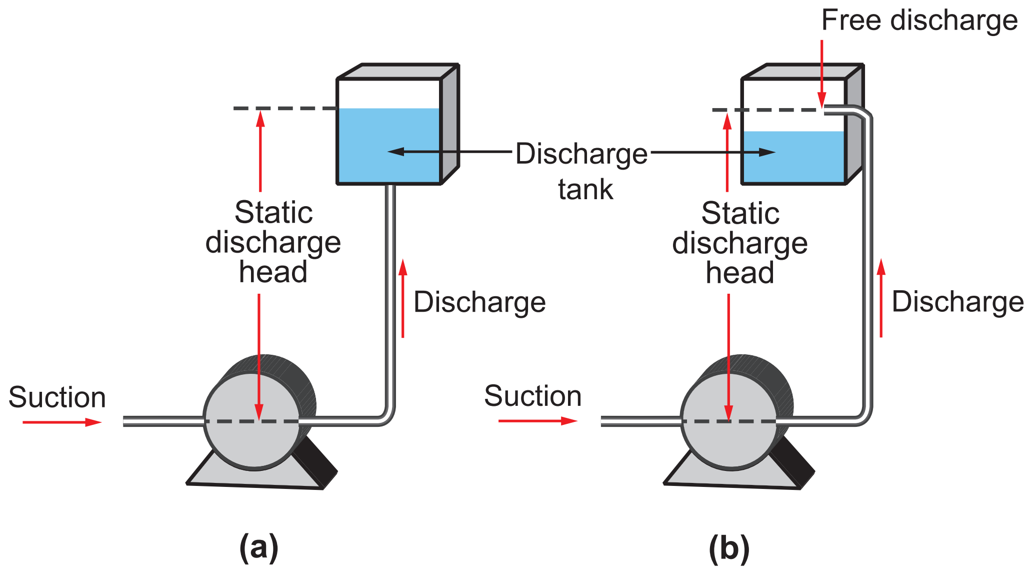
Static head is the head of a pumping system, without taking into consideration fluid velocity or friction of pipe, valves, and fittings. Simply put, static head is the head measured with the pump off, and with no liquid flowing.

Fluid velocity and friction of pipe fittings are dynamic head considerations (discussed later). Static head considers only the relative heights of a piping system's suction and discharge piping.

Static Discharge Head

Static discharge head is the distance above the centre line of the pump and the liquid level of an elevated discharge tank (Figure 2(a)), or to the point of free liquid discharge (Figure 2(b)).

Figure 2 – Static Discharge Head



Static Suction Lift

Lift is a distance measured below the centerline of the pump. In this regard, "lift" is like "negative head." **Static suction lift** is the distance between the surface of the liquid level of a supply tank below a pump and the centre line of the pump (Figure 3(a)). A pump has suction lift when it draws liquid from below its centre line.

Consider a pump with a supply source (such as a pond or a tank) located below its centerline, as in (Figure 3(a)). The pump is able to lift water because of the downward pressure of the atmosphere on the surface of the water in the supply tank or pond.

When a pump is running, the movement of plungers or pistons creates a partial vacuum in the pump and suction piping. The atmospheric pressure of the water supply is greater than the pressure inside the pump, so the water is forced up the suction piping and into the pump.

Atmospheric pressure varies with altitude or height above sea level. At sea level, the atmospheric pressure is about 101.3 kPa. This is equivalent to the pressure exerted by a column of water 10.34 metres high. In Winnipeg, Manitoba (altitude 240 m), the atmospheric pressure is around 98.5 kPa. This is equivalent to approximately 10 m of water head. In Calgary, Alberta (altitude 1100 m), the atmospheric pressure is only around 89 kPa. This is equivalent to approximately 9.1 m of water head.

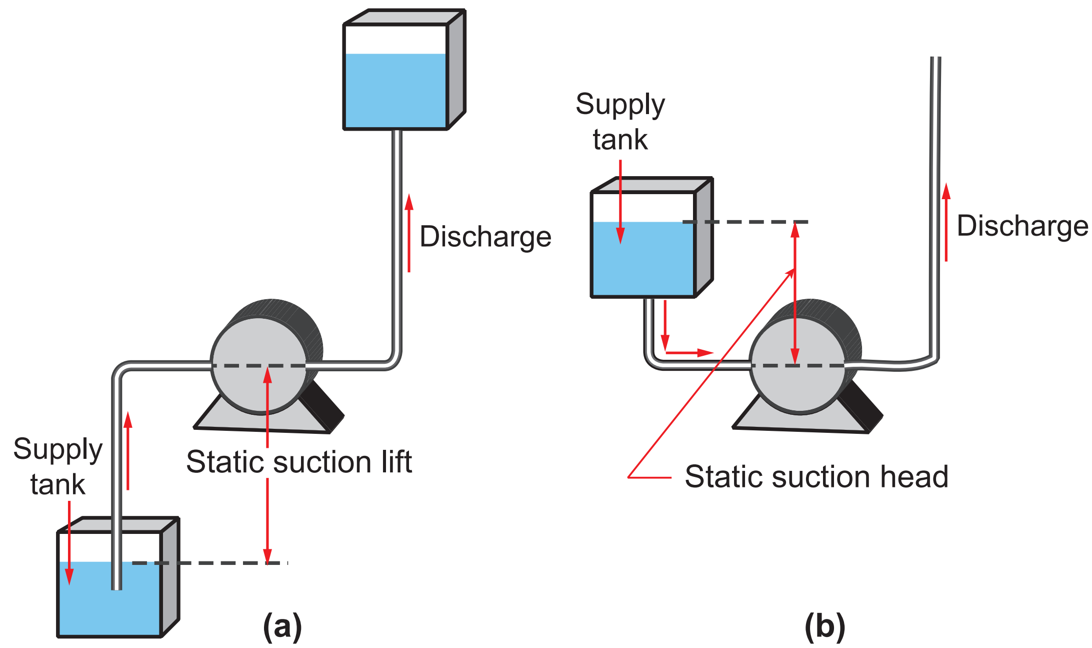
Theoretically, the maximum suction lift of a pump is 10.34 m at sea level, 10 m at 240 m altitude, and 9.1 m at 1100 m altitude. In reality, this lift cannot be attained because of friction in the pump and piping, and leakage past the piston or plunger, and valves. Centrifugal pumps, particularly, have a much poorer suction lift than piston or plunger pumps. They should always be placed close to, or preferably below, the water supply.

Based on these factors, no pump should be set above the water supply any more than necessary.

Static Suction Head

Static suction head is the distance between centre line of a pump and the surface of the liquid level in an elevated supply tank (Figure 3(b)).

Figure 3 – Static Suction Lift and Head



Pressure Head

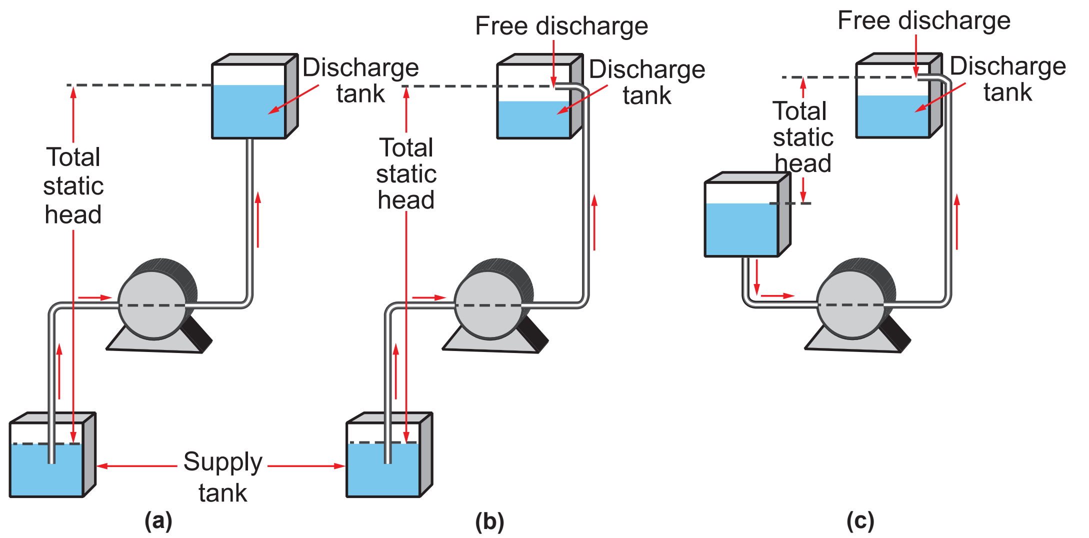
When a pump discharges water into a vessel that is under pressure, such as a boiler or deaerator, it must impart additional pressure to the water in order to overcome the vessel pressure. This pressure, expressed in metres equivalent, is called the **pressure head**. Pressure head is a form of static head, because it does not vary with liquid flow.

Total Static Head

The **total static head** is the vertical distance between the surface liquid line of the supply tank to the surface of the liquid line in the discharge tank (Figure 4(a)), or to the highest liquid level of the free discharge (Figure 4(b) and 4(c)). In other words, it is the total height that the liquid is moved by the pump.

If pumping into a pressurized vessel, total static head also includes pressure head.

Figure 4 – Total Static Head



Dynamic Head

A certain amount of pressure is required to overcome friction of pipes, to accelerate fluid, and to maintain fluid velocity through the pipes. These factors only come into effect when fluid is moving (in other words, when the pump is on). The pressure required to develop and maintain velocity, or to overcome friction, increases with increasing flow rate. Because these conditions vary with flow, the head required to overcome friction and develop velocity is called **dynamic head**.

Friction Head

The liquid that the pump moves meets resistance in pipes, valves, and fittings. **Friction head** is the pressure, measured in equivalent metres, to overcome this friction. As fluid flow rates increase, friction head increases. Friction head is found on both suction and discharge sides of the pump.

Velocity Head

Velocity head is velocity converted to head in metres. It is determined by the kinetic energy of the fluid within the pipe, converted to potential energy, and expressed in equivalent metres of head. Applying the law of conservation of energy, it can be seen that kinetic energy can be converted to potential energy. Recall:

$$K.E. = P.E.$$

$$\frac{mv^2}{2} = mgh$$

$$\frac{v^2}{2} = gh$$

$$\therefore h = \frac{v^2}{2g}$$

Using this method, liquid velocity can be expressed in equivalent head.

Velocity head is found on both the suction and discharge sides of the pump.

Total Dynamic Head

The **total dynamic head** is the sum of the total static head and the dynamic head. This is the total head required to move the liquid from the source to the point of discharge. It takes into account dynamic suction head, dynamic discharge head, static suction head, static discharge head, and pressure head.

Net Positive Suction Head (NPSH)

Net positive suction head (NPSH) is categorized as **net positive suction head available ($NPSH_A$)** or **net positive suction head required ($NPSH_R$)**. The $NPSH_A$ is calculated by taking into account the fluid densities, vapour pressures, velocities, pipe friction, pressure head, and static head or lift on the suction side of the pump. The $NPSH_R$ is a pump design characteristic. Various pumps require various minimum suction heads. The $NPSH_A$ of a pumping system must be greater than the $NPSH_R$ of the pump. This is so that the pump will not cavitate or become vapour-bound (see discussion on cavitation, further on in this chapter).

Shut-Off Head

Shut-off head is the head developed by a centrifugal pump when running with its discharge valve shut.

Objective 3

Describe the common pumps found in plants.

Types of Pumps

Pumps are generally classified in two categories:

1. **Positive displacement pumps**
2. **Dynamic pumps** (also known as **roto-dynamic pumps**)

Positive Displacement Pumps

A positive displacement pump moves liquid by creating a void. After liquid flows into the void, the void is either decreased in size, forcing liquid out, or the void is moved in position from the suction to the discharge side of the pump.

The liquids must move into, out of, or with the void because liquids are incompressible. The voids are created, changed in size, or moved using pistons, plungers, vanes, or other means. Therefore, at a constant operating speed, a positive displacement pump moves a specific amount of liquid regardless of pump head. Typical positive displacement pumps apply energy to the fluid stream intermittently; this causes the discharge pressure to pulsate.

Positive displacement pumps are divided into two main classes:

1. Reciprocating
2. Rotary

Reciprocating Pumps

When a **reciprocating pump** is operating, the movement of the plungers, pistons, or diaphragms creates voids in which a partial vacuum forms. When the pump is in operation, the atmospheric pressure exceeds the pressure in the void. The atmospheric pressure, acting on a liquid surface, moves the liquid into the low-pressure void of the pump.

In this type of pump, the pumping action is produced by the back and forth (reciprocating) movement of a plunger or piston within a cylinder, or a reciprocating diaphragm. The liquid being pumped is drawn into the cylinder through one or more suction valves. The liquid is then forced out through one or more discharge valves by direct contact with the plunger, piston, or diaphragm.

A plunger style pump uses a machined reciprocating cylindrical rod to increase and decrease the size of the void, thus moving the liquid. The piston style pump has a piston rod and a larger piston on the end of the rod, to give the pump more capacity than the plunger-style pump.

The diaphragm pump uses a flexible diaphragm to increase and decrease the size of the void. The diaphragm is mounted on the end of a shaft that is like a piston rod. The diaphragm must be made of a material that will not react with the pumped fluid. Diaphragm materials can be selected for pumping corrosive liquids, or those that react with metals.

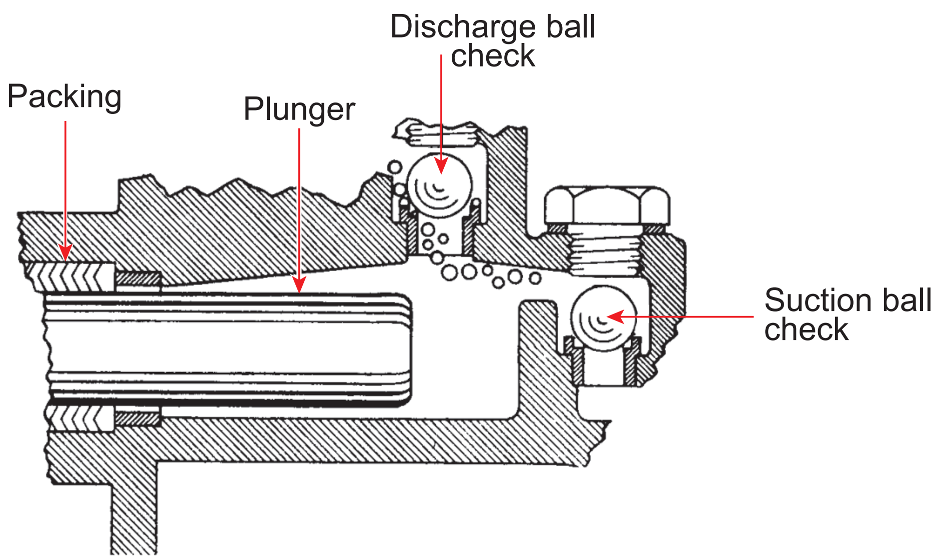
Pump action can be described as **single-acting** or **double-acting**. In a single-acting pump, the fluid is only moved on one stroke of the plunger, piston, or diaphragm. Only one set of valves is required for a single-acting pump.

In the double-acting pump, the pump plunger, piston, or diaphragm moves the fluid on each stroke. This style needs two sets of valves, one for each stroke. Variations of this type of pump include the **simplex** (one stage), **duplex** (two stage), **triplex** (three stage), or **multiplex** (more than three stages) pump. In these pumps, the pressure increases as the fluid moves from one stage to the next. Each stage change requires its own set of valves. In a reciprocating pump, the cylinders can operate in parallel with each other and can deliver liquid to a common discharge.

The valve arrangements may be as simple as steel or ceramic balls on a seat. They are held in place by either the vacuum of the suction stroke, or the pressure of the discharge stroke. The valves may also have springs to help them seat tightly.

Figure 5 illustrates a single-acting, reciprocating plunger-type positive displacement pump. When the plunger moves from right to left, the liquid is drawn into the cylinder through the suction ball check. When the plunger reverses and moves from left to right, the liquid is forced out through the discharge ball check. The discharge ball check is forced open by the pressure of the liquid. At the same time, the suction ball check is forced closed.

Figure 5 – Single Stage Simplex Plunger Pump

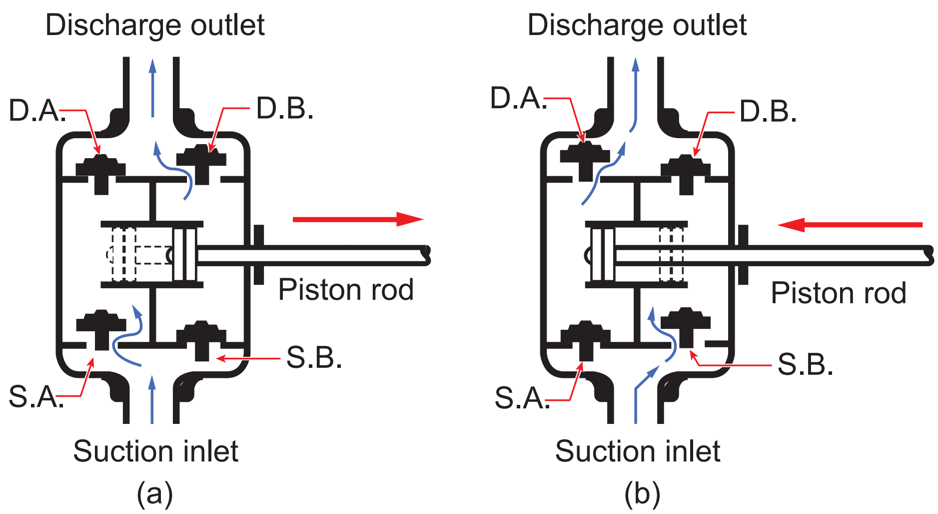


The movement of the plunger in the cylinder in one direction is called the stroke of the plunger. The distance the plunger moves in and out of the cylinder is called the length of the stroke.

As can be seen in Figure 5, only one side of the plunger takes part in the pumping action. Water is discharged during only one of every two strokes. For this reason, the pump is called single acting.

Figure 6 shows a basic diagram of a double-acting, reciprocating piston-type pump. The pump has two discharge valves (D.A. and D.B.), and two suction valves (S.A. and S.B.). When the piston moves from left to right (Figure 6(a)), the liquid is drawn in through the suction valve (S.A.). At the same time, the liquid is being forced out through the discharge valve (D.B.). When the piston reverses and moves from right to left (Figure 6(b)), liquid is drawn in through the suction valve (S.B.). At the same time, liquid is being forced out through the discharge valve (D.A.).

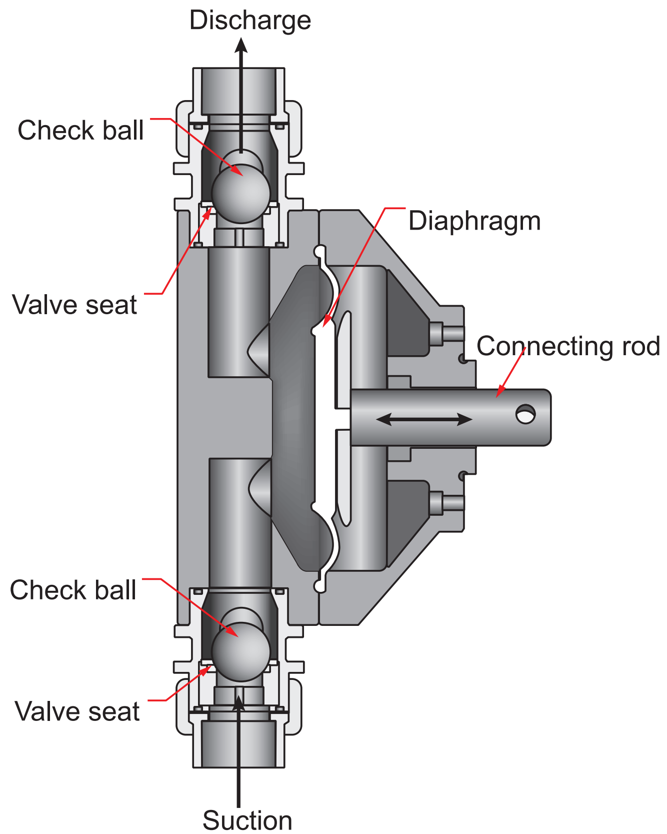
Figure 6 – Positive Displacement - Double Acting (Piston) Pump



With this arrangement, both sides of the piston take part in the pumping action. Liquid is discharged when the piston moves in either direction. For this reason, it is called double-acting.

Figure 7 shows a diaphragm pump. It works like a plunger or piston pump, but a flexible diaphragm is used to move the fluid. Diaphragm pumps are commonly used to pump chemicals for feedwater treatment because they pump low volume at high head. Diaphragm pumps can pump corrosive, erosive, and viscous fluids. This makes them suited to pumping fluids containing solids, and they are often used as sump pumps.

Figure 7 – Simple Diaphragm Pump



Rotary Pumps

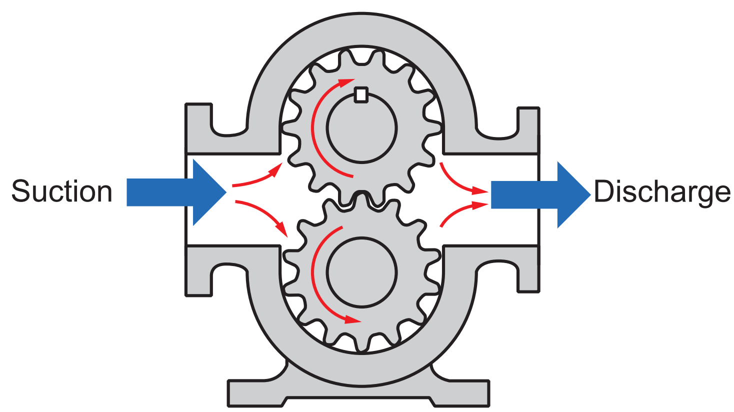
Rotary pumps are positive displacement pumps. Most rotary pumps transfer pockets of liquid from the low-pressure side of the pump to the high-pressure side. Then, the pockets are forced to empty themselves and return to the low-pressure side, to be refilled with the fluid being pumped.

Rotary pumps deliver high pressure liquid without the pulsations that occur in reciprocating pumps.

Rotary Gear Pump

Figure 8 shows a gear pump, also called a **spur gear pump** or an **external gear pump**. It consists of a housing, a driving gear, and an idler gear. Arrows indicate the direction of rotation of the gears. As the gears rotate, they convey pockets of liquid to the discharge side of the pump by trapping the fluid in the pocket of the gear and the pump housing. The fluid is expelled from the gear pockets as the teeth of the gears mesh because the liquid and the tooth cannot be in the gear pocket at the same time. Further rotation of the gears causes the teeth to become unmeshed on the suction side of the pump. Fluid flows in to fill the void created as the gear teeth come out of the pockets. Gear pumps can be used for pressures up to 10 000 kPa.

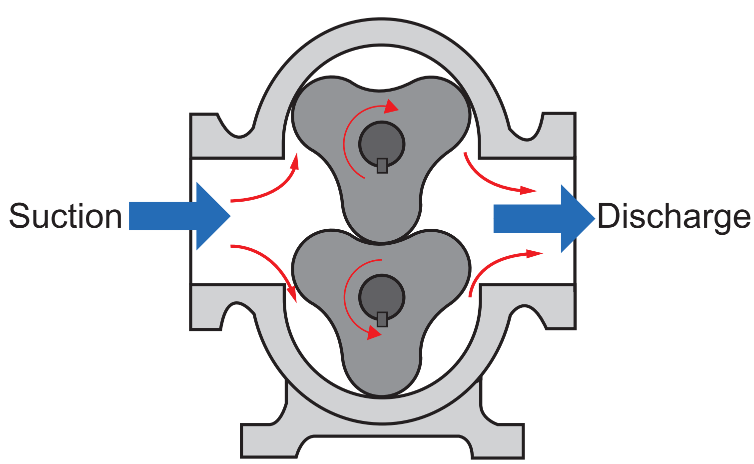
Figure 8 – Gear Pump



Rotary Lobe Pump

Rotary lobe pumps (shown in Figure 9) are similar to gear pumps in theory, as liquid is transferred around the outside of rotating lobes and expelled when they mesh. One difference is that the lobes are both driven by external gears, which keep the lobes synchronized.

Figure 9 – Rotary Lobe Pump

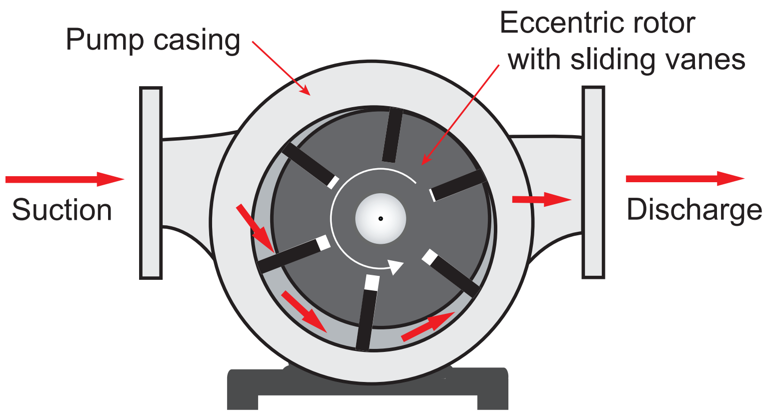


Sliding Vane Pump

Figure 10 shows a **sliding vane pump**. It consists of a casing, sliding vanes held within a rotor, and a rotor that is located eccentric (off-centre) to the casing. As the rotor turns, the vanes slide in and out to conform to the changing proximity of the pump casing.

Pockets of liquid are transferred as indicated by the arrows. As the vanes retract with the diminishing clearance to the pump casing, the size of the pockets decreases and the liquid is forced out. As the vanes rotate past the point of minimum clearance with the pump casing, the size of the pockets begins to increase again and the liquid on the intake side of the pump flows in to fill the increasing void.

Figure 10 – Sliding Vane Pump



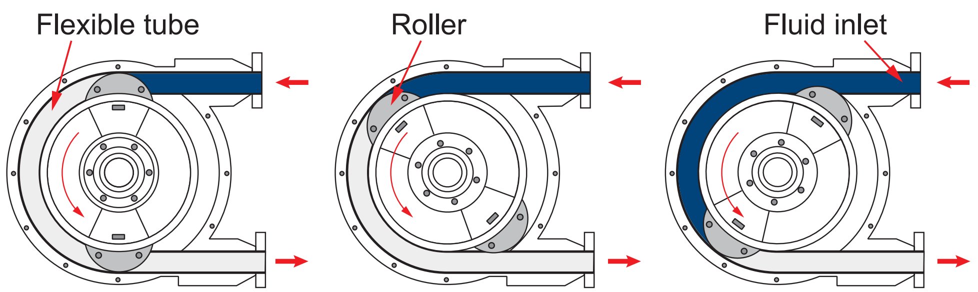
CAUTION

When positive displacement pumps are used, a pressure relief device must be installed in the discharge line before the discharge stop valve. If the discharge stop valve is inadvertently closed, excessively high pressures could be produced. This could cause damage to the pump or piping.

Peristaltic Pump

Peristaltic pumps move fluid through a flexible tube that is squeezed progressively by a roller. The roller moves around the housing, and pushes trapped liquid toward the discharge of the pump (see Figure 11). This pump is used in feedwater treatment and chemical dosing systems because the fluid and the pump parts (other than the tube) do not make contact.

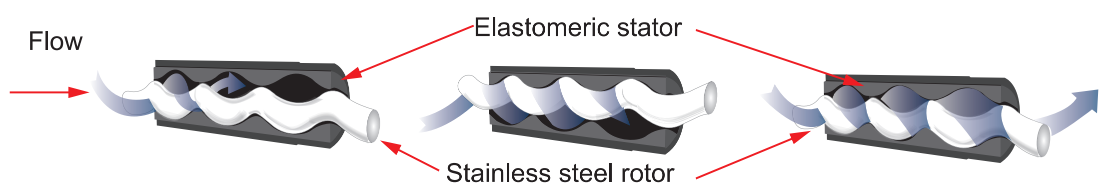
Figure 11 – Peristaltic Pump



Progressive Cavity Pump

Progressive cavity pumps (also known as **progressing cavity pumps** or PC pumps) are positive displacement pumps, having a single helical stainless steel rotor mounted within an elastomer-lined stator (see Figure 12). The rotor forms tightly sealed cavities between itself and the casing. When the rotor turns, the cavities between the rotor and the stator move toward the discharge end of the pump. Liquid fills the cavities at the suction end of the pump, and is moved toward the discharge end as the rotor turns. The liquid being pumped lubricates the rotor and stator.

Figure 12 – Progressive Cavity Pump Operation



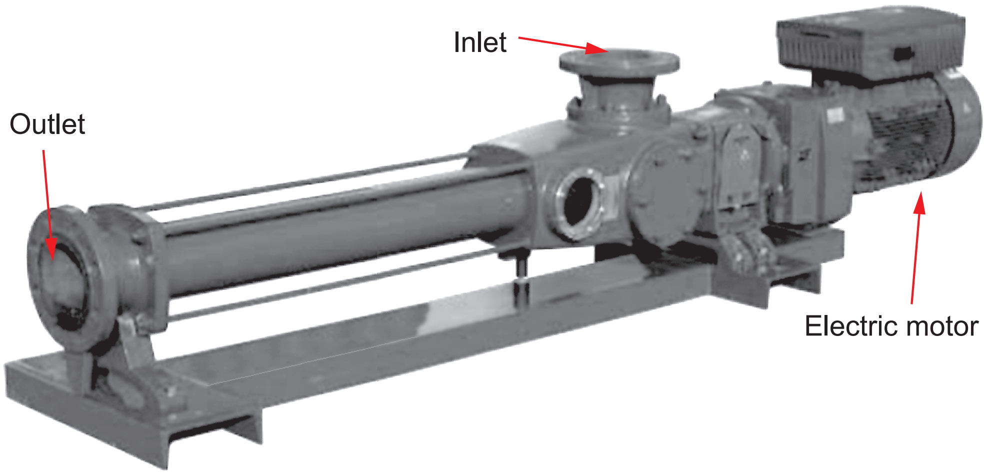
This design does not need suction or discharge check valves. The pump produces a constant flow with little or no pressure pulsation. They are self-priming, and have suction lifts up to 8 m. As well, the simple design makes them easy to service and maintain.

These pumps are suitable for pumping

- Sludge and slurries
- Abrasive liquids
- Industrial sewage
- Emulsions
- Crude oil
- Produced water
- Diluted bitumen
- Industrial chemicals and detergents
- Paper stocks
- Delicate solids

Figure 13 shows a progressive cavity pump of a variety used in the oil and gas industry. Note that the flanges are located so that the pump can be moved easily from its base for servicing.

Figure 13 – Progressive Cavity Pump



Dynamic Pumps

Dynamic (roto-dynamic) pumps include centrifugal pumps and turbine pumps. These pumps add energy continuously. Centrifugal types have rapidly rotating impellers that generate centrifugal force. This adds kinetic energy to the fluid in the form of velocity. At the pump discharge, the velocity is converted back to pressure. Turbine pumps rely on repeated impulse forces to raise the fluid pressure.

Centrifugal Pumps

Centrifugal pumps are constructed of one or more impellers, rapidly rotating in a casing. The rotating action of the **impeller** imparts energy to the liquid, increasing its velocity. The velocity of the liquid reduces as it proceeds through the casing. The velocity energy (kinetic energy) is converted to pressure energy (potential energy), in accordance with the law of conservation of energy.

Centrifugal pumps can be subdivided into the following types:

1. Radial Flow
   a. Volute
   b. Diffuser
2. Axial flow
3. Mixed flow

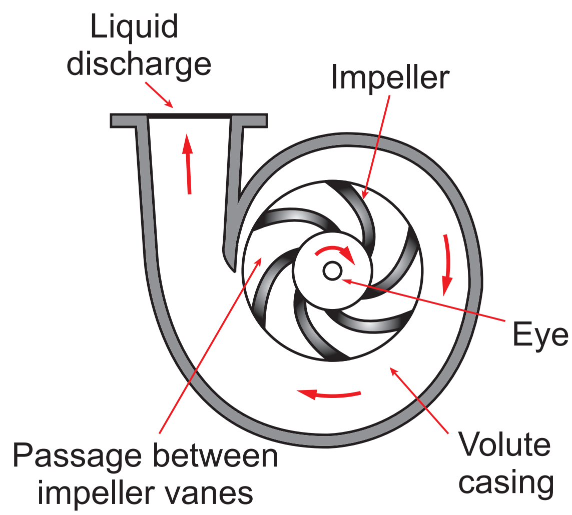
1. Radial Flow Pumps

The radial flow centrifugal pumps are the most commonly used design. Liquid enters the centre, or **eye of the impeller**, and exits perpendicular (at a right angle) to the pump shaft in a radial direction (Figures 14, 15 and 16).

1a. Volute Pumps

The general construction of the volute centrifugal pump is shown in Figure 14. The liquid being pumped is drawn into the eye of the impeller and discharged radially from the impeller into the **volute casing**. The volute casing has an increasing cross-sectional area as it approaches the pump discharge. In this area, the velocity of the liquid discharged from the impeller is lowered and converted to pressure.

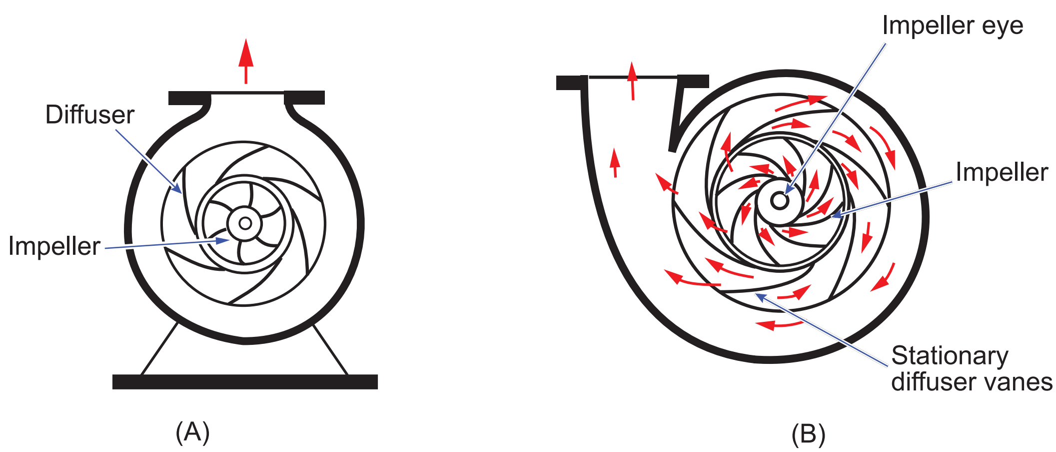
Figure 14 – Volute Centrifugal Pump



1b. Diffuser Pumps

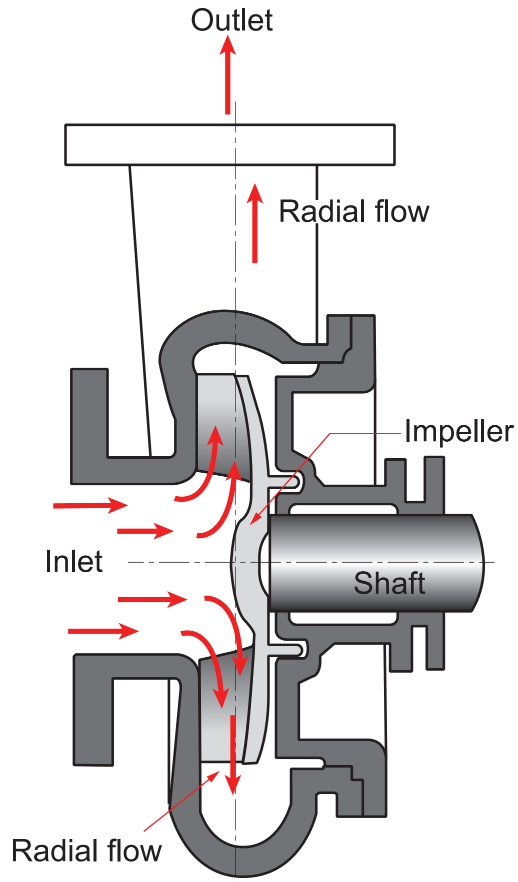
To make the conversion from velocity to pressure more effective, stationary **diffuser vanes** can be installed around the rim of the impeller. This construction gives rise to the term **diffuser centrifugal pump**, as shown in Figure 15.

Figure 15 – Diffuser Centrifugal Pump



The combination of centrifugal force and pressure created by the velocity decrease accounts for the total pressure developed by the volute or diffuser pumps.

Figure 16 – Radial Flow Pump

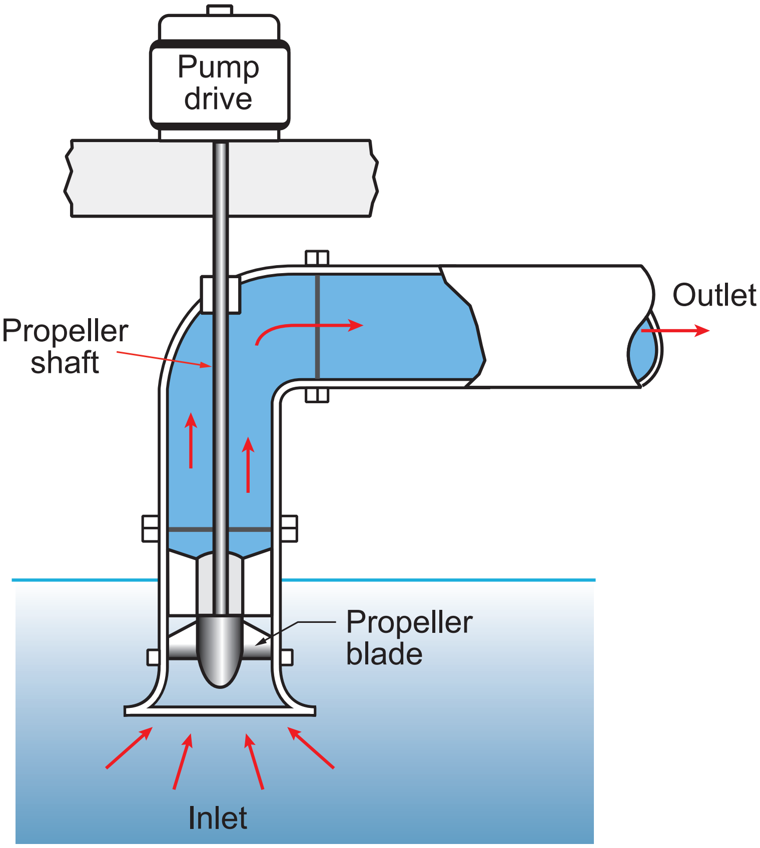


2. Axial Flow Pumps

Axial flow pumps use a **propeller** instead of an impeller. The propeller changes the rotational motion of the water into forward thrust. This moves the fluid axially, parallel to the pump shaft (see Figure 17).

These pumps are mostly used in low head, high flow applications. In agricultural settings, they are used for irrigation pumps. In industrial settings, they move water from a lake or river to the plant.

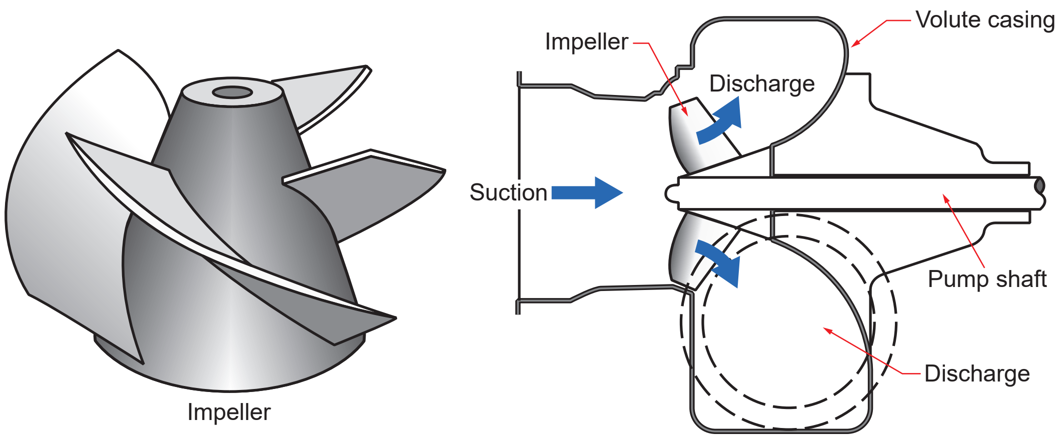
Figure 17 – Axial Flow Pump



3. Mixed Flow Pumps

A **mixed flow pump** (Figure 18) is a combination of both the radial and axial flow design, and moves the liquid flow diagonally to the shaft. Mixed flow pumps are typically used in applications that require high flow and low pressure, similar to an axial flow pump.

Figure 18 – Mixed Flow Pump



Centrifugal Pump Characteristics

Positive displacement pumps running at a constant speed move a specific amount of liquid regardless of pump head. The capacity of a centrifugal pump, on the other hand, changes with the change in head.

When the discharge head (static plus dynamic) increases, the capacity of a centrifugal pump decreases; when the discharge head decreases, the capacity increases. When the head is increased so much that it exceeds the design head for the pump, the output drops to zero, which is called shut off head.

Therefore, it is vital to carefully consider the total head of the pumping system when selecting a centrifugal pump. The pump must be selected to efficiently deliver the required amount of liquid against the system head.

Adjusting the discharge valve can regulate the flow of a centrifugal pump. Throttling the discharge valve increases the flow resistance. This increases the friction head and causes the flow to decrease. The discharge pressure gauge on the pump will show a moderate increase in pressure; however, this increase will not damage the pump or piping as it will with a positive displacement pump.

CAUTION

Do not run a centrifugal pump for extended periods of time with its discharge valve shut. The energy applied to the impeller will churn the trapped liquid within the casing, against the liquid's internal fluid friction. This energy, in overcoming the friction, is converted to heat. The heat generated will boil the trapped liquid, resulting in cavitation, vapour-binding, and damage to the pump.

Always operate a centrifugal pump with its suction valve wide open. Never use a suction valve for flow control. Throttling or closing this valve starves the impeller of its water supply, and may cause destructive cavitation. Cavitation results in damage to the impeller and excessive vibration that may ruin the bearings. A lack of liquid may also damage stuffing boxes and seals. These require a certain amount of liquid for lubrication and cooling.

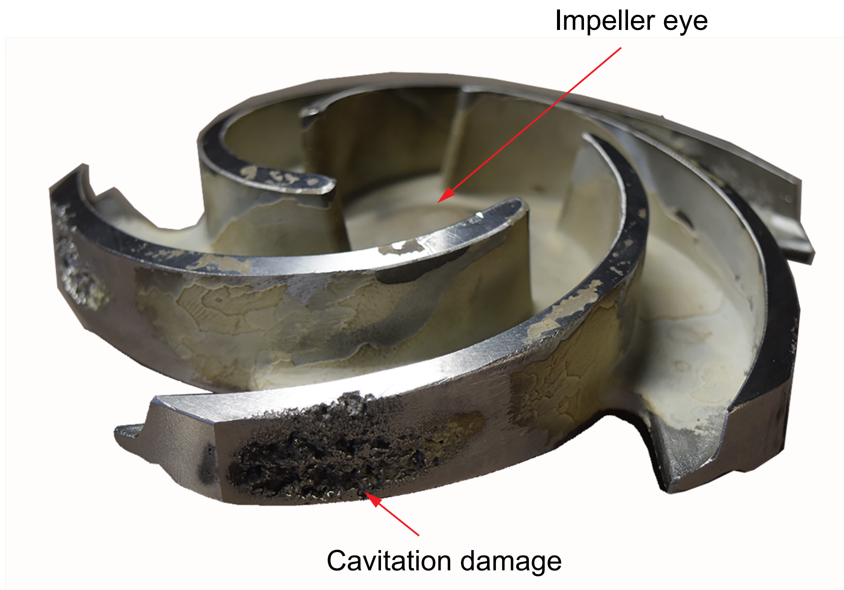
When the flow is throttled, the pump's power requirement is also reduced, in spite of the resulting pressure increase. To take advantage of this fact, large centrifugal pumps are started with a closed discharge valve.

In some situations, a pump motor may trip off on overload if the pump is started with the discharge valve wide open. Also, since the no-flow power requirement is relatively small, excessive power surges during the pump startup can be avoided. It is very important to avoid power surges in buildings with large electric lighting loads, such as office buildings. Severe dimming of lights due to a power surge can be disturbing, and can cause some equipment to shut down.

Cavitation

When the pressure, at any point inside a centrifugal pump, drops below the vapour pressure that corresponds to the temperature of the liquid, the liquid will vaporize and form bubbles. These bubbles are carried along with the flow until they reach a region of higher pressure, where they collapse and produce a shock wave. This phenomenon is called **cavitation**.

Figure 19 – Cavitation



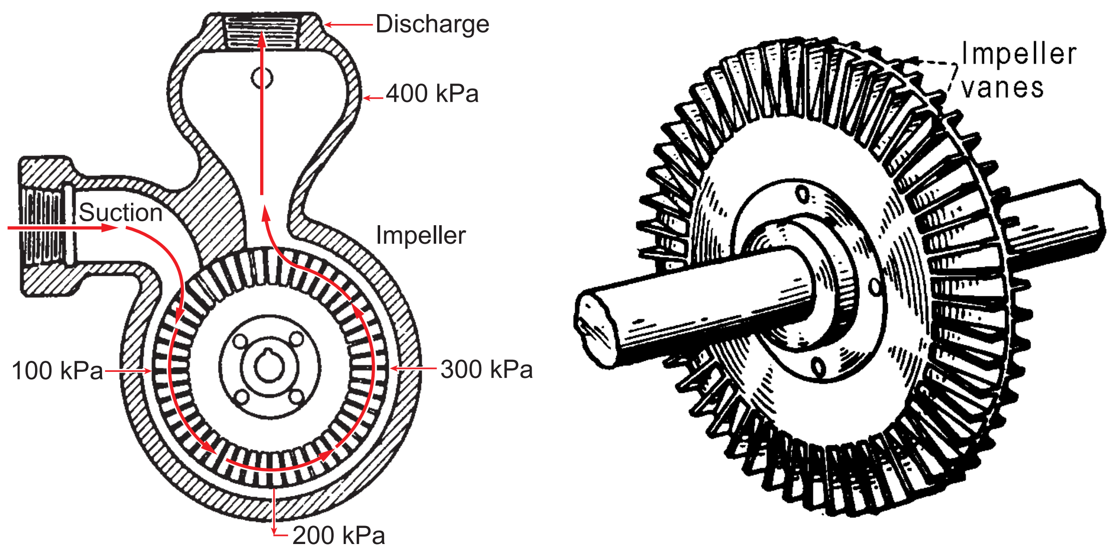
When the bubbles are carried onto the surface of the impeller and collapse there, the impact damages the metal surface. When this action is repeated in rapid succession, the metal is worn away, as shown in Figure 19. This will produce other mechanical effects, such as noisy operation and vibration. This wearing and vibration may result in the mechanical destruction of the pump if left unchecked. Cavitation occurs mainly on the suction side of the pump or in the inlet portion of the impeller.

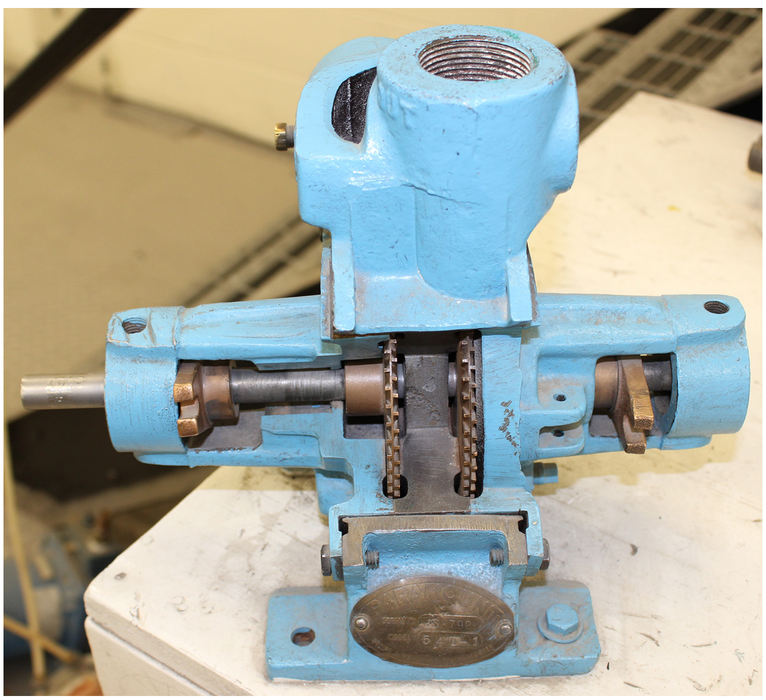
Turbine (Regenerative) Pump

Figure 20 shows a **turbine pump** or **regenerative pump**. The liquid being pumped enters at the pump suction and is circulated by the impeller almost 360 degrees around the casing, where it is discharged. The impeller vanes travel through a channel in the pump casing. The pumped liquid receives continuous impulses from the fast moving vanes, increasing the liquid pressure substantially as it approaches the pump discharge.

The regenerative pump can develop pressures several times that of a centrifugal pump of similar size and speed. This pump must have flow through it at all times; never operate this pump with the discharge valve fully closed.

Figure 20 – Turbine (Regenerative) Pump





Chapter Summary

In this chapter, common pump applications were listed, such as supplying water to boilers or chemicals for feedwater treatment, and to circulate cooling water. Pump theory and terms associated with pump performance like suction, discharge, lift, and head were discussed.

This chapter also covered:

a) Positive displacement

b) Dynamic pumps

c) Pump types, styles, and designs, such as:

- Reciprocating
- Rotary
- Centrifugal
- Regenerative

Through these explanations and accompanying video clips, an understanding of the general principles of pump operation should have been gained. In the next chapter, pump operation and maintenance is discussed.

CHAPTER 2

Pump Operation and Maintenance

Learning Outcome

When you complete this chapter you should be able to:

Describe the major considerations and procedures for pump operation and maintenance.

Learning Objectives

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

1. *Discuss the components of a driver and pump assembly.*
2. *Discuss pump shaft sealing, compression packing, and the replacement of compression packing.*
3. *Describe the standard types of mechanical seals.*
4. *Describe pump bearings, shaft alignment procedures, and the equipment used to align shafts.*
5. *Describe centrifugal pump startup and priming procedures.*
6. *Describe positive displacement pump operating characteristics, priming, startup, and routine checks.*

Chapter Introduction

This chapter discusses the operation and maintenance of the pumps covered in the previous chapter.

Pumps, when new, correctly installed, and running within their design parameters, have unique sounds, pressures, vibration, and bearing temperatures. These are the baseline conditions that future pump performance is measured against. Changes from these conditions could signal trouble, and lead to sudden failure or shortened operating life. If caught early, repairs can be planned and executed, in order to avoid expensive upsets and downtime.

This chapter introduces the parts, operation, and maintenance of pumps. Proper operation, diagnosis, and routine maintenance will reduce the likelihood of unplanned equipment outage. After studying this chapter, operators will better understand how to care for and operate pumps.

Objective 1

Discuss the components of a driver and pump assembly.

Driver And Pump Assembly

Most pumps are motor-driven. The motor may be a steam turbine, internal combustion engine, or an electric motor. This chapter focuses primarily on pumps driven by electric motors, since they are the most common.

Figure 1 shows three electric motor-driven, multi-stage, centrifugal boiler feedwater pumps, awaiting installation. Each has an electric motor, with its shaft connected to a pump shaft, by way of a **coupling**. The electric energy input to the motor is converted to mechanical energy, and transmitted from the electric motor to the pump through the coupling. The pump transfers the mechanical input energy into work done, to pressurize and move fluid.

Pump internals often turn at high speed. If the motor and pump are new, carefully installed, properly aligned, and operating within their normal parameters, the pump should operate smoothly, efficiently, and have a long life. The pump will lose efficiency and may fail prematurely if parts are out of alignment, poorly installed, damaged, or worn.

Figure 1 illustrates the location of some of the common pump components listed below. Some parts are specific to dynamic pumps. Applied to positive displacement pumps, these parts appear different, but serve similar purposes. The components listed below require special attention while installing, maintaining, and operating the pumps.

Electric motor: Converts electrical energy to mechanical energy, to move fluid. The motor must be powerful enough to drive the pump, and must rotate in the proper direction.

Metal base: A strong, level, metal base supports the motor and the pump, and keeps them in proper alignment.

Coupling: A device that transmits power from one shaft to another. Couplings must be properly sized to transmit the necessary power from the motor to the pump.

Bearing cover: The cap or cover that protects the bearing from dust, debris, and water.

Bearing: The part that supports and guides the shaft, and reduces friction between the moving shaft and the pump casing. Bearings can be sleeve or anti-friction, depending on the pump design.

Shaft: Transmits the power from the driver to the pump. In a centrifugal pump, the impeller is mounted on one end of the shaft.

Bearing housing: The structure that holds the bearing and supports the shaft.

Slinger: A device that deflects leaking fluid away from the electric motor.

Seal cover or **stuffing box**: The part of the casing that holds the seal.

Seal: A device that stops fluid from leaking out of the pump along the shaft.

Shaft sleeve: A replaceable metal sleeve that fits over the shaft, and protects it from being damaged by the seal packing.

Figure 1 – Motor-Driven Centrifugal Pumps, Before Installation

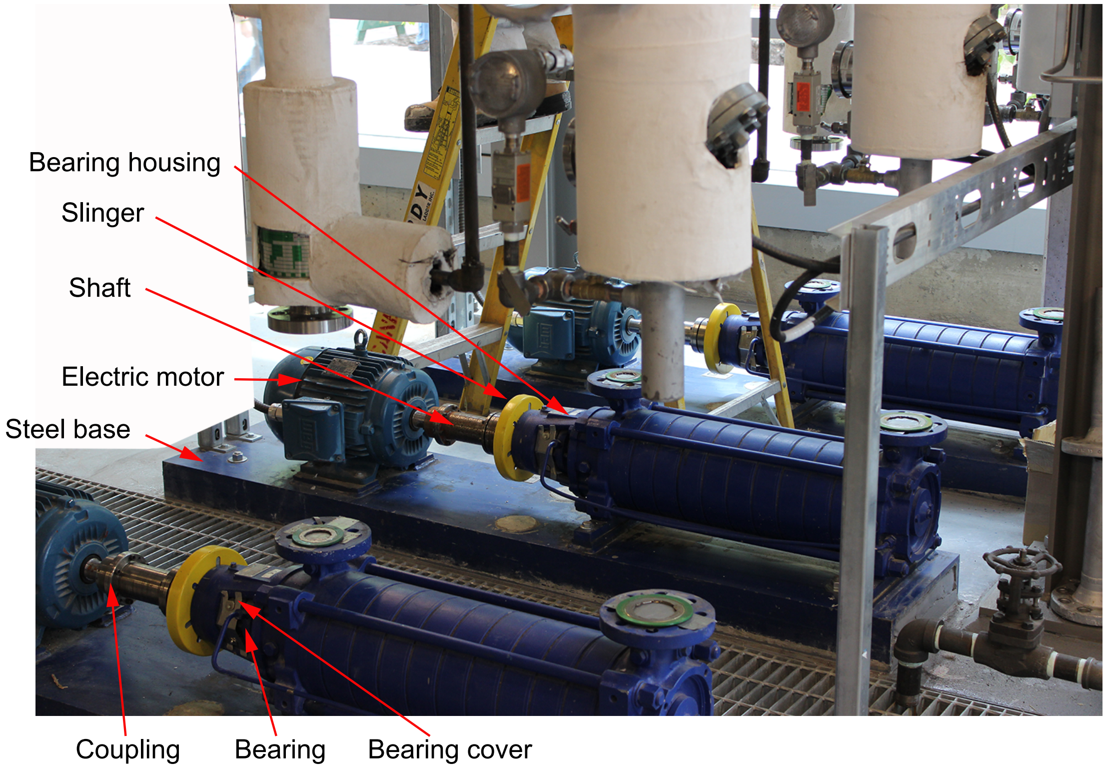
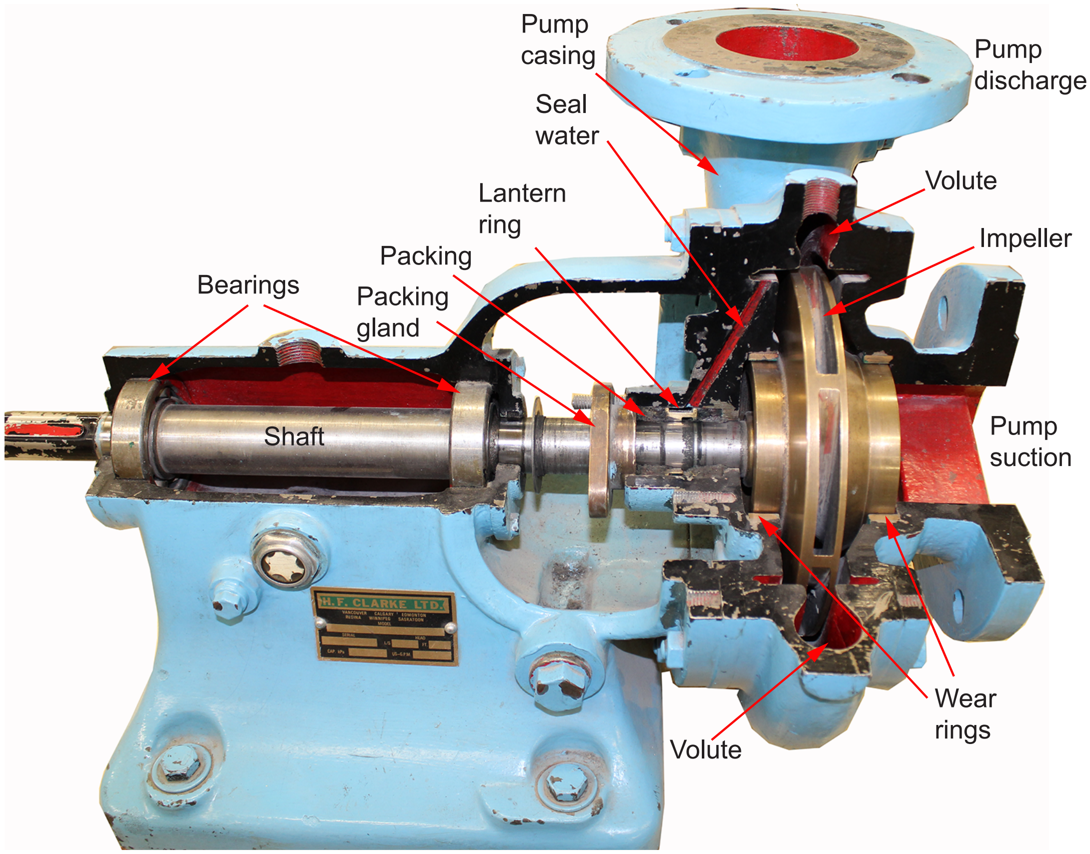


Figure 2 shows the details of the volute centrifugal pump. Two bearings support the shaft, and maintain it in both axial and radial alignment. These bearings sit in a housing that also holds a reservoir of lube oil. The impeller is supported by the shaft at one end. A coupling (not shown) would be installed at the opposite end of the shaft. This pump's shaft is sealed with **compression packing**. A **lantern ring** provides water to the packing to keep it cool and lubricated. **Wear rings** protect the impeller from excessive wear. The following discusses centrifugal pump parts in greater detail.

Figure 2 – Centrifugal Pump Components

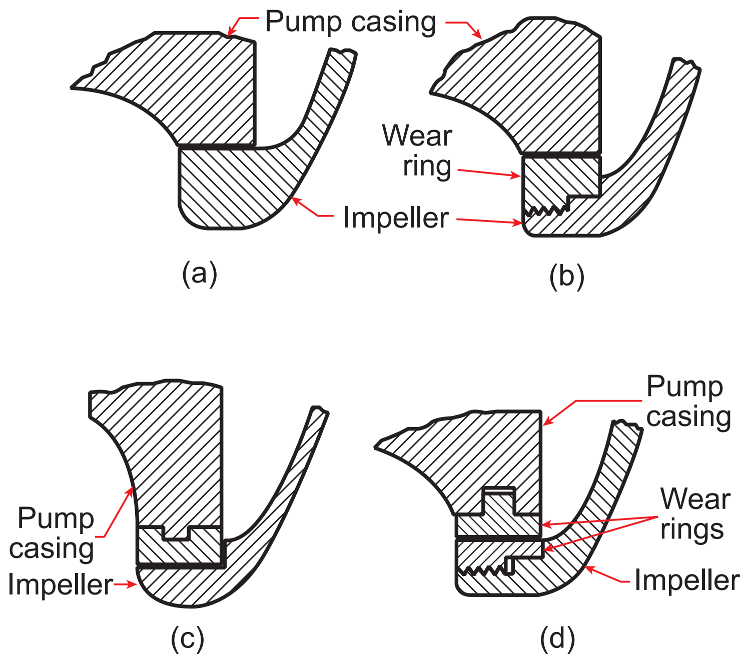


Wear Rings

Wear rings prevent leakage between the hub of the rotating impeller and the stationary parts of the pump. These rings are installed on the impeller, or the casing, or both. They reduce the clearance between the rotating impeller and the stationary casing to a very small amount. By reducing the clearance, water leakage from the discharge side of the pump to the suction side is minimized, which increases pumping efficiency. Wear rings also prevent wear of the impeller and the pump casing. When the wear rings show excessive wear, they are easily replaced. This is far more economical than replacing the impeller, or the entire pump due to wear.

Figure 3 shows wear rings installed on the pump casing. Figure 3(a) shows the interface of an impeller and the pump casing, and the small clearance between the two. This low-cost pump is not equipped with wear rings. Over time, the impeller and casing will wear, pumping efficiency will drop, and either the impeller, or the entire pump, will require replacement. Figure 3(b) shows a single, flat, replaceable wear ring threaded onto the eye of the impeller. This ring prevents damage to the impeller. The ring can be replaced without incurring the cost of a new impeller. Figure 3(c) shows a wear ring fitted onto a ridge on the casing. Again, the wear ring can be readily replaced to restore the original clearance. Figure 3(d) shows the arrangement with renewable wear rings on both the casing and the impeller.

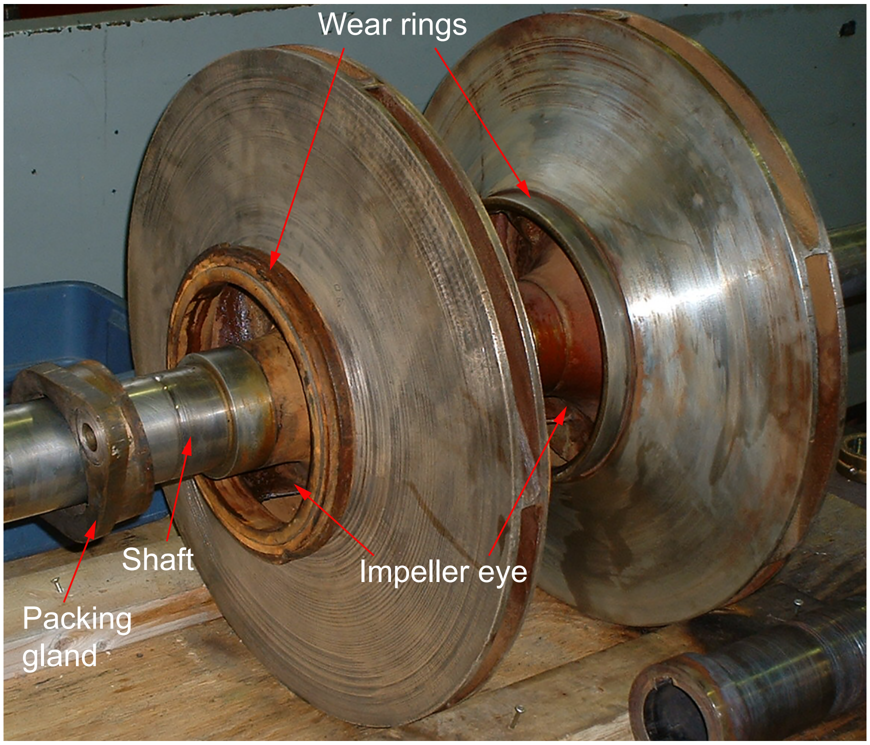
Figure 3 – Impeller and Casing Wear Rings



The preferred materials for wear rings are bronze and cast iron, because they tend to wear in a smooth manner. Newer nonmetallic materials are now being used for wear rings. They offer the advantage of less scoring, wear, and expansion due to heat. With non-metallic materials, a tighter fit can be obtained, which improves pump efficiency.

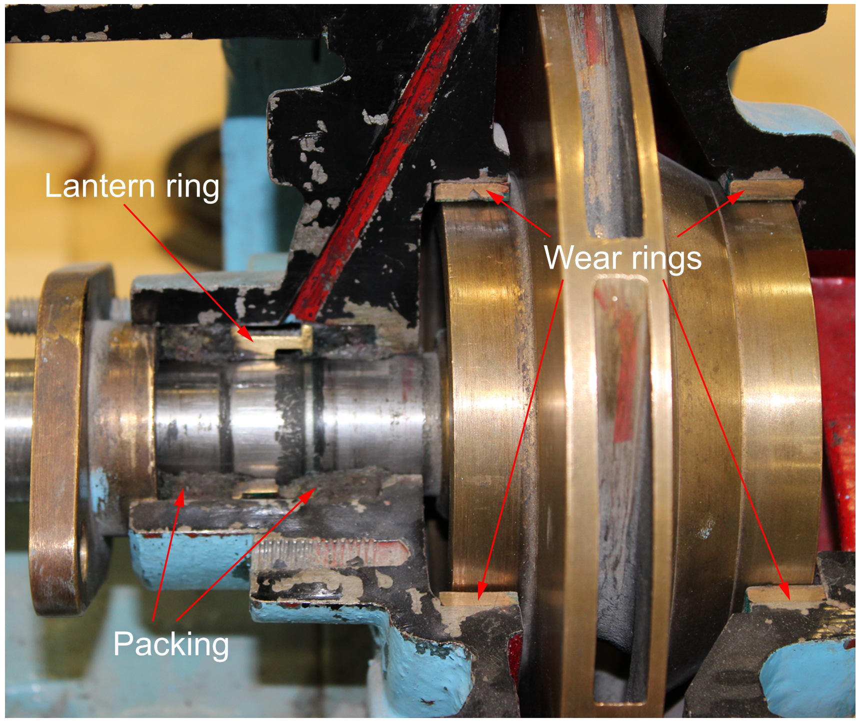
Figure 4 shows the location of the wear rings on a two-stage centrifugal pump. Wear rings are installed on the hub of the impeller, either by threading or shrinking.

Figure 4 – Impeller Wear Ring Locations



Casing wear rings (Figure 5) consist of either a continuous ring, or two half rings, which are pressed into place. Vertically split casings use the continuous ring design. Horizontally split casings are equipped with wear rings that consist of two halves. Split rings can be fitted onto a ridge or into a groove in the casing. This will prevent any axial movement should the rings work loose.

Figure 5 – Casing Wear Ring



Objective 2

Discuss pump shaft sealing, compression packing, and the replacement of compression packing.

Pump Shaft Sealing

In most pumps, a shaft must penetrate the pump casing to connect the impeller with the driver. The place of penetration must be sealed, so that process fluids cannot leak from the pump casing to the surroundings. Excessive leakage could result in loss of valuable process fluid, or environmental contamination.

Side Track

Where fluid retention is critical, there must be zero leakage. This requires more sophisticated shaft sealing methods. However, these are beyond the scope of **Fourth Class Power Engineering**.

Two common methods of pump shaft sealing include:

1. Compression packing
2. Mechanical seals

This objective covers compression packing.

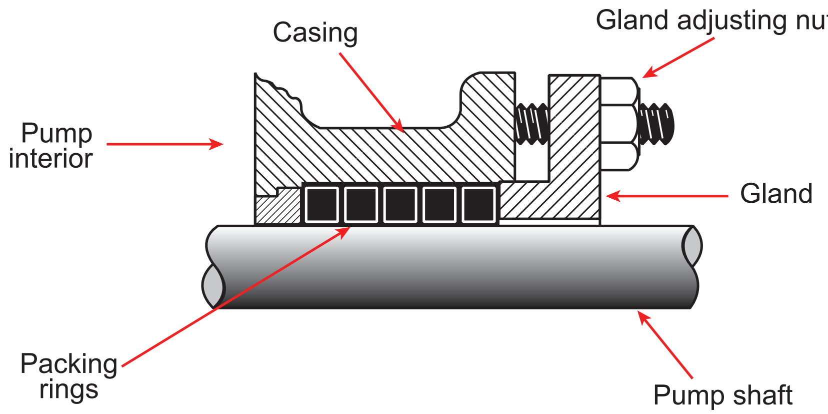
Compression Packing

Packing is a soft, durable material, manufactured with specific cross-sectional dimensions, so that it fits between a shaft and the walls of a stuffing box. Rings of packing are placed in the stuffing box where the shaft penetrates the casing. The packing presses against the pump shaft and the stuffing box walls, which reduces leakage.

Packing is made from a wide variety of materials, including nylon, flax, Teflon, lead, copper, and aluminum. Often a lubricating material (called the **saturant**), such as graphite or grease, is incorporated into the packing material.

Figure 6 shows the basic construction of a stuffing box that holds five rings of packing. The **gland**, also called a follower, holds the rings in place. The gland can be adjusted to compress the packing by tightening the adjusting nuts.

Figure 6 – Stuffing Box and Packing



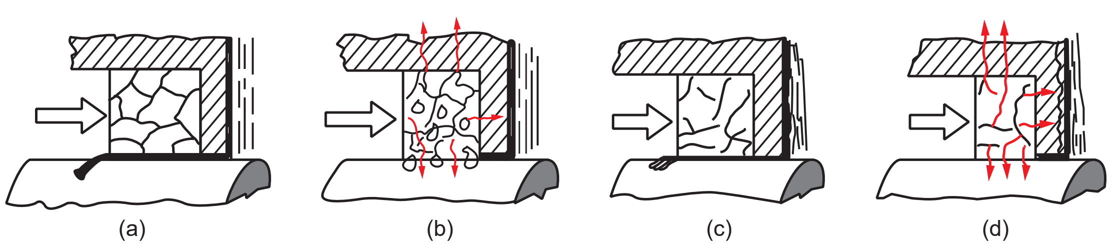
The sealing of the rotating pump shaft with packing is simple, as long as the shaft is perfectly round, has a smooth finish, and is running dead true. But shafts are usually eccentric by a few micrometers, due to clearance in the bearings. Shafts that are grooved make it difficult for packing to seal correctly. When packing is used, replaceable shaft sleeves are usually installed over the shaft. These sleeves are similar in function to wear rings. The sleeve takes the wear from contact with the packing, and can be replaced without incurring the cost of replacing the entire shaft.

Packing in the stuffing boxes of a centrifugal pump is not designed to stop leakage entirely; packing should only restrict the leakage. A slight amount is necessary to cool and lubricate the packing. If leakage stops, the lubricant in the packing compensates to a certain extent until the proper amount of leakage is restored. It is sometimes necessary to provide lubricant from an outside source.

Operators must have a good understanding of how compression packing works. If not fully understood it may result in wasted packing, scored shafts, excessive downtime, and expensive repairs.

Consider the following scenario. Figure 7(a) shows a ring of new packing before the gland has been tightened. When saturant is lost, the packing shrinks away from the shaft, since its volume is reduced. This shrinking increases the fluid leakage along the shaft. If the operator tightens the gland so that all fluid flow stops, fluid lubrication will be unavailable (Figure 7(b)). The shaft and the packing will then heat up, due to friction. This causes the lubricant in the packing to compensate. The high temperature, due to friction, melts the lubricant in the packing, which lubricates the shaft. When lubricant leaves the packing, it occupies less volume. Then, the liquid from the casing starts leaking again, which supplies the needed lubrication and cools the shaft (Figure 7(c)).

Figure 7 – Gland Packing

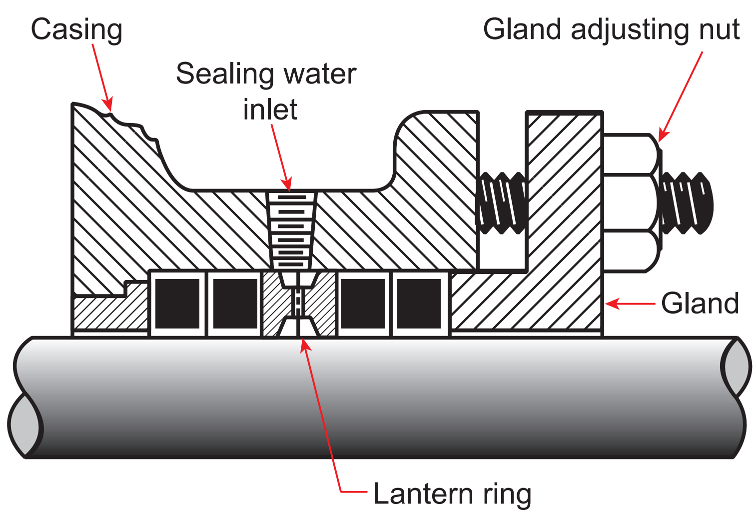


If leakage is observed again, operators may be inclined to further tighten the **packing gland**. In this situation, the cycle described in the previous paragraph repeats. However, packing only contains a limited amount of lubricant. Tightening the packing can only be repeated a limited number of times before all saturant leaves the packing, and its volume cannot be further reduced.

When the gland is tightened again to stop leakage, the excessive heat caused by the friction burns the packing, and scores the shaft (Figure 7(d)). An understanding of this simple principle will stop operators from over-tightening packing glands. This helps to avoid shaft damage, and prolongs packing life.

Often the pressure inside the pump at the stuffing box is below atmospheric pressure. Instead of water leaking out through the packing, air leaks into the casing. In this case, the stuffing box is provided with a sealing water (or pumped fluid) connection and a lantern ring, as shown in Figure 8.

Figure 8 – Stuffing Box with Lantern Ring



The lantern ring (also called the **seal cage**) is a metal ring with radial holes, inserted in a stuffing box, alongside rings of packing. The lantern ring distributes sealing water to the packing, to prevent air leakage, and to lubricate the packing. This water is usually supplied from a higher-pressure section of the pump. When pumping water that contains sand, grit or other abrasives, clean sealing water may be supplied from a separate source.

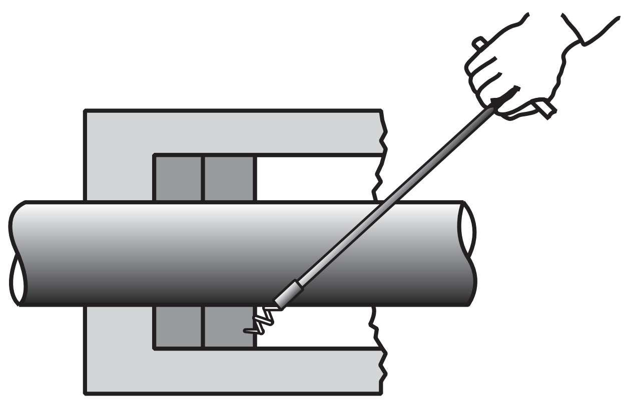
Replacing Pump Packing

Pump packing must be replaced periodically due to its deterioration from compression and loss of saturant. How often this needs to be done depends on the operating conditions of the pump, the quality of the packing used, and the care with which the packing was installed and adjusted. Frequency of replacement may vary between a few months, such as in the case of severe operating conditions, to several years under more moderate conditions.

The recommended steps for replacing packing are as follows:

1. Take out a safe work permit.
2. If necessary, place the standby pump in service.
3. Shut down, isolate, and drain the pump.
4. Lock out and tag out the pump. Follow site-specific lockout/tagout procedures. As a minimum:
   a) Make sure the pump motor disconnect switch is locked open, and the fuses are removed.
   b) Make sure inlet and outlet valves are closed tight and locked.
   c) Make sure the pump casing is depressurized, and the contents are appropriately drained.
5. Remove the gland adjusting nuts and slide the gland away from the stuffing box. Then remove all the old packing using a packing puller or hook (Figure 9). Count the number of rings before and after the lantern ring. This is important so the lantern ring is returned to the same place. This will ensure the seal water opening and the lantern ring line up.
6. Make sure the stuffing box is thoroughly clean and free from any small pieces of old packing. Check that the sealing water connection to stuffing box is clear.

Figure 9 – Removing Packing



7. Check the condition of the shaft and the shaft sleeve. If the surface is grooved or scored, then it should be replaced. Rough surfaces will damage packing.
8. To determine the correct size (thickness) of packing to use:
   a) Measure the bore of the stuffing box.
   b) Subtract the diameter of the pump shaft.
   c) Divide the difference by two.

Example 1

The stuffing box bore on a pump is 76.2 mm and the shaft diameter is 57.2 mm. What size of packing should be used?

Solution 1

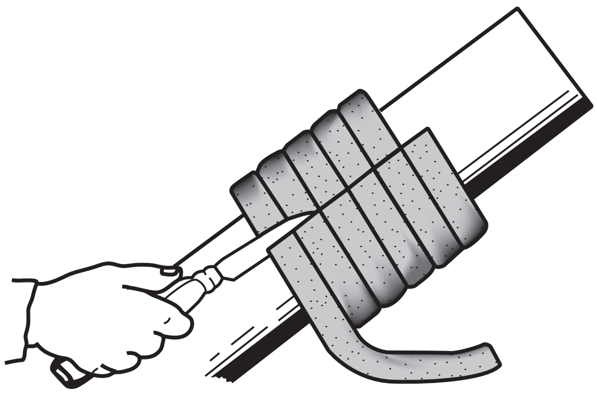
Difference between stuffing box bore and shaft diameter:

$$76.2\text{ mm} - 57.2\text{ mm} = 19\text{ mm}$$

$$\textbf{Packing size (thickness)} = \textbf{19 mm/2 = 9.5 mm (Ans.)}$$

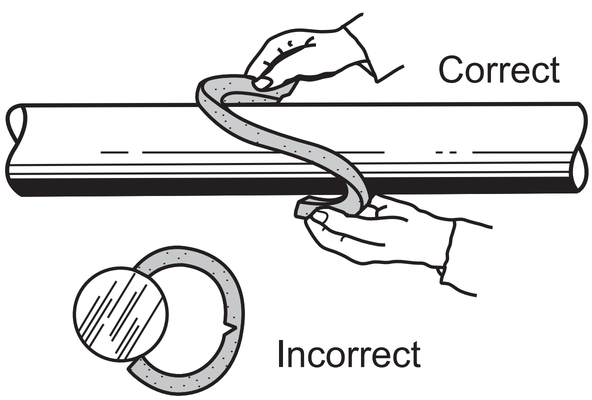
9. Select the correct type and size of packing for the application.
10. Securely clamp a rod, with the same diameter as the shaft, in a vice. Wrap a coil of packing around the rod, and cut through each turn as shown in Figure 10. If the packing is slightly too large, do not flatten it with a hammer. Place each turn on a clean surface, and roll it out with a clean piece of pipe.

Figure 10 – Cutting Packing Rings



11. Put a light coating of oil or grease on the inner diameter of each ring. Install the packing rings one at a time on the shaft. Slide each ring sideways over the shaft, as shown in Figure 11, to prevent the packing ring from breaking.

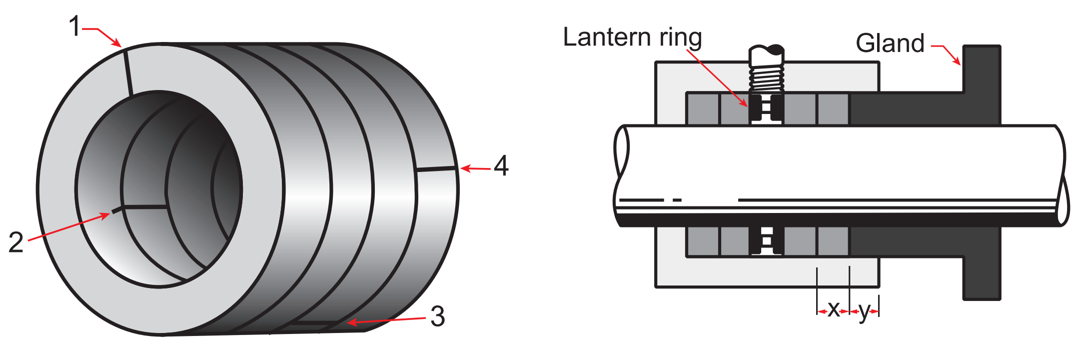
Figure 11 – Sliding Rings onto Shaft



12. Tamp the rings into the stuffing box one at a time. Use a split wooden bushing or metal ring to push the rings into place. Make sure the ring joints are staggered, and the lantern ring lines up properly with the sealing water inlet. See Figure 12.
13. Put the gland follower in place, and compress the packing slightly by tightening the gland nuts. Then loosen off to just finger tight to allow for expansion of the packing. In the case of small pumps, the shaft should turn freely by hand.
14. Remove the lockout.
15. When the pump is first put in service, allow the packing to leak freely. After about 20 minutes of running, tighten the follower gradually until only the necessary operating leakage is apparent.

The above method for installing packing is essentially the same for centrifugal, rotary, and reciprocating pumps.

Figure 12 – Staggered Packing Rings and Lantern Ring Position



Self-Test 1

A shaft has a diameter of 28.6 mm. The bore of the stuffing box is 50.8 mm. What size of packing should be used? Provide the answer in both SI and Imperial units.

11.1 mm, 7/16” (Ans.)

Objective 3

Describe the standard types of mechanical seals.

Mechanical Seals

Instead of utilizing a stuffing box with packing, many pumps use **mechanical seals** to prevent leakage along the shaft. Mechanical seals have the following advantages over packing:

- They require much less maintenance.
- They do not produce wear of shafts or shaft sleeves, as do packing rings.
- They reduce leakage to a minimum.
- They can be designed to work under very high temperatures and pressures.

However, mechanical seals have a greater initial cost. Also, when they fail, the pump must be taken out of service for a longer period to replace the seal than would be necessary with the simple stuffing box and packing method.

All types of mechanical seals feature two flat sealing faces perpendicular to the pump shaft. One is called the sealing ring, which is held in position by a spring. The other, in contact with the sealing ring, is called the mating ring.

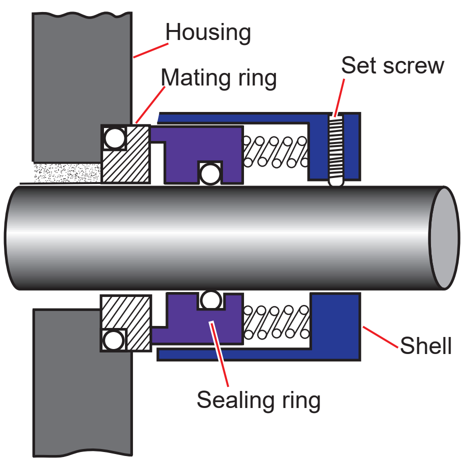
Mechanical seals may be divided into two general types:

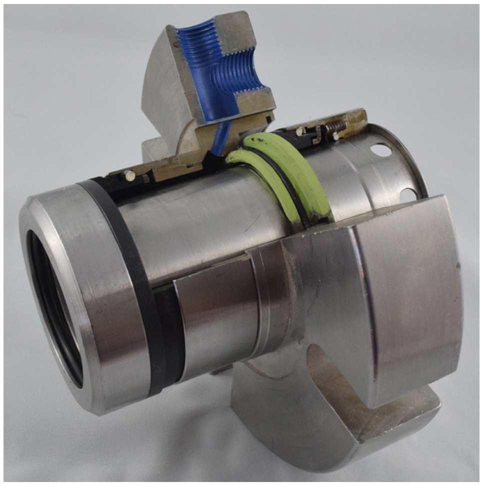
1. Rotating
2. Stationary

Rotating Mechanical Seal

In the rotating seal (see Figure 13), the sealing ring and spring are held in place by a shell. The shell is fastened to the pump shaft with a set screw. Therefore, the sealing ring turns with the shaft. The mating ring, however, is held stationary within the pump casing.

Figure 13 – Rotating Seal



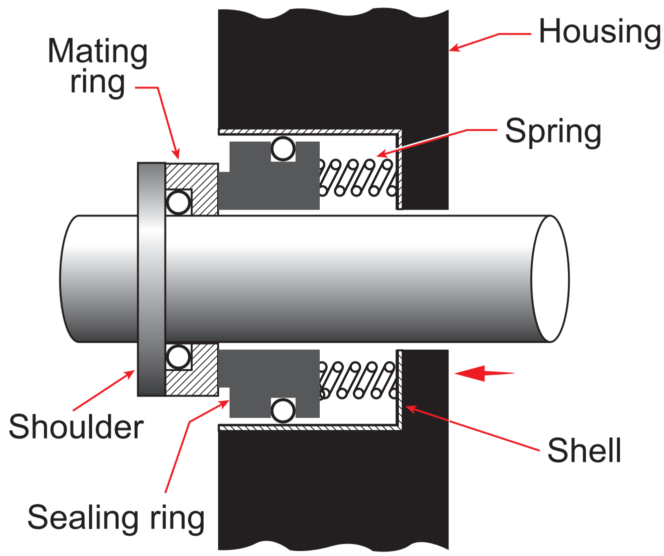


As the pump shaft turns, the rotating sealing ring is forced against the mating ring, and consequently prevents leakage between the faces. "O" ring type gaskets prevent leakage between the casing and the mating ring, and between the shaft and the sealing ring.

Stationary Mechanical Seal

In this type of seal (see Figure 14), the sealing ring assembly is held stationary within the pump housing. The mating ring is fastened rigidly to the shaft, usually against a shoulder or collar. The mating ring turns with the shaft. The stationary sealing ring presses against the rotating mating ring, which prevents leakage between the two faces. "O" ring gaskets are used to stop leakage between the shaft and mating ring, and between the sealing ring and housing.

Figure 14 – Stationary Seal



Sealing Ring Materials

The materials chosen for the sealing and mating rings vary depending on the:

- Type of liquid being pumped
- Fluid temperature
- Fluid pressure
- Pump speed
- Seal design

Materials commonly used for sealing and mating rings include bronze, carbon graphite, ceramics, Stellite™, and tungsten carbide.

Care of Mechanical Seals

It is extremely important that mechanical seals never run dry; otherwise, the sealing surfaces will become overheated, grooved, and scored. The following precautions should therefore be followed:

- Never run the pump in a dry condition, even for a few minutes.
- Vent all air from the seal housing before startup.
- Make sure an adequate flow of quenching or cooling liquid is flowing to the seal.

A squealing sound is an indication of a dry seal. However, this sound is not always present if the seal runs dry.

A leaking seal may be caused by the following:

- Scored or grooved seal faces.
- Distortion of the rings, caused by seal housing bolts that are too tight.
- “O” ring gaskets cut or nicked during installation.
- Distortion of pump parts caused by misalignment of piping.
- Misaligned shaft couplings.
- Excessive pump shaft vibration.

Objective 4

Describe pump bearings, shaft alignment procedures, and the equipment used to align shafts.

Pump Bearings

The only moving parts of a centrifugal pump are the impeller, and the shaft on which it is mounted. Bearings hold the shaft in place and support it. This allows the shaft to rotate with a minimum of friction. Often, pump bearings are designed to support the shaft in both radial and axial directions. The bearings used by pumps may be:

1. Shell (sleeve) bearings
2. Antifriction bearings

Side Track

Bearings are covered in **Part B, Unit 1, Chapter 2 Types of Bearings and Lubrication**.

Pump Alignment and Flexible Couplings

The majority of centrifugal pumps are driven by electric motors. Nearly all these motors drive the pumps directly, which means that pump and motor shafts are coupled together. The pump therefore operates at the same speed as the motor. Direct drive requires the pump and motor to have their shaft centres perfectly aligned. If perfect alignment could be achieved and maintained during operation, the shafts could be connected together by a rigid coupling. In reality, though, perfect alignment is very difficult to obtain, and nearly impossible to maintain.

Figure 15 illustrates two forms of shaft misalignment. Figure 15(a) shows angular misalignment. Looking down from the top, the motor and pump shaft are in line. However, looking from the side, the center lines are at an angle (the angle is exaggerated here for the sake of clarity).

Figure 15 – Angular Misalignment and Axial Misalignment

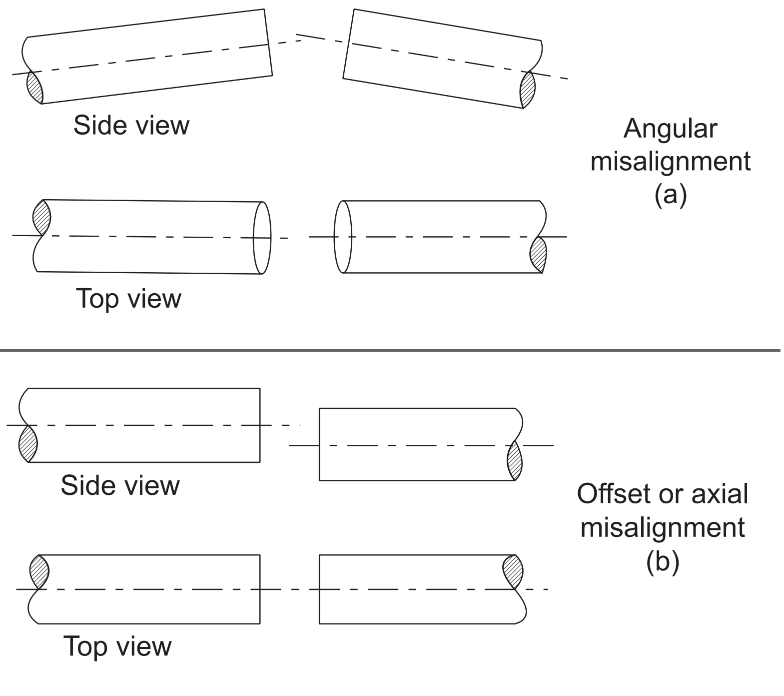


Figure 15(b) shows axial or offset misalignment. The shafts are parallel, but their axes are out of alignment. Angular and offset misalignments can also appear in combination with each other.

Misalignments of shafts connected by rigid couplings cause:

- Overheating
- Excessive bearing wear
- Increased power consumption
- Severe bending stresses in the shafts, which lead to shaft failure
- Vibration
- Noise

Various causes can contribute to misalignment. Poor installation or assembly is one of the main problems. Bearing wear, thermal expansion, and flexing of shafts can cause misalignment during operation, even though the original installation was correct.

To protect the machinery against any of the negative results of misalignment, flexible couplings are used to connect the pump and motor. This coupling should not be considered a remedy for misalignment due to poor installation. Proper alignment is still vitally important, but flexible couplings can compensate for the unavoidable misalignment that may develop during operation.

Some equipment is misaligned intentionally at installation due to temperature changes that happen when the equipment is running. For example, chilled water pumps get colder, while the drive motors get hotter, which causes increasing misalignment as normal operating conditions are approached. Millwrights calculate the change in alignment that occurs due to changes in temperature, and vertically misalign by this amount when the pump is out of service, and the motor and pump are at ambient temperature.

Most flexible couplings allow a limited amount of angular, as well as offset misalignment. They dampen vibration and allow a certain amount of end float of the shafts.

Figure 16 shows a few of the many types of flexible couplings.

Figure 16 – Flexible Coupling

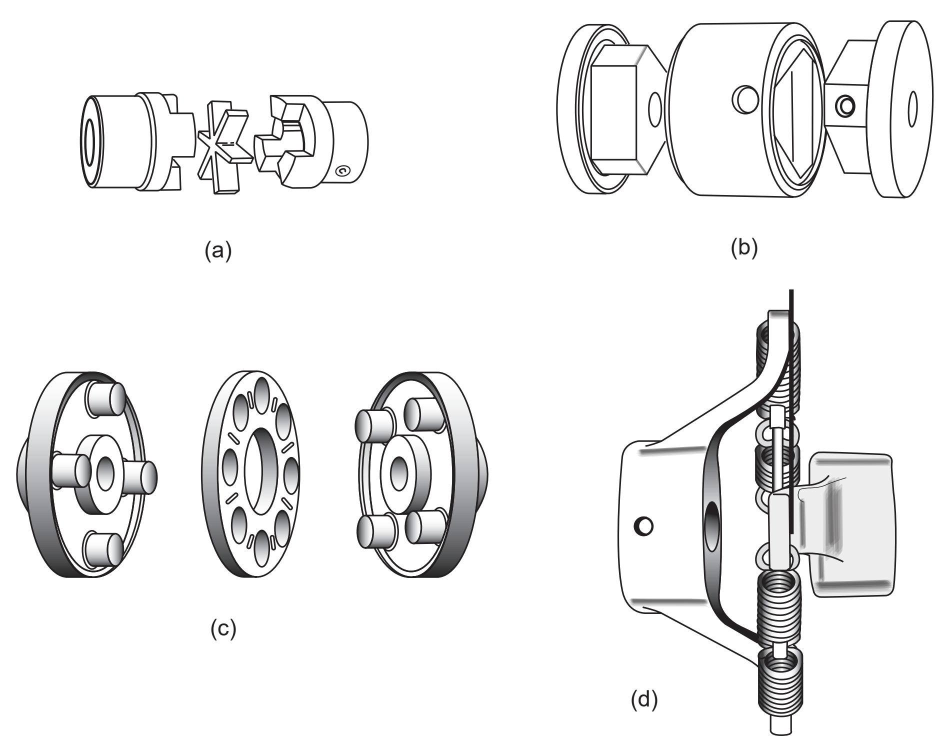


Figure 16(a) shows a jaw type coupling that has a non-metallic spider-like insert with six arms. This insert may be of synthetic rubber, laminated leather, or Bakelite.

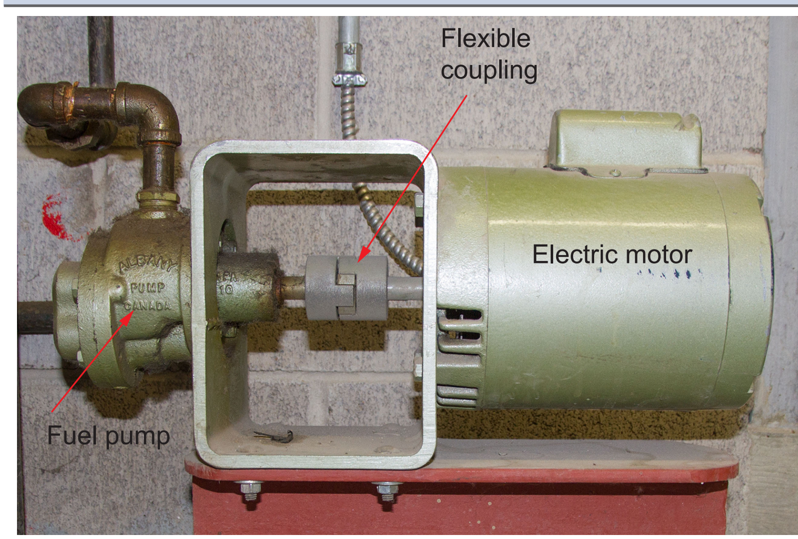
Figure 16(b) shows triangular coupling members fit into the ends of a rubber-lined metal sleeve.

Figure 16(c) shows coupling flanges fitted with pins. These pins fit into the holes of a rubber disk, which becomes the yielding member.

Figure 16(d) shows a coupling with fork-like flanges, connected by springs.

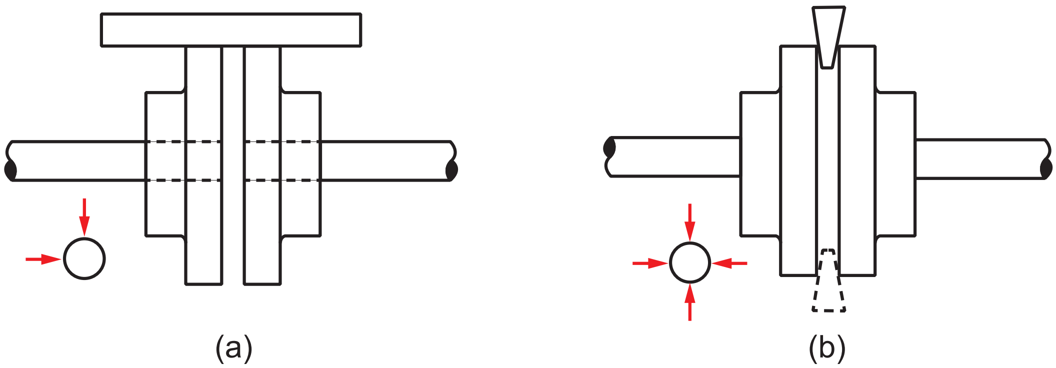
Figure 17 shows a flexible coupling connecting the shafts of an electric motor and a fuel oil pump. This is like the coupling shown in Figure 16(a).

Figure 17 – Oil Pump



For couplings with hubs or flanges of the same diameter, and with suitable machined faces, a straight edge can be used to check offset or axial alignment (Figure 18(a)). The measurement is taken along the top and side of the flanges. To check the angular alignment, a tapered feeler gauge is used (Figure 18(b)). When the faces of the flanges are exactly parallel, the measurement at each 90° of the circumference should be the same. Raise or lower the pump or motor, as necessary, during alignment by inserting shims under the feet of either unit. Make sure to check the alignment again after the adjustments are made.

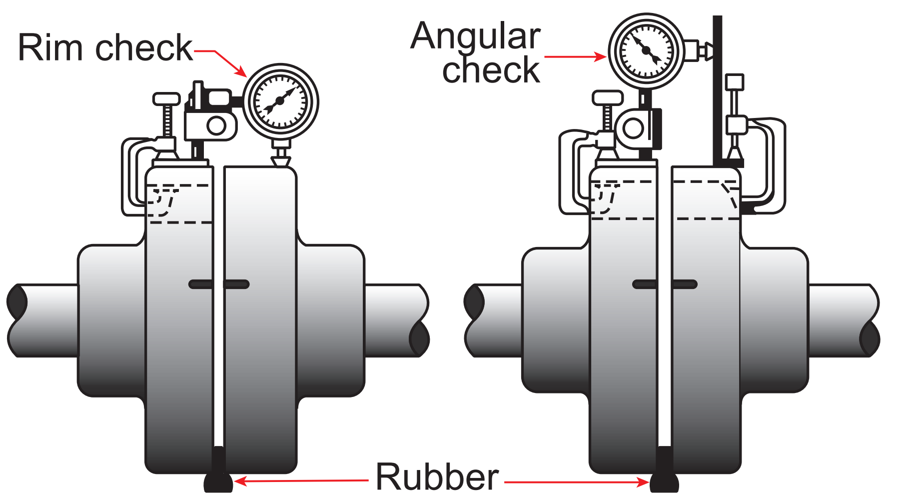
Figure 18 – Checking Alignment



The use of straight edge and tapered feeler gauges for alignment will give fairly accurate results; however, this method cannot be used for all types of couplings. Micrometer dial indicators can more accurately align shafts. This method is suitable for all types of couplings.

Figure 19 shows how a micrometer dial indicator is used to measure offset and angular misalignment. Mark the coupling halves. Place a piece of rubber between the halves to hold them apart. Reset the dial indicator to "0" at the top. Rotate the two halves together, and take readings at each 90° angle. If the alignment is out, the gauge will indicate the amount of misalignment. Make the adjustment accordingly.

Figure 19 – Dial Indicator



Laser alignment is now standard industry practice. This method of measurement is much more precise, and less open to interpretation, than other methods. A laser is mounted to one shaft, and a sensor to the other. These shaft-mounted components transmit precise laser measurements to a hand-held computer, using wireless or Bluetooth technology. The operator enters the following information into the computer:

- The distance between the laser and sensor.
- The distance from the laser to the coupling.
- The diameter of the coupling.
- The distance between the pump and motor feet.
- The distance between the front and rear feet of the motor.

The two shafts are clamped so that they turn together. Then, the shafts are slowly rotated by hand. The laser and sensor rotate with the shafts. The computer calculates the misalignment, and shows where to shim the motor. The computer stores the alignment data, the pump and motor nameplate information, and equipment numbers. Then, these download to a plant maintenance program. This makes the historical data available for reference when future maintenance activities are performed.

Objective 5

Describe centrifugal pump startup and priming procedures.

Centrifugal Pump Priming and Starting

Priming a pump means filling the pump casing and suction line with the liquid being pumped.

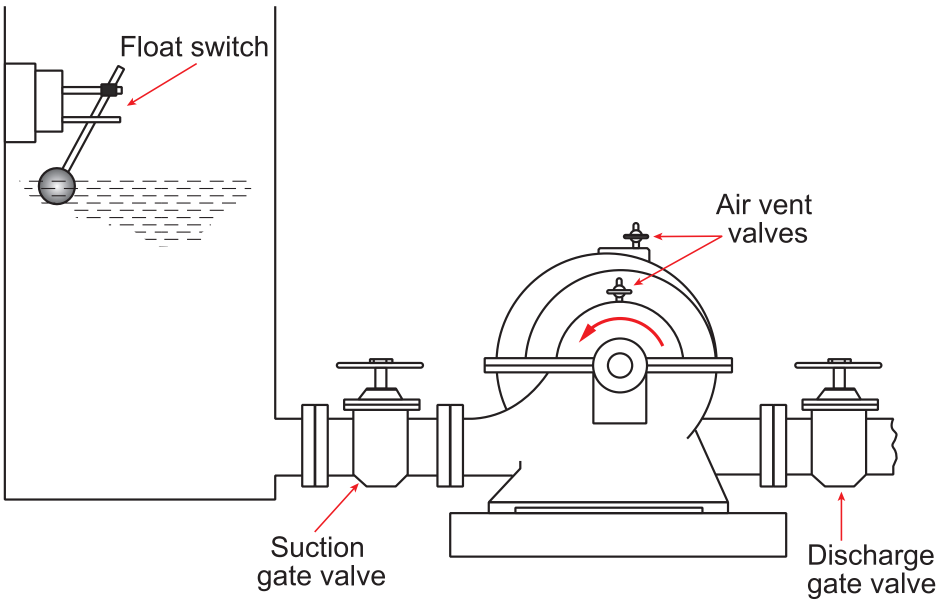
CAUTION

Before starting a centrifugal pump, it must first be primed. Otherwise, its impeller will simply churn air instead of producing suction. In addition, the wearing rings, mechanical seals, and packing will have no liquid for lubrication and cooling. Serious damage occurs to pumps that dry, even for relatively short periods of time.

Methods of Priming Centrifugal Pumps

In the case where the pump is below the source of supply, as in Figure 20, the pump is primed in the following manner.

Figure 20 – Flooded Suction Method



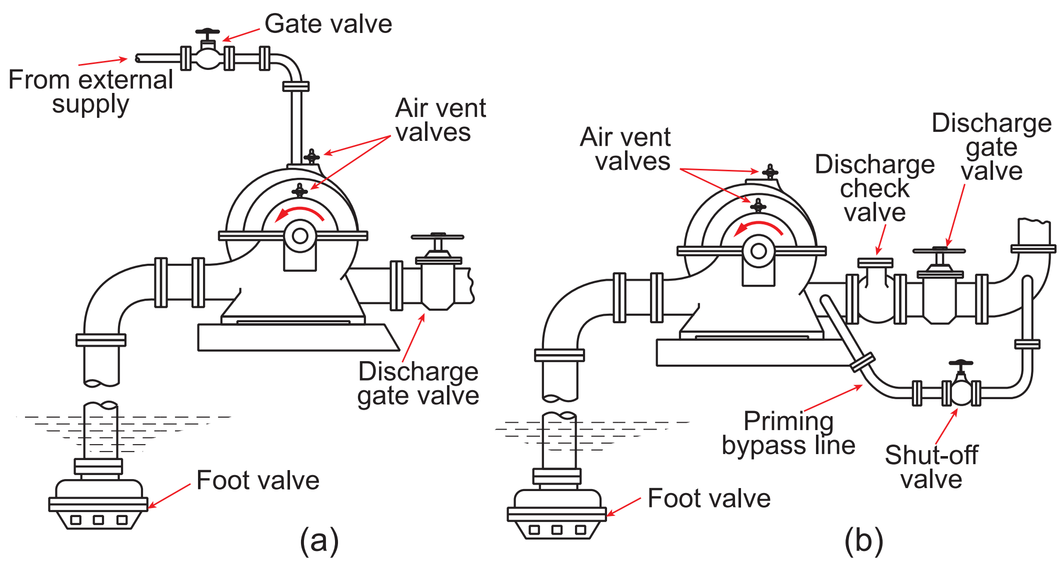
Close the discharge valve and open the suction valve. Then open the air vent valves to allow the air in the pump casing to escape. When water flows from the vents, they can be closed. The pump is now in a primed condition, ready for starting.

When the pump is located above the source of supply (pump has a suction lift), various methods of priming can be used. In each method, the pump suction line is equipped with a **foot valve**. This is a flap type check valve which allows water to enter the suction line, but prevents the water from flowing back out of the suction line.

In Figure 21(a), the priming water comes from an external source. To prime the pump, the discharge valve is closed. Then, the external supply valve is opened, as are the vent valves. The water flows into the pump, and then into the suction line, where the foot valve prevents the water from escaping. The water fills the suction line and then the pump casing. When water flows from the vent, the vent and external supply valves are closed. The pump is then ready for starting.

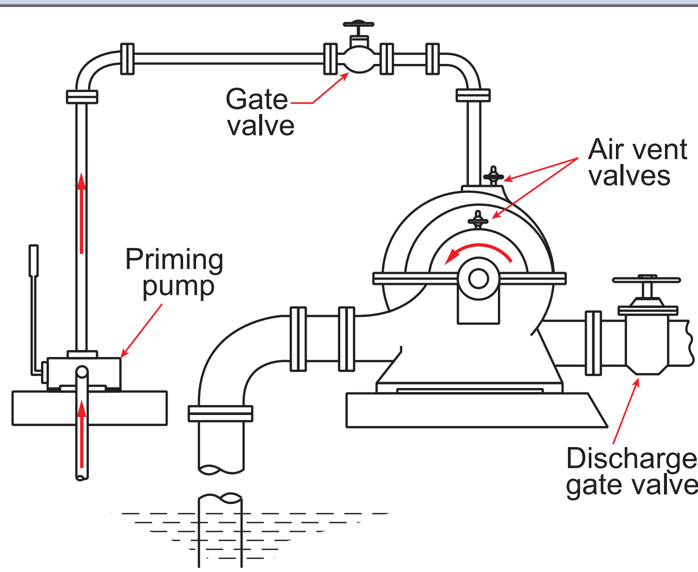
In Figure 21(b), the pump is primed by water supplied from the pump discharge line. The discharge valve is shut, and the priming valve and air vents are opened. Water from the discharge line fills the pump casing and the suction line. When water flows from the vents, the vent valves and priming valve are closed. The pump is ready for starting.

Figure 21 – Priming Methods



In Figure 22, a separate hand-operated positive displacement priming pump is used. The main pump discharge valve is shut, and the priming pump valve is opened. Then, the priming pump is operated. Water from the priming pump fills the pump casing and forces out air. When water issues from the main pump vent, the priming pump valve is shut. The main pump is ready for starting.

Figure 22 – Suction Lift Methods



Installation

Proper placement of the pump and driver on their foundation, plus alignment and installation of the connecting piping, are usually the responsibility of a contractor. However, operators should familiarize themselves with these procedures. In many new plants, troubles develop after a short period of operation, due to improper installation.

The best way to become familiar with the proper installation procedures for any particular type of equipment is by studying the instruction manual supplied by the manufacturer.

Preparing for Post-Installation Initial Start

Starting a centrifugal pump for the first time can be troublesome, unless a thorough check of the unit is made during and after installation. More trouble develops during initial starting of a pump than at almost any other time. Factors that should be considered before starting the pump are:

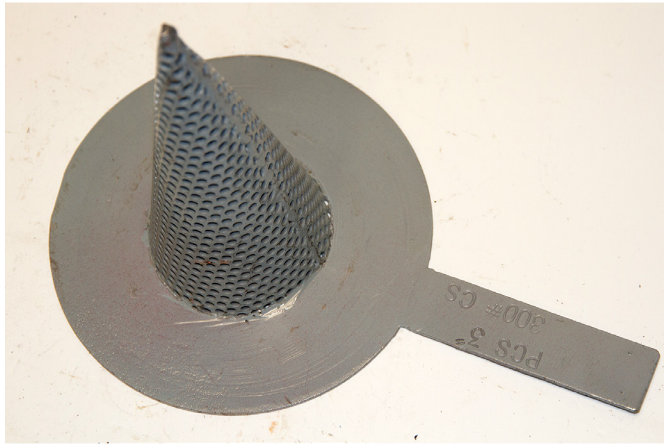
- Pipe cleanliness
- Pump alignment
- Pump rotation
- Bearings

Pipe Cleanliness

Many single-stage pumps have close-clearance running parts that must be protected from abrasive particles often found in new piping systems. To prevent the larger particles from reaching the pump, a conical or cylindrical mesh strainer (Figure 23) is installed in the suction line, as close as possible to the pump suction.

The conical strainer is installed between the pump and suction line flanges. The cylindrical strainer is in a y-type strainer. The mesh size of the strainer will depend on pump clearances, type of fluid being pumped, and purity of fluid.

Figure 23 – Conical and Cylindrical Mesh Strainer



Conical

Cylindrical

When starting the pump for the first time, watch the suction pressure gauge. A drop in suction pressure indicates the screen is plugging. Stop the pump, remove the screens, clean, and re-install them. It may be necessary to clean the screens several times during the first few days of operation. They can be removed permanently when there is no further clogging. Some applications require that screens be kept in service at all times, and that the pressures, before and after the strainer, be monitored regularly.

Pump Alignment

The pump and its driver should be aligned before the pump is put into operation for the first time. After the pump has run for a short time, and the motor and pump have assumed their normal operating temperatures, the alignment should be rechecked. The change in temperature may have changed the alignment. Make sure the connected piping is properly supported; the pump should never support the weight of the connected piping. Turn the pump over by hand. It should turn freely, without binding, scraping, or making any noise. Inspect pump footings to ensure that any devices for expansion of the casing are free, and in good working condition.

Rotation

Always check the driver and pump rotation. Touch the starter button just long enough to make the motor turn a few revolutions. The pump shaft should turn in the direction of the arrow on the casing.

Bearings

Before any pump is started, its bearings must be carefully inspected, cleaned, and lubricated. With oil lubricated sleeve bearings, remove the cap, linings, and drain plug. Flush the housing with solvent. Wash the bearing parts thoroughly, and reassemble them in the housing. Flush the bearing and housing with lubricating oil. Replace the drain plug, caps, and other parts. Fill the bearing as directed by the manufacturer.

Grease-lubricated ball, roller, and needle bearings are usually packed with grease at the factory. Therefore, no lubrication may be necessary before starting the pump. However, it is advisable to check the condition of the grease by removing the bearing housing cover.

Starting The Pump

The normal start procedure applies to centrifugal pumps being duty-swapped, or placed into service for some other routine reason. To start the pump, follow the sequence below:

1. Prepare the system that provides cooling water for pump bearings, stuffing boxes, and mechanical seals.
2. Check the oil level in the bearing housing.
3. Line up the pump valves according to the priming procedure required.
4. Close all drains in the casing, suction, and discharge piping.
5. Make sure the pump is properly primed.
6. Start the pump and bring it up to speed.
7. If the pump is started with a closed discharge valve, open this valve slowly.
8. Check leakage from the stuffing boxes.
9. Adjust the flow of the sealing liquid to the packing or mechanical seals.
10. Check that the oil rings on sleeve bearings are turning freely.
11. Check the suction and discharge pressures.
12. Monitor the pump bearings for overheating and vibration.

Objective 6

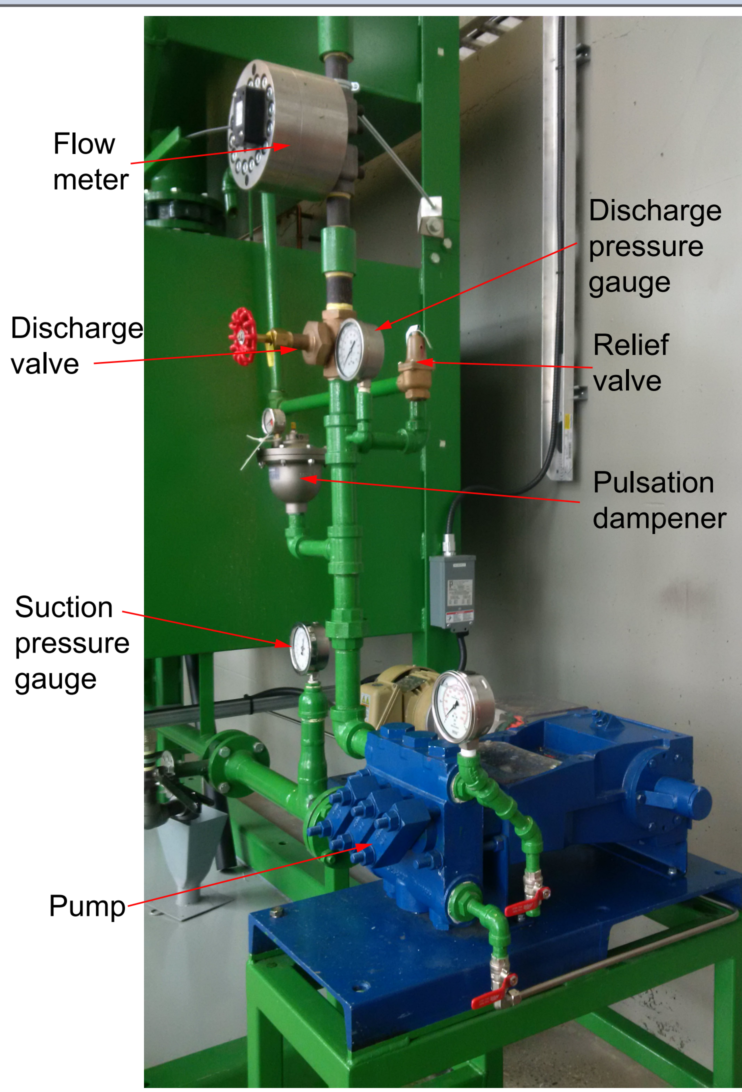
Describe positive displacement pump operating characteristics, priming, startup, and routine checks.

Operating Characteristics of Positive Displacement Pumps

Positive displacement pumps operate by creating a void at the suction inlet, filling the void with incompressible fluid, and then moving the fluid from the pump inlet to the discharge. If driven at a constant speed, these pumps supply a constant volume of fluid regardless of the discharge head. Because of this, these pumps can develop extremely high pressures. If the discharge valve is inadvertently closed, the high pressure could damage the pump or piping system. Therefore, positive displacement pumps must be equipped with a pressure relief device in the discharge line, located before the discharge valve.

Note the relief valve in the discharge line of the pump shown in Figure 24. When this valve opens, it relieves fluid back to the storage tank.

Figure 24 – Reciprocating Pump Lab Set Up



Priming Positive Displacement Pumps

Centrifugal pumps have large clearance between the impeller and the volute casing. This allows them to churn fluid if operating deadheaded.

In contrast, positive displacement pumps have a minute clearance between the pressure-imposing element (the piston, plunger, or rotary element) and the pump housing. With such small clearances, the positive displacement pump can develop considerable discharge pressure, as well as considerable vacuum at its suction inlet. This is because fluid cannot easily pass between the pressure-imposing element and the pump housing.

Because positive displacement pumps can develop great vacuum, they can draw fluids to considerable height. They are therefore considered self-priming. Reciprocating pumps – having the smallest internal clearances – develop the greatest suction lift of all the positive displacement pumps. Rotary types of positive displacements pumps also develop great suction lift, but not as much as reciprocating pumps.

Though they are self-priming, it is advisable to manually prime them before starting. Rotary types do not develop great suction lift like reciprocating pumps do, and therefore benefit from priming when the suction lift is great.

Regardless of the style of pump, it is always preferable to run pumps when full of liquid. This tends to cool and lubricate the internal pump surfaces, and helps to reduce wear. Therefore, some types of positive displacement pumps are equipped with air vents for priming. Priming is done the same as priming centrifugal pumps.

Prestart Checks for Positive Displacement Pumps

The following are generic considerations when starting and running positive displacement pumps. Each installation will have unique startup and shutdown procedures. Operators should review and understand all site-specific procedures before starting, operating, or stopping pumps.

The following checks are performed prior to removing a lockout.

1. Check that all piping connections are secure and not leaking.
2. Ensure the piping is free of blanks or other obstructions, and valves are in the appropriate positions.
3. Ensure the supply tank is full.
4. Ensure the pump is firmly mounted to its base, and that the base is in good shape.
5. Examine the coupling. Ensure it is secure and does not have excessive play.
6. Ensure the coupling guard is in place.
7. Ensure the driver and pump have the required lubrication.
8. Ensure the gland lubrication supply is open.
9. Open the suction valve.
10. Prime the pump by opening the air vent.
11. Close the air vent when liquid flows out.
12. Open the discharge valve.
13. Remove the pump lockout.

Post-Start Checks (All Pumps)

After starting a pump, monitor the:

1. Suction and discharge pressures.
2. Pump temperature.
3. Pump vibration. This may indicate shaft misalignment, which should be corrected as soon as possible.
4. Connections and seals for leakage.

Routine Checks (All Pumps)

Routine checks should be performed during scheduled rounds, in order to identify problems in their early stages when they are easily dealt with. These checks may include:

1. Monitoring lubricator levels, and adding oil when required.
2. Monitoring suction and discharge pressures, to ensure they are in normal operating range.
3. Monitoring the flow rate through the pump.
4. Checking for leaks in mechanical seals or packing, and tightening the packing if required.
5. Checking the pump for vibration, noise, and temperatures. Changes in these may be early indications of bearing wear, coupling wear or misalignment, valve malfunction, or other mechanical problems.
6. Reporting and logging maintenance concerns discovered during rounds.

Shutdown (All Pumps)

To shut down a pump:

1. Turn the pump off.
2. Close the discharge valve.
3. Close the suction valve.

Chapter Summary

This chapter introduced the operation and maintenance of centrifugal and positive displacement pumps.

Pumps have features that permit them to be repaired and maintained. Wear rings, shaft sleeves, bearings, couplings, mechanical seals, and packing can all be renewed – at relatively low cost – to prolong the life of pumps.

To avoid unnecessary maintenance and repair, pumps must be properly installed and operated. Shaft alignment is crucial to maintain the integrity of bearings, drive belts, couplings, and seals. Quenching water is vital for the longevity of seals and packing. Operators must know how to recognize adverse conditions that can affect the integrity of these components.

Finally, to ensure pumps function properly, they must be started and operated correctly. They must be properly primed, they must not operate deadheaded, and they must not run dry for any great length of time.

CHAPTER 3

Introduction to Compressors

Learning Outcome

When you complete this chapter you should be able to:

Describe the operating principles of the different types of compressors.

Learning Objectives

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

1. *Describe the main classifications and types of compressors.*
2. *Describe gaseous compression systems.*

Chapter Introduction

Compressor operation is one of the daily responsibilities for Power Engineers, whether in a central heating plant, a power generating station, or a processing plant.

Among their many purposes, compressors pressurize:

- Air for plant services or instrumentation
- Refrigerants for cooling
- Natural gas for pipeline transmission
- Air for self-contained breathing apparatus

This chapter will explain compressor:

- Classification
- Construction
- Operating principles

Also covered are compressor parts, related equipment, and typical installations.

Much of what applies to pumps also applies to compressors. However, since compressors handle gases, there are some significant differences.

This chapter will help develop and understanding of compressors. It will also assert why it is important to be familiar with their operation.

Objective 1

Describe the main classifications and types of compressors.

Compressed gases are very useful. When entering a burning building, firefighters use self-contained breathing apparatus (SCBA). The SCBA contains compressed breathing air. Hospitals and ambulances use compressed oxygen. Chefs use compressed nitrous oxide to make whipped cream. Many people use compressed propane to fire up their barbecues.

In energy plants, compressed air operates pneumatic controls and tools. Other compressed gases are used for air conditioning, refrigeration, welding, continuous emissions monitoring and more. In the natural gas industry, hydrocarbons are compressed for transportation through a pipeline.

Unlike liquids, gases can be compressed. This means they can be forced into a smaller volume, which in turn increases the pressure. The gas laws explain the relationship between pressure, volume, and temperature of gases. Bernoulli's principle explains the relationship between pressure and velocity. Compressors represent the practical application of these physical laws. The construction and operation of compressors focuses on managing these four variables:

1. Volume
2. Pressure
3. Heat
4. Velocity

Compressor Classification

Like pumps, compressors are divided into two classifications:

1. Positive displacement
2. Dynamic compressors

A positive displacement compressor draws the gas into the cylinder, traps it, reduces its volume, and then discharges it. This type of compressor may be a reciprocating or rotary type.

Dynamic compressors accelerate the gas using impellers or blades. They convert the kinetic energy of the high velocity, low-pressure air into low velocity, high-pressure air. Examples of dynamic compressors are centrifugal and axial flow compressors.

On Track

When gases are discussed, it can be assumed that this includes air, since air is made up of gases - oxygen, nitrogen, argon, carbon dioxide, and others. The principles apply no matter what gas is being compressed.

Positive Displacement Compressors

Reciprocating Compressors

The reciprocating compressors that most people are familiar with are the air pumps used to pump air into bike tires or soccer balls.

A reciprocating compressor is one in which the air is compressed within a cylinder by a piston that moves back and forth, or up and down. The cylinder is equipped with suction and discharge valves to control the flow of air entering and leaving. This type of compressor is suitable for all ranges of pressures. It is used in a wide variety of applications, including:

- Power plant service
- Commercial and industrial buildings
- Natural gas transmission operations
- Mining installations

Single or Double-Acting Compressors

Reciprocating compressors can be single or double acting, depending on the cylinder design. In a single-acting type, compression and discharge take place at one end of the cylinder only. Therefore, there is one compression stroke for every crankshaft revolution, as illustrated in Figure 1.

Figure 1 – Positive Displacement Compressor

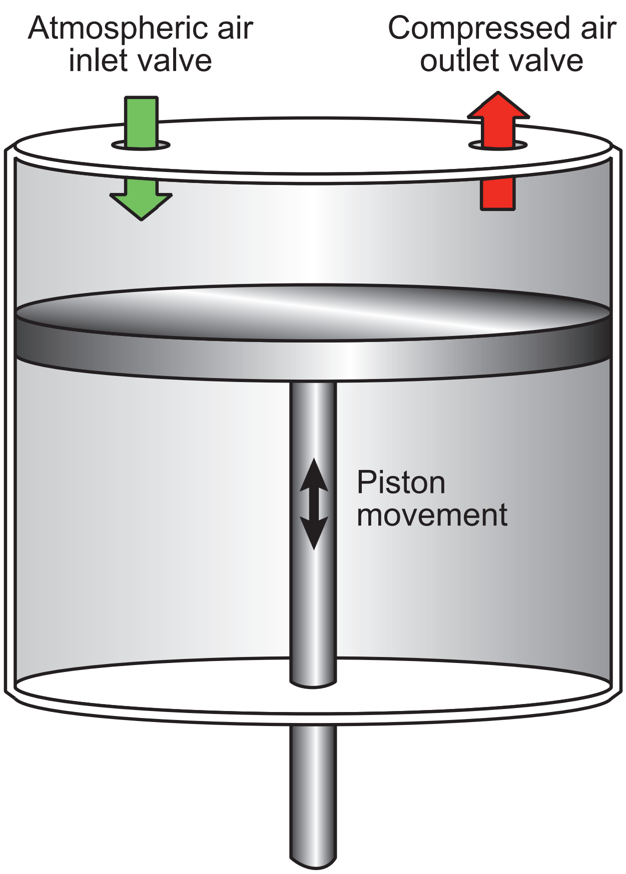
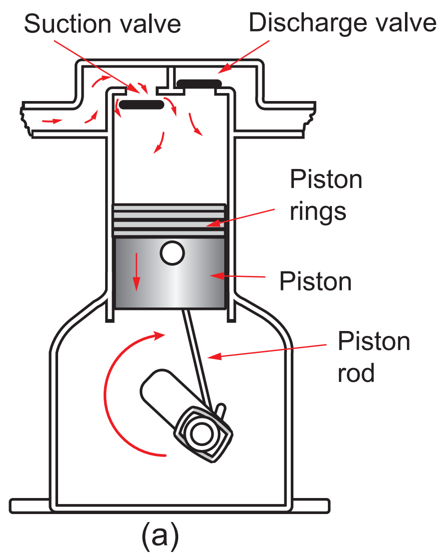


Figure 2 shows more detail of a single-acting compressor. In Figure 2(a), a vacuum is created above the piston, due to its downward travel. This vacuum will cause the suction valve to open, due to the atmospheric air pressure, and the discharge valve to remain closed.

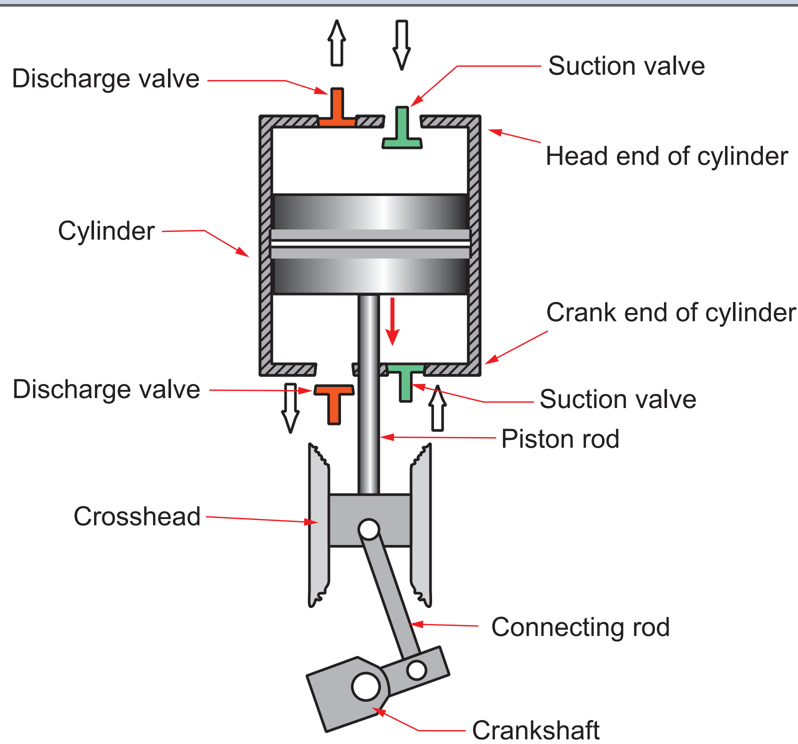
Figure 2(b) indicates that the cylinder is moving upwards. The pressure created above the cylinder forces the suction valve closed and forces the discharge valve open. The piston rings create a seal between the piston and the cylinder wall. This prevents the gas from leaking past the piston. The gas then flows into the discharge piping.

Figure 2 – Single Acting Compressor



In a double-acting type, as illustrated in Figure 3, compression and discharge take place at both ends of the cylinder. Therefore, there are two compression strokes per revolution of the crankshaft.

Figure 3 – Double-Acting Compressor Cylinder



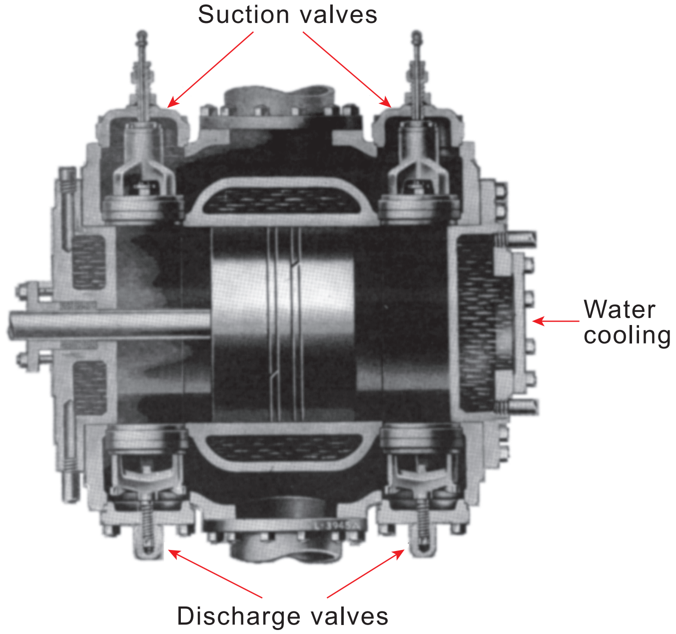
Refer to Figure 3. When the piston moves down, a partial vacuum forms above the piston (head end) of the cylinder. As a result, the air pressure outside the cylinder is greater than inside. The head end suction valve opens, and air is drawn in. At the same time, air in the crank end of the cylinder is being compressed.

When the air in the crank end reaches the required pressure, the discharge valve at that end is forced open. The compressed air leaves the cylinder, and enters the discharge line.

When the piston reverses and moves up, it compresses the air in the head end of the cylinder, and forces the air through the head end discharge valve. At the same time, air is drawn into the cylinder through the crank end suction valve.

Figure 4 is a cutaway of a double-acting reciprocating compressor.

Figure 4 – Double-Acting Piston



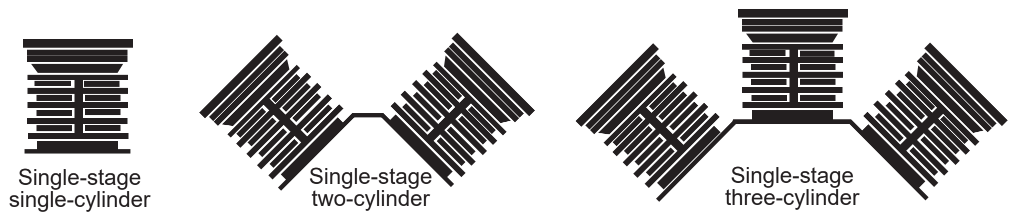
Single-Stage, Two-Stage, and Multiple Cylinders

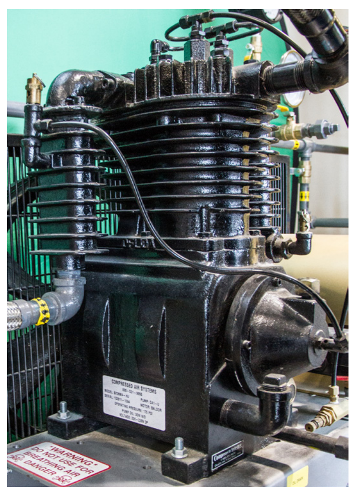
Compressors for general industrial use are usually single-stage or two-stage. The maximum operating pressure needed determines which type of compressor used. When the required air pressure is greater than a single-stage compressor can supply, a two-stage or multistage compressor is used.

Single-Stage, Multiple Cylinders

A single-stage compressor may have one or more cylinders, as shown in Figure 5. A single-stage compressor with more than one cylinder is used to produce a greater volume of compressed air than possible with only one cylinder. The pressure of the air leaving the discharge valve will be the same from each cylinder.

Figure 5 – Single-Stage Compressor Variations





Single-stage single-cylinder

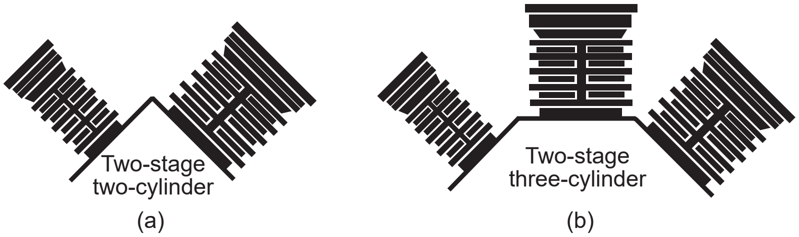
Two-Stage, Multiple Cylinders

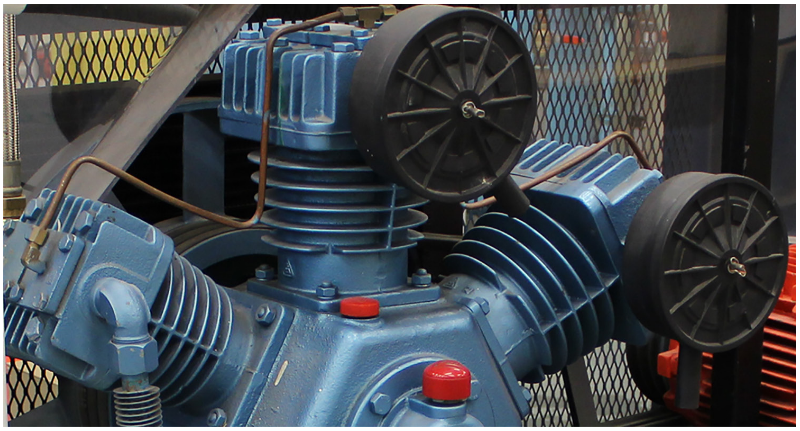
A two-stage compressor has two or more cylinders. The first stage is larger in diameter than the second. Figure 6 shows two variations of two-stage compressor design.

Figure 6(a) shows a two-stage, two-cylinder air compressor. A suction valve draws atmospheric air into the first stage to be compressed to its initial pressure. The air is then discharged into the inlet of the second stage, where it is compressed to its final pressure and discharged into a storage tank.

When a larger volume of compressed air at a moderate pressure is required, two low-pressure cylinders (both first stage) may discharge into a single high pressure or second stage. See Figures 6(b) and 6(c).

Figure 6 – Two-Stage Compressor Variations





Two-stage, three-cylinder
(c)

Another way to categorize compressors is according to the cylinder arrangement. They can be:

- Vertical
- Horizontal
- 45° inclined
- V-type
- W-type
- Radial

The single-acting type is usually arranged with vertical cylinders. The double-acting type is normally arranged with horizontal cylinders, although sometimes the vertical or V arrangement is used.

Figure 7 – Two-Stage Compressor

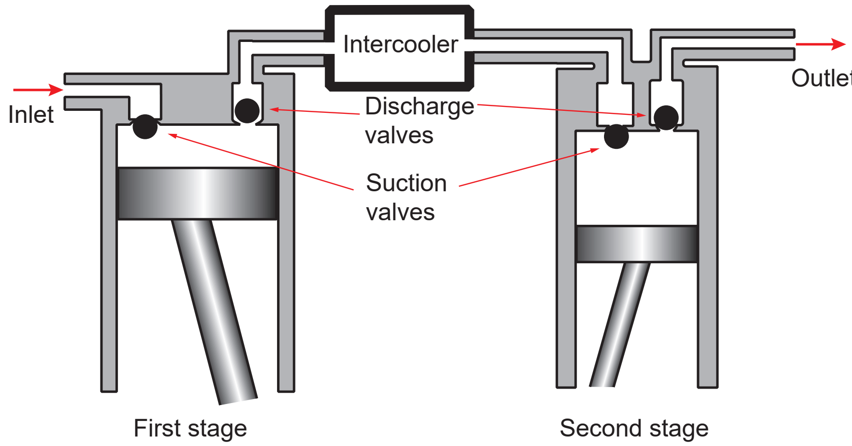


Figure 7 shows the location of an intercooler on a compressor. The air (or gas) is compressed in the first stage. It is then cooled before entering the second stage. The intercooler may be an air cooler or a water jacket type. Cooling the gas reduces the temperature and the volume.

Reciprocating Compressor Parts

The main parts of a compressor are the:

- Compressor block
- Suction and discharge valves
- Crankshaft
- Pistons and connecting rods
- Compressor bearings

Compressor Body

The compressor block may be constructed in either one-piece or two-pieces. A one-piece block has the crankcase and cylinders cast in one piece. The two-piece block has these parts cast separately. The parts are then bolted together, with a gasket in between. The cylinders are made with integral fins for air-cooling. If water is used for cooling, then the cylinder must have a water jacket.

Cylinders in larger machines may have replaceable cylinder liners.

Crankshaft

The main and connecting rod bearing surfaces of crankshafts are perfectly round, usually case hardened, and highly polished. When used with forced lubrication, the shafts have drilled oil passages.

Small capacity compressors are often equipped with an eccentric type of crankshaft, as shown in Figure 8. Larger compressors are equipped with the conventional type crankshaft, as illustrated in Figure 9.

Figure 8 – Eccentric Type Crankshaft

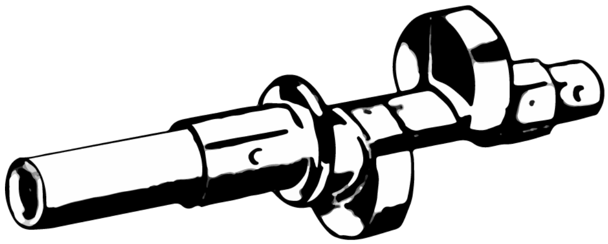


Figure 9 – Conventional Type Crankshaft

Pistons and Connecting Rods

Except for the smallest sizes, compressor pistons are fitted with piston rings. These rings provide a flexible seal to prevent the compressed vapour from escaping into the crankcase.

The lower ring is usually an oil ring. It distributes the lubricating oil evenly over the cylinder wall, and allows excess oil to return to the crankcase.

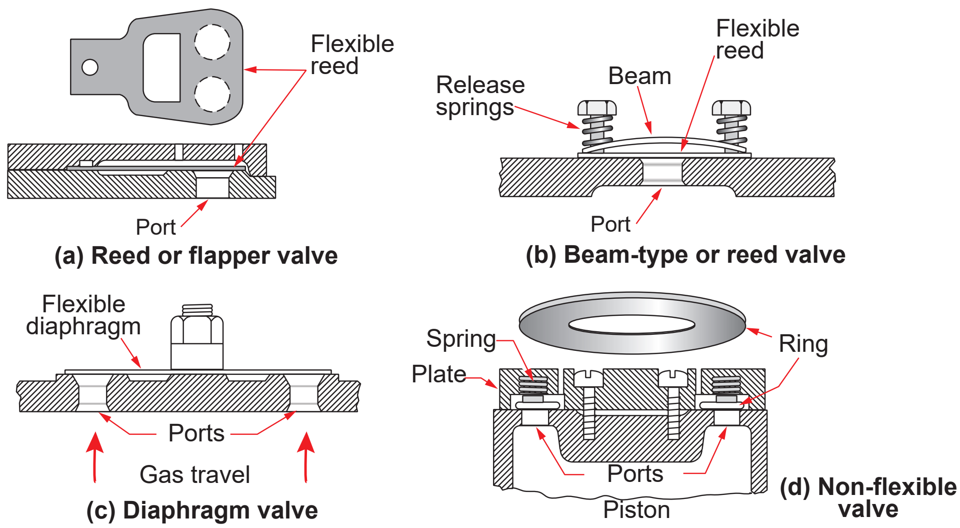
The connecting rods are connected to the pistons with wrist pins made of case-hardened steel. A wrist pin may be locked in place in the piston, so that the connecting rod moves on the pin. Or, the wrist pin may be locked in the connecting rod, so that the pin moves in the piston. The pin may also be free floating within both the piston and the connecting rod.

Suction and Discharge Valves

Two basic types of compressor valves (Figure 10) are commonly used:

1. Flexible reed and disc valves
2. Non-flexible ring valves

Figure 10 – Compressor Valves



Flexible reed and disc valves consist of a thin, flexible piece of spring steel, part of which covers the suction or discharge port in the valve plate located at the top of the cylinder. Some reed valves are anchored firmly to the valve plate, and held in position by a valve cage. The inherent spring tension of the valve tends to keep it closed. The valve will open when the force exerted below it becomes larger than the combined spring tension and the force above the valve.

Flexible reed valves are available in numerous shapes and sizes. Figure 10(a) shows a reed valve (also called a flapper) that covers two ports. A valve guard, bolted onto the valve plate, restricts movement of the valve.

The beam type reed valve, in Figure 10(b), consists of a rectangular reed that covers the port and an upward bent rigid beam. Two bolts pass through holes in the end of the beam and the reed, and hold the valve in position. Two springs hold the beam and the reed down on the valve plate.

During normal operation, the beam restricts the lift of the reed. However, if any liquid enters the compressor, the resulting high pressure at the end of the stroke forces the reed and the beam upwards. A large port opening is provided, so the compressed vapour and trapped liquid can escape. This prevents damage to the compressor.

The diaphragm valve, in Figure 10(c), is centrally attached to the valve plate. It covers a series of ports which form a circle. Gas pressure will cause the outer rim of the diaphragm to flex upward.

A cross-sectional view of a non-flexible ring valve is shown in Figure 10(d). The ring covers a number of ports placed in a circle. It is held in place by the valve cage. A number of light springs assure that the ring seats properly. The ring lifts off its seat when the cylinder pressure overcomes the combined force of the vapour pressure on top of the ring and the tension of the springs.

The tightness and proper seating of compressor valves is extremely important in a refrigerating system. Leaking valves allow some of the hot compressed vapour to flow back from the discharge line into the compressor, or from the compressor back into the suction line.

Leaking valves reduce the compressor output, and therefore, the capacity of the refrigeration system. Leaking also causes the compressor to operate at higher than normal temperatures. This could result in compressor damage if the failed valve is not repaired in time.

Leaking compressor valves should be repaired as soon as possible. Flexible reeds and discs should be replaced, and the seats resurfaced by grinding. Ring plates can often be resurfaced as well.

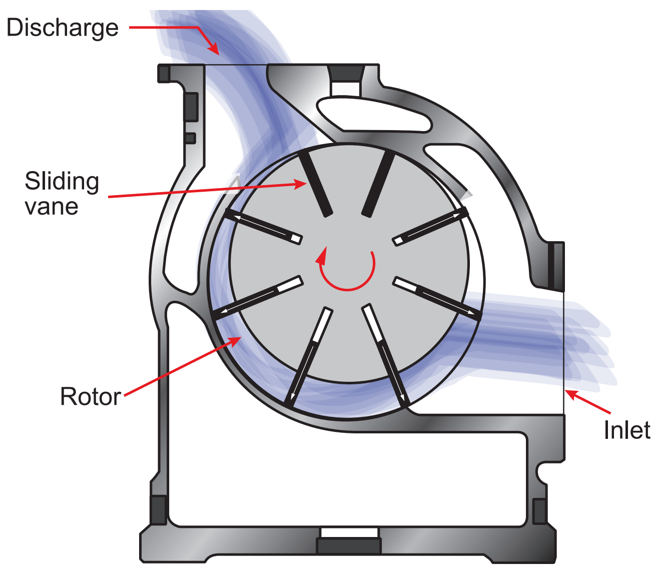
Rotary Compressors

A rotary compressor is a type of positive displacement compressor. The most common designs used for gas compression are the sliding vane, rotary lobe, and rotary screw.

Sliding Vane Compressors

A sliding vane compressor, as shown in Figure 11, consists of a cylindrical rotor with sliding vanes fitted into radial slots. The rotor is contained within a water jacketed cylinder or casing and is supported by bearings so that it is eccentric to the casing. As the rotor turns, the sliding vanes move out against the casing wall, due to centrifugal force. Pockets of air are trapped between the vanes and the wall. Due to the eccentricity, these pockets decrease in volume as the vanes move around the casing from the intake to the discharge, and compress the trapped air.

Figure 11 – Sliding Vane Compressor, Sectional View



In a two-stage sliding vane compressor, the air is first compressed in a low-pressure compressor. It then flows through a shell and tube intercooler to a high-pressure compressor. A flexible coupling connects the two compressor shafts. The drive for the unit may be applied at either the high or low-pressure side.

The operating speeds of these types of compressors range up to 3000 r/min, with the most common drive being a directly connected electric motor. Internal combustion engines are also used with speed-reducing or speed-increasing gears, where necessary. Discharge pressure can be as high as 1000 kPa.

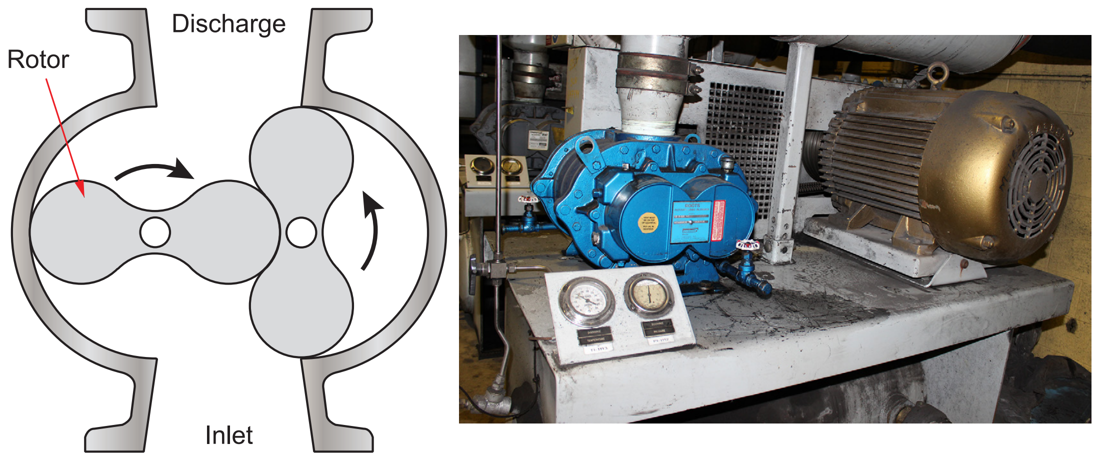
The sliding vane compressor is less efficient than the reciprocating compressor, but it is less costly, and produces a steadier flow of air. In addition, it has low starting torque requirements. On starting, compression does not begin until there is sufficient speed to cause the vanes to move out against the cylinder wall, due to centrifugal force.

Another important advantage of the sliding vane compressor is that it does not require inlet or discharge valves, since it has suction and discharge ports like a centrifugal design. This advantage is common to all rotating compressors.

Rotary Lobe Compressors

A rotary lobe compressor has two figure-eight shaped impellers that revolve in opposite directions within a casing. Figure 12(a) shows a cross section of the lobes. Figure 12(b) is a photo of a rotary lobe blower with a belt drive and an electric motor. One impeller is driven directly, and the other maintains relative position to the driven lobe by means of timing gears.

Figure 12 – Rotary Lobe Compressor



(a) (b)

As each lobe sweeps past the inlet, a pocket of air is trapped between the lobe and the casing wall. The air is then carried to the discharge on the opposite side of the casing.

The impellers do not come in contact with each other or with the casing. Therefore, a cylinder lubricant is not required.

The rotary lobe compressor runs at speeds up to about 1750 r/min. It may be driven directly by an induction motor or internal combustion engine.

Pressures produced by this type are quite low, approximately 100 kPa for single-stage, and 200 kPa for two-stage.

The lobe compressor has the advantage of being compact, and requiring no inlet or discharge valves. In addition, it produces an even flow of oil-free air.

Rotary Screw Compressors

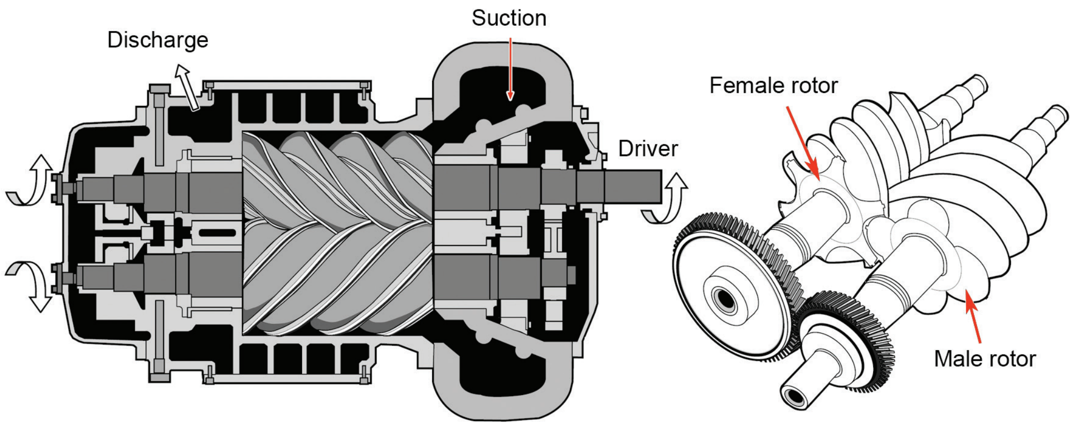
Rotary screw compressors feature two intermeshing rotors contained within a close fitting casing. The male rotor has less convex lobes than the female rotor has concave flutes. As the rotors turn and intermesh, the air is compressed and forced out of the discharge. The rotors do not come in contact with each other or with the casing; therefore, internal lubrication is not required. The male rotor is usually driven directly. The female rotor is driven by means of timing gears.

The rotary screw compressor is suitable for high speeds ranging from 3000 rpm to 12 000 rpm. Due to this high-speed requirement, a speed increasing gear is normally required between the compressor and the driver.

The single-stage type will develop discharge pressures to about 400 kPa. For higher pressures, multistage designs are used.

The advantages of the rotary screw compressor are similar to those of the rotary lobe type, including compactness, vibration free operation, smooth flow, and no suction or discharge valves. This compressor can come as oil lubricated or oil-free, depending on its application. Like other rotating types, its efficiency is less than that of a reciprocating type.

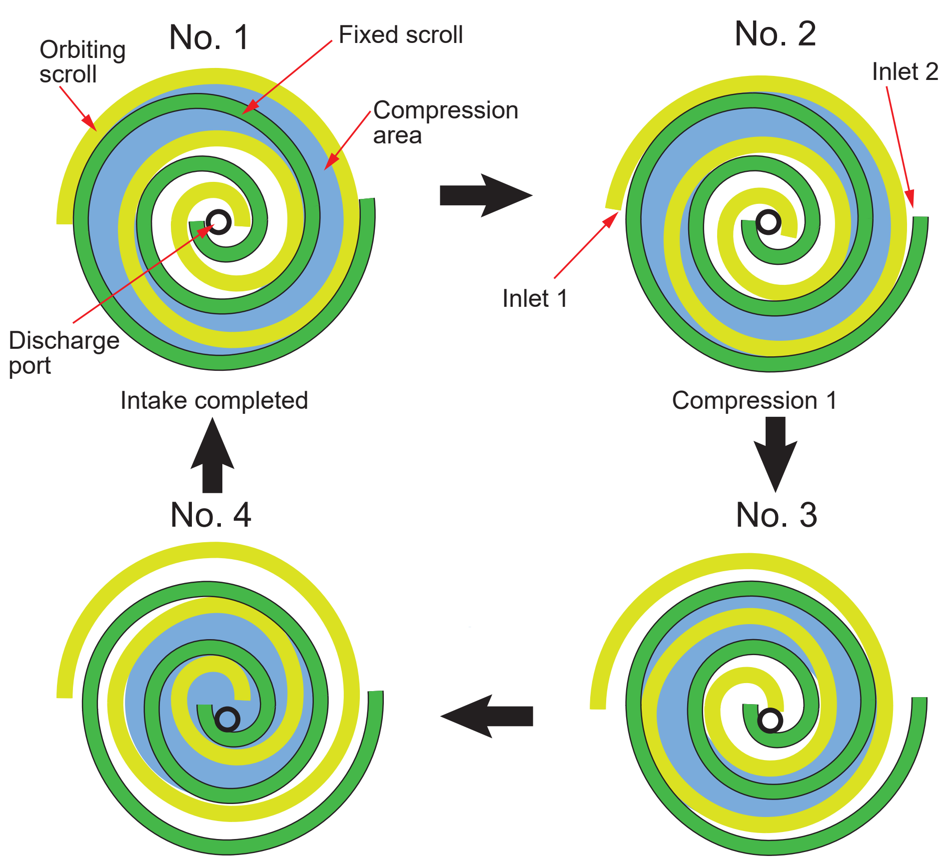
Figure 13 – Rotary Screw Compressor



Scroll Compressors

The scroll compressor is made up of two spiral disks that fit together; one is stationary and one rotates. As the scroll moves, the gas is trapped in the spaces and compressed. The scroll compressor is more tolerant of liquids in gases. This type is commonly used in commercial chillers and air conditioners. Its quiet operation is a big advantage over other compressors. Scroll compressors come in either horizontal or vertical arrangements.

Figure 14 – Scroll Compressor Operation



Dynamic Compressors

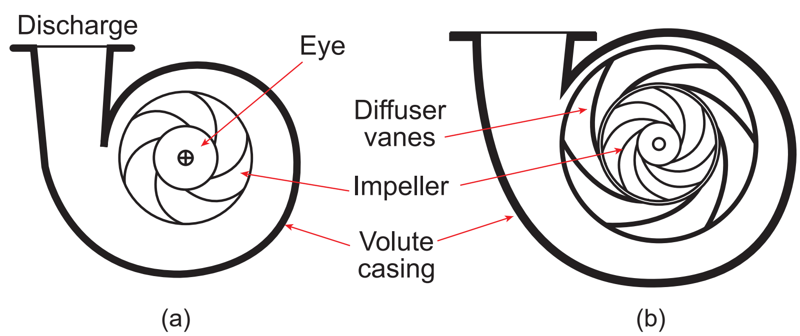
Dynamic compressors use spinning impellers to give the gas high velocity and low pressure. As the gas passes through the diffuser, it changes to high pressure and low velocity. In other words, dynamic compressors operate according to Bernoulli's principle. There are two general types or designs: centrifugal and axial flow.

Centrifugal Compressors

This compressor is similar in operation and construction to a centrifugal pump. It consists of an impeller rotating at high speed inside a volute shaped casing. In many cases, it also has a stationary ring of diffuser vanes, in addition to the casing. Air is drawn in at the centre, or eye, of the impeller, and is discharged at the impeller periphery with high velocity, due to centrifugal force. On leaving the impeller, the high velocity air passes through the diffuser vanes attached to the casing. Here, some of the kinetic energy is converted to potential energy.

The air then passes through the volute shaped casing, where a further conversion of velocity into pressure takes place. See Figure 15.

Figure 15 – Volute and Diffuser Arrangement

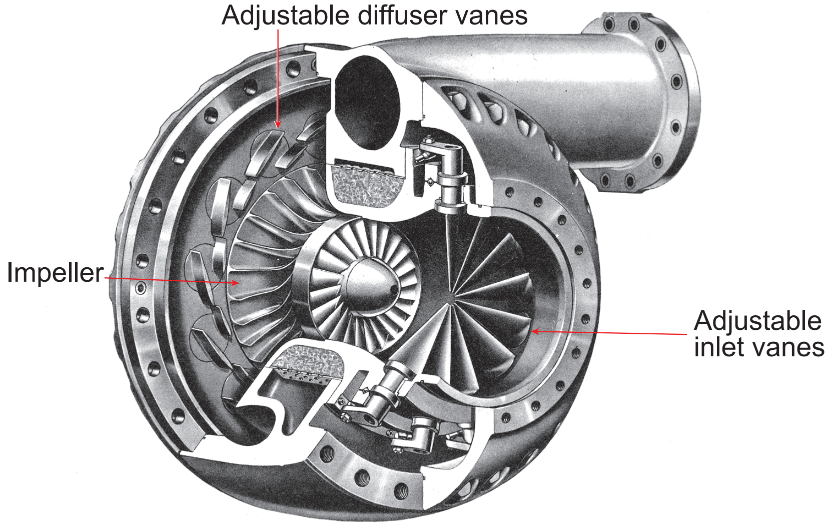


The advantage of a centrifugal compressor, over other types of compressors, is its simplicity of operation. There are no valves, pistons, or cylinders. Since the shaft and impeller are the only moving parts, only the bearings that support the shaft are subjected to wear. Therefore, maintenance is minimal.

Single-Stage Centrifugal Compressor

A single-stage centrifugal compressor has a single impeller, and may be able to compress atmospheric air to a pressure of about 300 kPa. Figure 16 shows a single-stage compressor having both diffuser vanes and a volute casing. The impeller is the cantilever type (mounted on the shaft end, with no bearing support), and only requires one shaft seal. The diffuser vanes are adjustable in order to change the operating characteristics of the compressor, when required. In addition, adjustable inlet vanes control the amount of air that flows to the impeller, and thus the capacity of the unit. The impeller itself is equipped with vanes at the eye. These are shaped to provide shockless entry to the impeller.

Figure 16 – Centrifugal Compressor with Diffuser Vanes

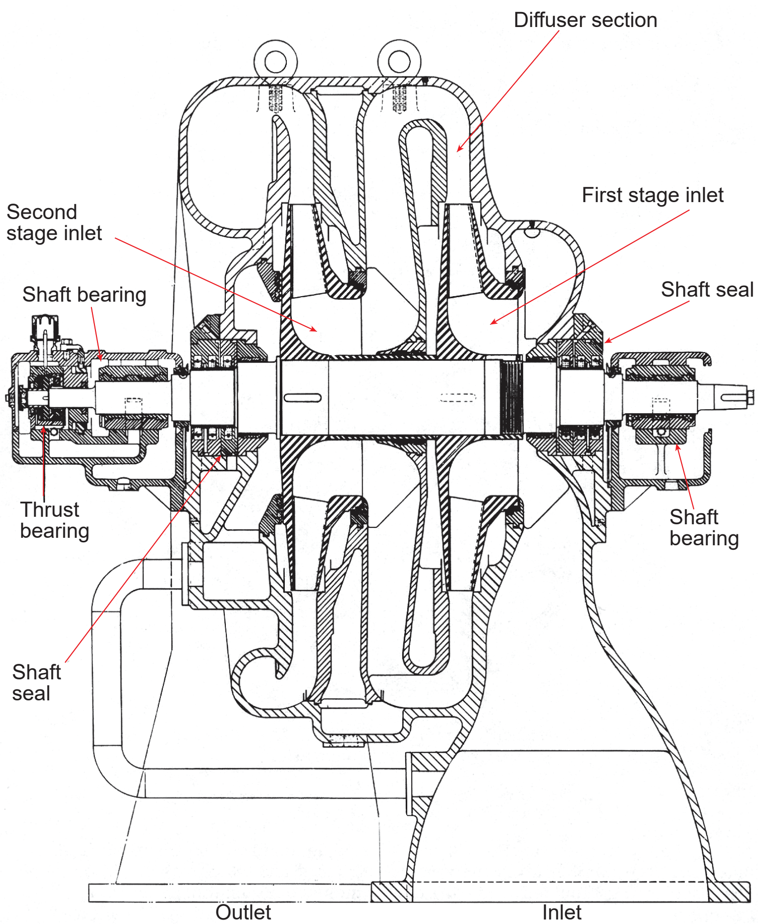


Two-Stage Centrifugal Compressor

If higher pressures are needed, a multistage compressor, having several impellers placed on a common shaft, is used.

Figure 17 shows a sectional view of a two-stage centrifugal compressor.

Figure 17 – Two-Stage Centrifugal Compressor with Diffuser Vanes



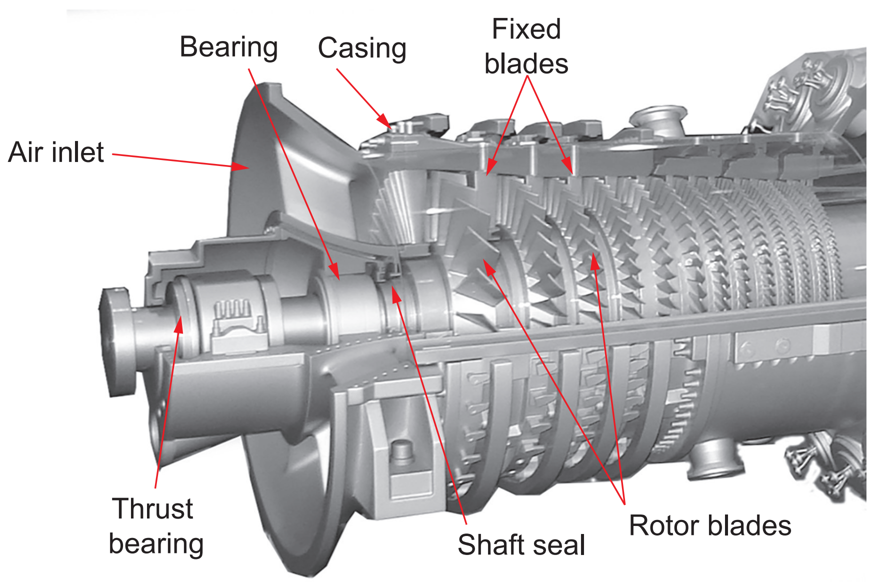
Centrifugal compressors are commonly used for large volume, low-pressure applications. They have simple and rugged construction, with low maintenance requirements. Since they do not require internal lubrication, they supply oil-free air. Their efficiency, however, is lower than the positive displacement type, and they are not suited for low capacity work.

Drivers commonly used with centrifugal compressors are electric motors and reciprocating type internal combustion engines. Centrifugal compressors require high speeds, so increasing gears are required when electric motors or reciprocating type internal combustion engines are used.

Axial Flow Compressors

In a basic design of an axial flow compressor, moving blades are attached to the rotor, and alternate with fixed blades attached to the casing (Figure 18). As the rotor turns, the velocity and pressure of the air increases in the moving blades. When the air passes through the fixed blades, its pressure is increased by converting high velocity air to low velocity air. The airflow is axial (parallel) to the compressor shaft.

Figure 18 – Axial Flow Compressor



Each pair of moving and fixed blades constitutes a stage. The pressure rise per stage is small, so to attain high pressure, a large number of stages are required.

Objective 2

Describe gaseous compression systems.

Compressors do not work alone. They are only part of extensive compression systems. This section will look at three of these systems:

1. Air Compression
2. Natural gas compression
3. Compression Refrigeration Systems

Compressor Systems

Air Compressor Systems

Compressor systems come in all sizes. They range from portable household compressors that can be stored under a work bench, to industrial compressors housed in large rooms, which supply compressed air to a plant that covers several hectares. Compressed air is essential for operating much of the equipment found in large industrial, commercial, and residential buildings.

Compressed air may be used to:

a) Operate pneumatic control systems, where air is used as a medium to transmit signals and drive power-actuated devices, such as pistons in cylinders and control valves.

b) Start emergency equipment driven by diesel and gas fired engines.

c) Atomize fuel oil in boiler combustion equipment.

d) Create a water spray in air humidification equipment.

e) Mix or agitate in water treatment processes.

f) Operate tools.

g) Spray paint.

h) Operate fire protection equipment.

i) Blast clean or sandblast.

Using compressed air to drive tools and other machinery has several advantages over the use of electricity or steam:

a) Compressed air machines cannot be damaged by overloading. When the load is too great, the compressed air machine simply slows down or stops.

b) Air driven hand tools are often lighter in weight.

c) Air driven hand tools do not become hot after extensive use.

d) Air driven hand tools do not create a shock hazard.

e) Compressed air machinery may be used safely in explosive atmospheres.

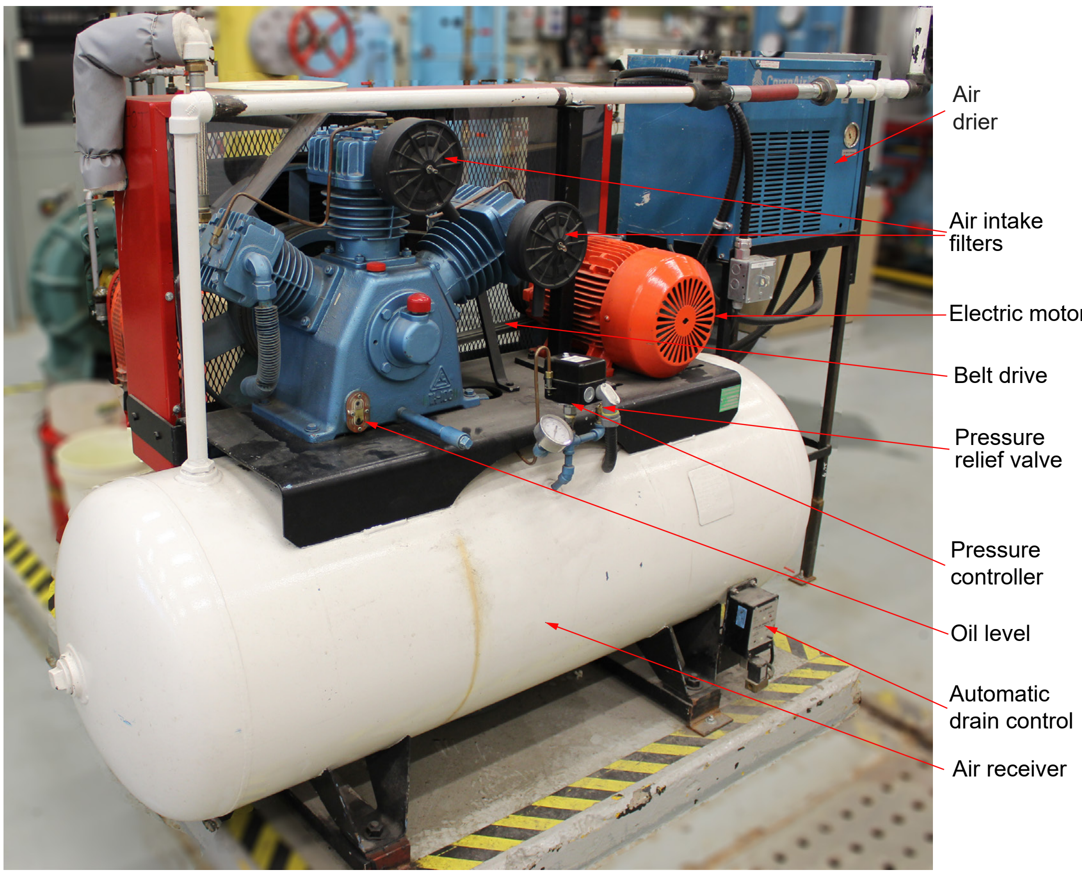
f) Transmission losses are less with compressed air than with steam, since the air will not condense.

g) Air piping and hoses remain cool to the touch; therefore, they do not require insulation.

Disadvantages of compressed air tools include:

a) They are usually more expensive than electrically driven tools.
b) Air transmission piping is more expensive and difficult to install than electrical wiring.

Figure 19 – Air-Cooled, Two-Stage Air Compressor



A compressor system will contain certain components (Figure 19):

- Air intake
- Air filter
- Driver
- Lubrication and cooling system
- Pressure relief valve
- Controller
- Receiver

Figure 20 – Compressed Air System

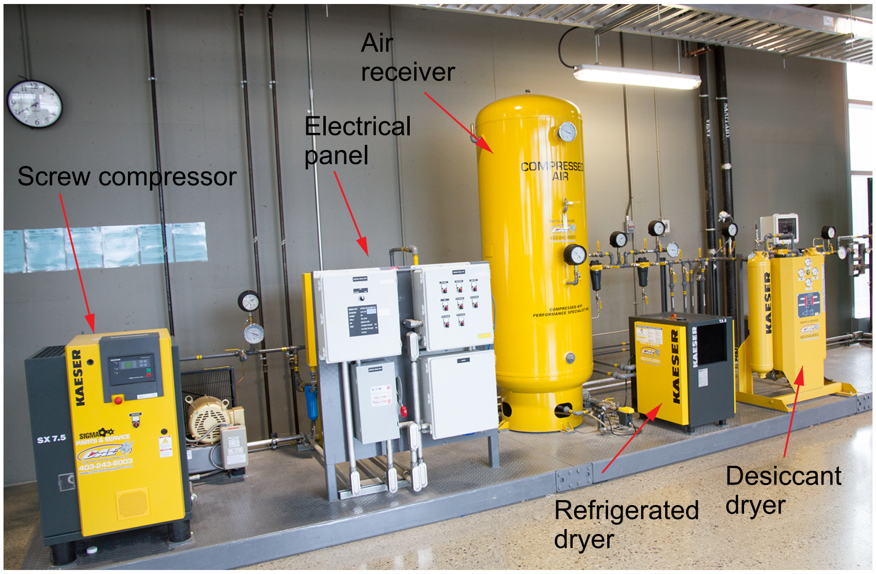


Figure 20 illustrates a typical compressed air system, which supplies compressed air for multiple functions throughout an energy plant. This system has an air dryer. Certain applications, like instrument air, require dry, clean, and oil-free air. Therefore, a dryer is installed to remove moisture from the compressed air before it is distributed.

Oil free rotary compressors are used in some processes to prevent mixing oil with the air. The system might also include filters to absorb oil from the air. Receivers store the compressed air. Moisture and oil drop out of the receivers. Automatic drain valves drain off liquids that collect at the bottom of the receivers. The pressure in the compressed air distribution is too high for many of the uses downstream, so pressure regulators are installed to reduce the pressure.

Certain types of sootblowers use compressed air. These types often have dedicated compressors because they need higher pressures, and lower quality air. Larger receivers are also located upstream of the sootblower, to store compressed air for the intermittent sootblower operation.

Air Compressor Installation

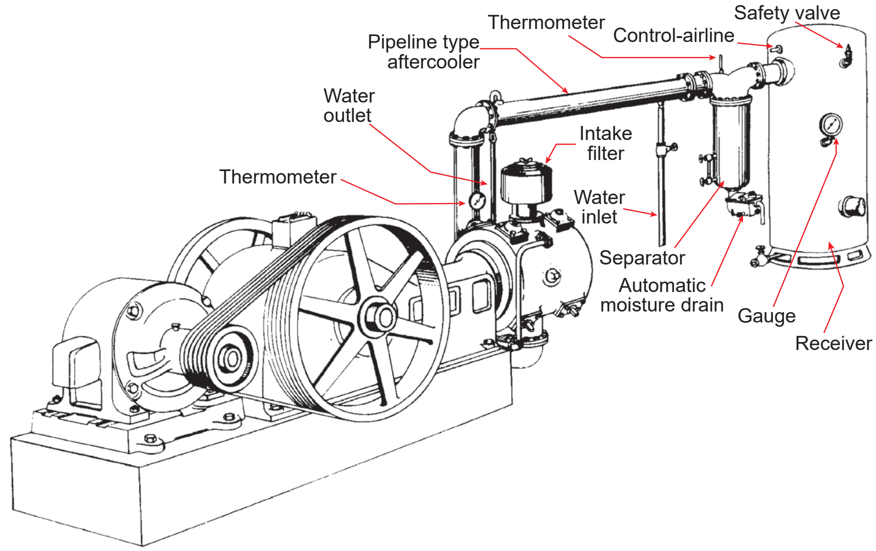
An air compressor should be located in a well-lit area that is easily accessible. The area must be clean, with no foreign material in the atmosphere. If several compressors are required, they should be in a central location for ease of maintenance and operation.

An air filter should always be installed in the inlet line. This will prevent dust and other particles from being carried into the compressor. Where possible, the air supplied to the inlet should be outside air. The air intake should be located away from engine or exhaust outlets. The inlet piping should be at least as large as the compressor intake connection. If the inlet pipe is extremely long, it should be a larger size than the intake connection.

The discharge pipe should be at least as large as the compressor outlet. The pipe should run directly to the aftercooler, or the receiver if no aftercooler is used. The line should be run with as few bends as possible. Drain valves should be provided at all low spots or pockets.

Figure 21 shows a general piping arrangement, from the compressor to the aftercooler and receiver.

Figure 21 – Compressor Discharge Piping



Gas Compressor System

Compressors are installed in gas plants, and located strategically along the entire length of the pipeline system. Most are near the wells that produce gas. The compressors are supplied with gas from individual or groups of wells. This boosts the pressure to move it into a pipeline, and to a processing facility.

Figure 22 – Gas Compressor Skid Package

Gas wells produce at a variety of pressures and flow rates. They may at first produce gas at a relatively high rate, but this declines over time. A reciprocating compressor draws the low-pressure gas from the wells, and boosts its pressure to meet the pipeline requirements to get the gas to market.

Figure 22 shows a compressor skid that may be used in natural gas compression. This type of natural gas compressor package can be transported as a unit, depending on the highway regulations. A compressor skid is compact, and more cost effective than constructing a new system on-site.

If the packaged unit cannot be built to fit highway regulations, it will be built in situ, component-by-component. The compressor is commonly two-stage. Figure 23 shows the layout of such a unit.

One of the greatest concerns in compressing natural gas is to prevent liquids from entering the compressor. Liquids are not compressible, and can seriously damage the compressor if not first removed from the gas stream. This is an important concern when compressing natural gas, because the gas naturally travels with liquid hydrocarbons and free water.

For this reason, suction scrubbers or separators are installed. Before entering the compressor, the gas must go through a scrubber, where liquids drop out, and drain away. The scrubber is fitted with a gauge glass, so the operator can monitor the liquid level. The scrubber also has automatic drain valves, and a high-level float or probe. This signals the compressor to shut down if the level gets too high.

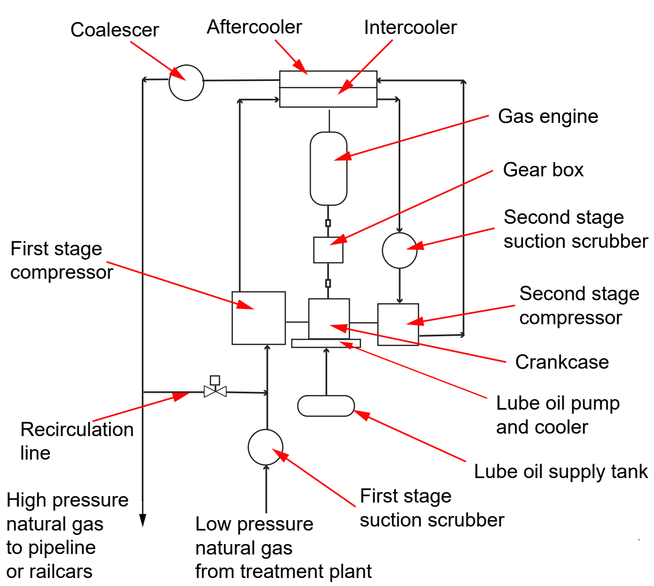
As in the air compression system, the heat generated by compression must be removed through intercoolers and aftercoolers. These heat exchangers are generally air-cooled. The fan runs off the same driver as the compressor. The intercooler cools the gas as it moves from the first stage to the second stage. As the gas cools, moisture will also drop out, and drain away in the intercooler.

From the intercooler, the gas again passes through a scrubber, and then into the second-stage cylinder. It is further compressed and subsequently heated. It then passes through the aftercooler. Again, the heat is removed. The moisture drops out and drains away as the gas moves on.

Before the gas is discharged to the pipeline, it passes through a **coalescer** or knockout drum, which minimizes the moisture entrained in the gas leaving the unit. A coalescer is equipped with a fine meshed type of filter, screens, or baffles. These collect droplets and drain them away.

The gas now moves to the discharge or, if required, it will recirculate through the compressor.

Figure 23 – Natural Gas Reciprocating Compressor Installation



A reciprocating compressor can never run with the suction valve or discharge valve closed. These gas compressors are designed for continuous operation, but upsets or other situations might cause a downstream discharge valve to close. In these situations, the automatic recirculation or bypass control valve will open. This will continue to circulate gas through the compressor until it can flow out the discharge again, or an operator can shut down the unit, if required.

Compressors not only pressurize the gas to move it from place to place, but they also reduce the volume of the gas as much as 600 times.

Compression Refrigeration System

A refrigeration system is different from the previous two systems, because it operates within a closed loop. In the previous systems, the high-pressure gas produced moves on to another service or process. In refrigeration, after the gas is compressed and discharged, it returns to the compressor suction to be compressed again.

The compressor is the heart of the refrigeration system. By understanding its operation, its characteristics can be understood, and its performance efficiency can be determined.

The function of the compressor is to draw the refrigerant from the evaporator, where it has absorbed heat by changing from a liquid to a vapour. The compressor must then raise the pressure of the refrigerant vapour sufficiently so that the condensing temperature of the vapour is higher than that of the cooling medium.

Positive displacement and dynamic compressors are used in refrigeration. The most common types are reciprocating, rotary vane, rotary screw, centrifugal, and scroll. The operating principles of compressors are the same in a refrigeration system, but there are some special considerations.

Since refrigerants may be toxic, flammable, or both, it is important to avoid leaks. This makes shaft sealing very important.

Compressor Housings

Compressor housings fall into three types:

1. Open
2. Hermetic
3. Semi-hermetic

Open Type

This type of compressor is called "open" because one end of the crankshaft extends outside the crankcase. A sealing arrangement is required to prevent the refrigerant from escaping along the shaft. This type of compressor is suitable for a variety of drives, such as an electric motor, turbine, or internal combustion engine. The driver can be either directly coupled to the crankshaft, or it can drive the compressor by means of pulleys and V-belts.

Hermetic Type

The hermetic compressor is driven by an electric motor directly connected to the crankshaft. Compressor and motor are mounted within the same housing, so there is no need to seal the shaft.

Since the housing is sealed by welding, servicing in the field is not possible. To provide for cooling of the motor windings, the low temperature vapour drawn from the evaporator is often passed around these windings before it enters the suction of the compressor. The sealed hermetic design is applied mainly to low-capacity compressors used in appliances, such as self-contained refrigerators, freezers, and air conditioning units.

Serviceable or Semi-Hermetic Type

The serviceable semi-hermetic screw compressor is similar in design to the hermetic type. However, the cylinder heads, end plates, and bottom plate can be removed for servicing of the internal mechanisms.

Safety Head

In a refrigeration system, the potential of liquid entering the cylinder of a reciprocating compressor is much higher. This is because the refrigerant is being converted from a gas to a liquid in the refrigeration cycle; therefore, it is very possible for liquid to enter the compressor.

To prevent damage to the compressor by the hydraulic pressure that results from trapped liquid at the end of the compression stroke, compressors are often fitted with a safety head. Figure 24 shows a safety head on an ammonia refrigeration compressor.

This head is kept firmly in place by a heavy spring during normal operation. The entire head will lift when the pressure in the cylinder becomes too high, due to liquid refrigerant in the cylinder. This allows the liquid to pass into the discharge line without doing any damage.

The same principle of construction is often applied in compressors equipped with ring plate valves. However, only the valve assembly is held down by the spring, instead of the entire cylinder head. The valve assembly lifts when excessive pressure occurs in the cylinder. See Figure 10(b).

Figure 24 – Compressor Safety Head

Chapter Summary

This chapter discussed positive displacement and dynamic compressors, and the types of compressors within these categories. As well, operation concepts, such as double and single acting, single, and multistage were covered. The general construction of these compressors and their operating principles should now be familiar.

Compressor systems were introduced, including:

- Air compression
- Natural gas compression
- Refrigeration

The special considerations of each application were discussed.

The gas laws and Bernoulli's principle were mentioned briefly. These physical theories relate conditions of volume, temperature, velocity, and pressure. These variables influence the operation of compressors and many other systems in a modern industrial plant.

In the next chapter, the auxiliary equipment, as well as, operations and maintenance of compressors will be presented. It will discuss the auxiliary equipment needed for the compression process to deal with heat, lubrication, and other considerations an operator needs to be aware of when operating and maintaining compressors.

CHAPTER 4

Compressor Operation and Maintenance

Learning Outcome

When you complete this chapter you should be able to:

Describe the major considerations and general procedures for compressor operation and maintenance.

Learning Objectives

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

1. *Describe compressor parts and auxiliary equipment.*
2. *Describe the construction and operation of seals for compressors.*
3. *Describe the capacity control of compressors.*
4. *Describe preventative maintenance and routine procedures for compressors.*

Chapter Introduction

The previous chapter discussed the different kinds of compressors, their principles of operation, and some of the systems where they are used.

This chapter looks at compressor systems, and the parts that make them up. The piping, valves, fittings, and other auxiliary equipment in a compression system depend on the application.

Compressors pressurize gases for many purposes, including:

- Operating equipment and instruments
- Cooling spaces
- Removing soot
- Agitating mixtures
- Transporting hydrocarbons

In some of these applications, the air must be dry, clean, and oil free. In some cases, such as refrigeration or gas plant/pipeline purposes, the focus is on proper handling of combustible and/or toxic gases.

OBJECTIVE 1

Describe compressor parts and auxiliary equipment.

A Power Engineer must be familiar with the auxiliary systems and equipment that manage the compression process, including upstream and downstream considerations. The components in a system:

- Cool the compressor or compressed gases.
- Control the pressure and flow.
- Control the quality of the gases entering and exiting the compressor.

COMPRESSOR DRIVES

Electric motors, gas turbines, and internal combustion engines are the principal methods for driving compressors.

Electric Motor Drives

Electric motors are commonly used to drive all sizes of compressors that are used for continuous service. They may be connected directly to the compressor shaft, or through a flywheel and V-belts. Reduction gears may be used to reduce the compressor speed when the electric motor speed is too high.

Gas Turbine Drive

Gas turbines may be used to drive large centrifugal compressors that re-pressurize natural gas in pipe lines. These gas turbines may be fueled directly from the natural gas pipeline. Often, these kinds of compressors are located in remote areas, with monitoring and control located in a central control room.

Internal Combustion Engine Drive

Internal combustion engines are often used to drive emergency compressors that operate during power failures. They may also be used to drive smaller portable compressors. These engines may be fueled by either gasoline or diesel, and are connected to compressors the same way as electric motors.

Objective 2

Describe the construction and operation of seals for compressors.

The efficiency and safety of a compressor is compromised when the compressed gases leak around the shaft of a compressor, and escape to atmosphere. This is a waste of the energy used to compress the gases. In the case of combustible or toxic gases, this creates a safety and environmental hazard.

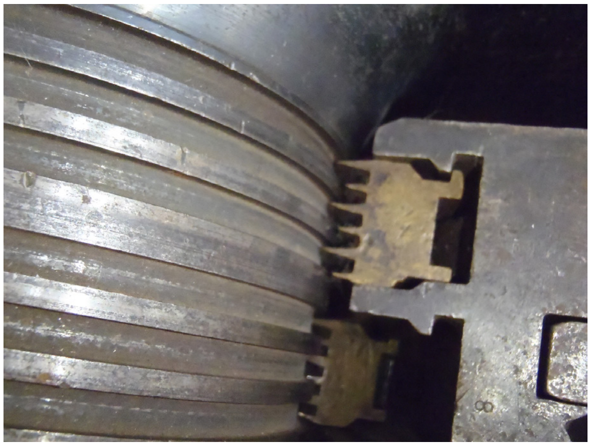
To prevent or minimize leakage, shaft seals are installed.

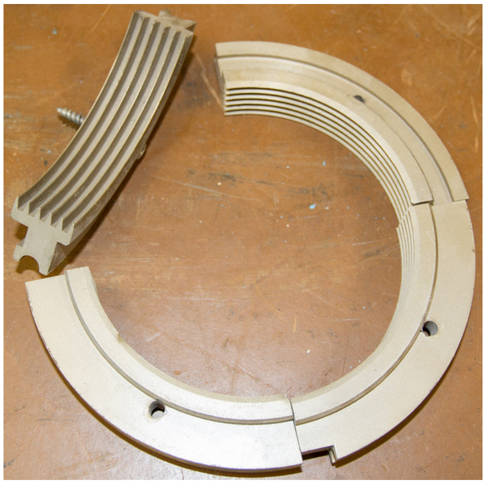
Shaft Seals

Labyrinth Seals

The labyrinth seal has a series of grooves. The peaks of these grooves make razor sharp edges. These edges maintain a close clearance to the shaft. Labyrinth seals present an intricate path that escaping gases must negotiate to reach the atmosphere. The forces within the labyrinth seal, caused by the rotating shaft and the seal's design, trap the gases. Labyrinth seals are generally used where some leakage is acceptable, such as air compressors. Figure 1 shows two examples of labyrinth seals.

Figure 1 – Labyrinth Seals

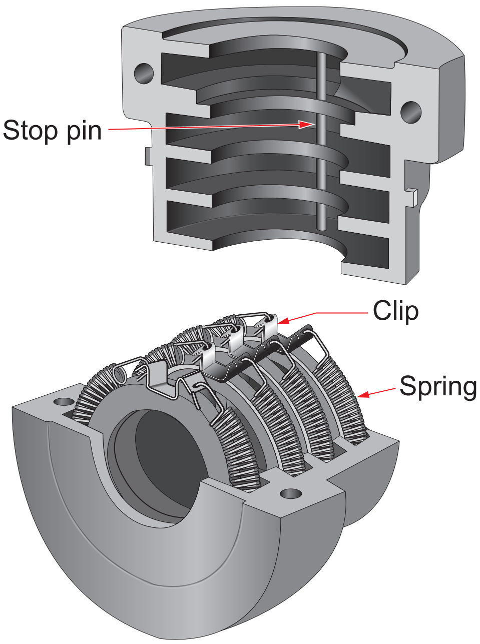




Carbon Ring Seals

Carbon rings are dry contact seals. The seals are segments held together with a spring. The entire seal assembly can be removed from the compressor when it is worn, or if broken segments need replacing. Because of the near zero clearance, there is considerable wear on this type of seal. This seal will also have minimal compressed gas leakage. Figure 2 shows the housing of several carbon rings, held in place with springs.

Figure 2 – Carbon Ring Seal



Liquid Film Seal

In a liquid film seal, a thin liquid film is created between the seal and the rotating shaft. Both the hydrodynamic forces generated by the rotating shaft, and the seal design, keep the film intact. The film and seals provide a barrier to keep the compressed gases from leaking to atmosphere.

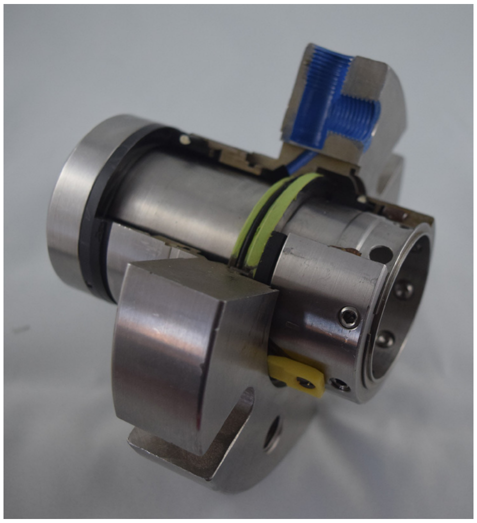
This seal has two or more rings that do not rotate, but are free to float with the shaft movement. Oil is injected between the rings at a pressure that allows it to flow between the seal rings and the shaft. The oil drains away to an oil sump. The oil film also reduces wear and heat generation. This seal controls leakage better than the labyrinth or carbon ring seal; therefore, it is used in hydrocarbon, refrigeration, and fertilizer applications where there must be no leakage (in either direction). Because oil is a safety hazard in the presence of oxygen, and it degrades the quality of compressed air, these seals are not used in high-pressure air or oxygen situations.

Mechanical Seal

Mechanical seals are used in the same applications, and for the same reasons, as liquid film seals. They provide better sealing than labyrinth and carbon ring seals. They also use a small amount of oil for sealing, and for friction heat removal.

Mechanical seals consist of rotating and stationary surfaces that remain in contact with each other to prevent leakage. Figure 3 shows a cut away of a mechanical seal. This seal may be supplied with liquid cooling, if necessary.

Figure 3 – Mechanical Seal



Dry Gas Seal

The dry gas seal solves the problems involved with seal oil in centrifugal compressors. Dry gas seals generally consist of a rotating ring and a stationary ring. Grooves are machined into the face of the rotating ring. When it begins to rotate, the grooves cause an aerodynamic force that makes a gap between the rotating and stationary ring.

A sealing or separation gas, usually an inert gas such as nitrogen, is injected into this gap at a pressure slightly greater than the process gas. The dry gas seal comes in three designs:

1. Single
2. Double
3. Tandem

Single dry gas seal is used for non-hazardous gases, at moderate pressure. The sealing gas leaks only in one direction, out to atmosphere.

Double dry gas seal is used in low pressure, toxic gas applications. This gas keeps the process gas from getting to atmospheric air and atmospheric air from getting into the process gas. A small amount of sealing gas may leak into the compressor; therefore, it must be compatible with the process gas.

Tandem dry gas seal, and tandem intermediate labyrinth seals, are used with flammable and toxic gases. They are common in the petrochemical industry.

Oil-Free Packing Ring Seals

For oil-free reciprocating gas compressors, oil-free packing rings, with oil wipers and deflectors, are used. This compressor is for applications where maximum oil leakage containment is critical for an oil-free product.

Compressor Bearings

Compressor bearings are usually the sleeve/shell type. The material used for crankshaft bearings is bronze for smaller compressors, and steel or bronze backed babbitt for larger ones. Ball and tapered roller bearings are used to a limited extent.

The bearings are lubricated by either the splash system, or the pressure system. The former system uses the bottom part of the crankcase for oil storage; the level is kept high enough for the crank to dip into the oil and splash it over the moving parts. The pressure system uses a gear pump, mounted on the end of the crankshaft. The pump draws oil from a sump in the crankcase and delivers it, under pressure, through special oil lines or drilled passages to the bearings and cylinder walls.

Compressor Lubrication

Lubricating oil is necessary in a compressor to:

a) Prevent wear by providing a film between surfaces.
b) Reduce friction and the resulting power loss by providing a film between surfaces.
c) Remove heat produced by friction.
d) Reduce corrosion by providing a coating for metal surfaces.
e) Provide sealing around piston rings, vanes, valves, and so on.

Compressor lubrication may be divided into two main sections:

1. External lubrication
2. Internal lubrication

External Lubrication

External lubrication refers to lubrication of moving parts external to the compressor cylinder or casing. These parts include:

- Crankshaft bearings
- Connecting rod bearings and crossheads on reciprocating compressors
- Rotor shaft bearings on rotary and dynamic compressors

For reciprocating compressors, a pump driven from the compressor shaft delivers oil under pressure to the crankshaft and connecting rod bearings. The oil is pumped from the crankcase to the bearings, and then it drains back to the crankcase again.

For small single-acting reciprocating compressors, a splash system of lubrication is frequently used. The movement of the crankshaft splashes oil onto the various bearings. This splash method provides internal lubrication at the same time, since some oil is splashed onto the cylinder walls.

In rotary and dynamic compressors, the rotor shaft bearings may be ring or chain oiled, but often a pressure system is used with a pump that forces oil to the bearings. This pump may also supply oil to the bearings of the electric motor driving the compressor.

Internal Lubrication

Internal lubrication refers to the lubricating oil applied to the cylinder walls and pistons of reciprocating compressors, and to the vanes and casing walls in some types of rotary compressors.

Dynamic types of compressors, such as centrifugal and axial flow, do not require internal lubrication, which is an important advantage.

Lubricating oil is generally fed directly to the cylinder walls of reciprocating compressors by means of a mechanical lubricator, driven from the crankshaft or crosshead. Each cylinder may have one or more points to which the oil is pumped, and each should be fed by a separate pump unit of the lubricator. After the oil enters the cylinder through these feed points, the compressor piston spreads the oil over the cylinder walls.

In a single-acting compressor, with the cylinder bottom open to the crankcase, cylinder lubrication is provided by splash lubrication. The oil is splashed from the crankcase onto the cylinder walls by the movement of the crankshaft and its attached parts.

Sliding vane rotary compressors require internal lubrication to prevent metal-to-metal contact between vanes and casing, and to provide a seal between vanes and casing. A pressure lubricator is used to supply the oil and discharge it into the air intake. The air then carries the oil along to the rotating vanes. The lubricator may also discharge the oil directly to points on the casing. In some designs, the oil is pumped through a longitudinal hole in the rotor shaft, and then through radial holes to the rotor periphery.

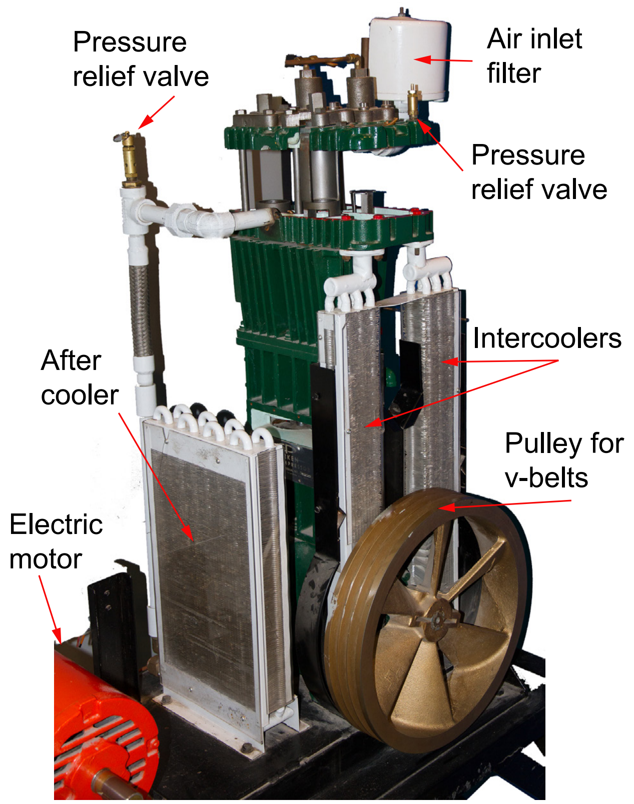
Some applications, such as in the food processing and medical industries, require oil-free compressors. These compressors have no internal lubrication. They produce less pressure with single stage because, without oil as a sealing agent between the rotary parts or piston and the internal walls, the compressor efficiency is affected. Multistage compressors may be needed to attain the required pressure.

Intercoolers and Aftercoolers

Due to the heat generated through compression and friction, some type of cooling system is usually required. These are often shell and tube type heat exchangers that may be designed to have water flowing through the tubes, while air passes over them or with air flowing through tubes surrounded by water. Their function is to cool the gas, either between stages of compression (intercoolers), or after the compression is completed (aftercoolers).

Figure 4 shows a two-stage positive displacement air-cooled air compressor. The head has been removed and supported on rods so that the working mechanisms can be observed. The air is drawn in through the inlet filter, and then compressed in the first stage. The air leaves the discharge of the first stage, and enters the intercoolers where some of the heat of compression is removed. There is a pressure relief valve on the discharge of the first stage. The air then enters the second stage, and passes into the aftercooler. The intercoolers and the aftercooler use fins to increase the surface area to remove the heat. The pulley for the v-belts has large fan blades to increase the airflow over the fins of the intercoolers and aftercooler.

Figure 4 – Intercoolers and Aftercooler



Some reasons for cooling the air include:

a) To remove water vapour and oil vapour from the air between compression stages and after the last stage. When the air is cooled, the water and oil vapours condense. The condensate can then be drained from the bottom of the coolers.

b) If the oil vapour is not condensed and removed, it can have a detrimental effect on air-operated instruments, and may build up deposits that could ignite and explode in pipes and reservoirs.

c) If water vapour is not removed from the air, it may condense and collect in pipelines. This causes water hammer or damage from freezing. In the case of air driven tools and machinery, the entrained water can wash away lubricating oil from the machine surfaces.

d) Intercoolers decrease the amount of power required to compress the air. Cooling the air during compression will increase the efficiency of operation, reducing costs.

e) Reducing the air temperature by means of coolers will also make cylinder lubrication more effective. Cooling reduces the weakening of parts caused by high temperatures, and reduces the possibility of an explosion of oil vapour mixed with air.

Intercoolers and aftercoolers may be either air-cooled or water-cooled.

The air-cooled type is normally used when the compressor itself is air-cooled. It consists of a finned pipe through which the compressed air passes.

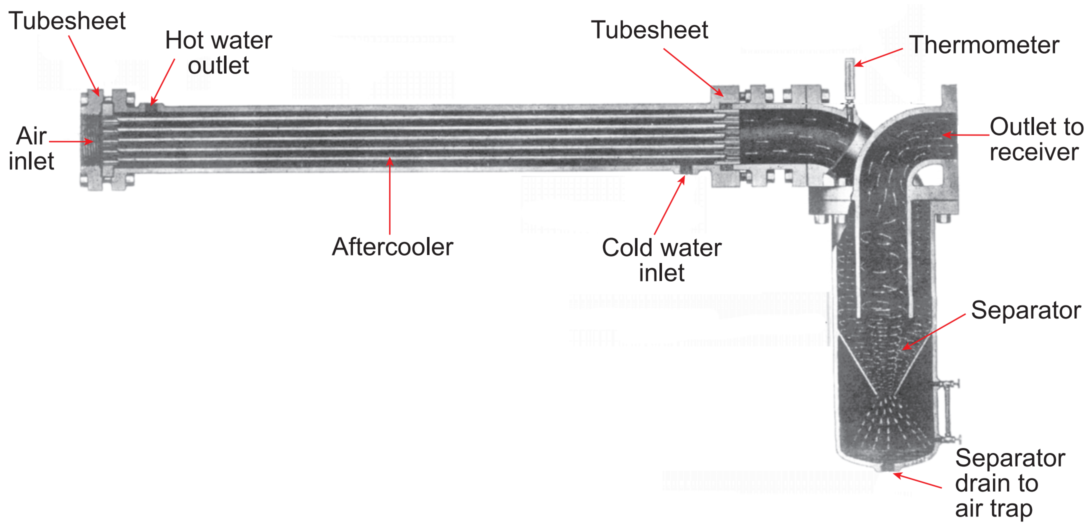
The water-cooled type, as mentioned previously, is of shell and tube construction with either cooling water passing through tubes surrounded by the compressed air, or compressed air passing through the tubes surrounded by water on the shell side.

Intercoolers should have a:

- Safety valve
- Pressure gauge
- Thermometer on the discharge air side
- Thermometer on the cooling water

Figure 5 shows an aftercooler in which the compressed air flows through the tubes, while the cooling water flows around them on the shell side. As the air discharges from the aftercooler, it passes through a cyclone separator. Condensed moisture and other particles drop out, and are removed from the air stream.

Figure 5 – Aftercooler with Cyclone Separator



Aftercoolers, like intercoolers, are fitted with pressure gauges and thermometers. If there is a shut-off valve between the aftercooler and the receiver, the aftercooler must be fitted with a safety valve. Aftercoolers should always have separators installed as close to the aftercooler as possible.

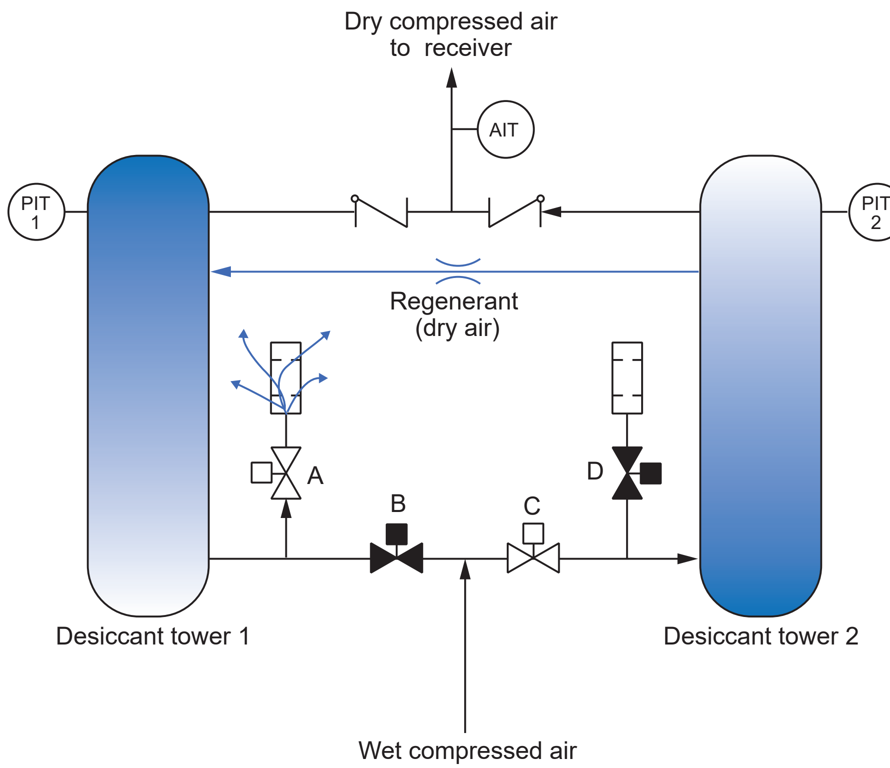
Air Dryers

Air used for instrumentation and control must have a low moisture content. If control air is moist, it can freeze in instrumentation lines or plug nozzles in controllers and positioners. The moisture is removed from the air by passing the air from the receiver outlet through an air dryer filled with chemicals called **sorbents**. Sorbents are divided into two classes:

1. **Adsorbents** (soaking up by surface)
2. **Absorbents** (soaking up by volume)

Figure 6 shows an air dryer system with Tower 2 drying the air before it goes to the receiver. Tower 1 is being regenerated.

Figure 6 – Air Dryers



Adsorbents (such as silica gel, activated alumina, and bauxite) are solid substances, which attract moisture from the air. The water vapour condenses on the surface of the adsorbent, and remains there as a thin water film. Because adsorbents are very porous, and have an extremely large surface, they are able to hold a large amount of moisture. Silica gel will hold an amount of moisture up to 40% of its own weight.

Adsorption is thus a condensation process. The latent heat released by the condensing water vapour is transferred to the air passing through the adsorbent layer, or bed, as sensible heat. This causes a rise in temperature. It will often be necessary to pass the dehumidified air through a cooling coil to reduce its temperature.

Figure 7 – Air Dryers

Figure 8 – Desiccant

When the adsorbent becomes saturated, it has to be regenerated. The bed is then taken out of operation, and heated to about 150°C. A small air purge flow drives the adsorbed moisture off by evaporation. Figure 6 shows a small stream of dry air from Tower 2 being directed to Tower 1, to regenerate the adsorbent.

Absorbents are not commonly used because they are difficult to regenerate. As a result, they are used in "throw away" type filters. Since they absorb internally, this adds a significant pressure loss to the dryer system.

Refrigerated Air Dryers

Refrigerated air dryers use a refrigeration system to cool the compressed air. In a typical arrangement, the air passes through two heat exchangers. One is an air-to-air heat exchanger, where the outgoing dry air and the incoming wet compressed air pass each other. Heat from the incoming wet compressed air warms the outgoing dry compressed air, which prevents further condensing of moisture from the dry air.

The second heat exchanger is a refrigeration heat exchanger or evaporator. The wet compressed air is cooled, which causes the water and oil vapours to condense and drop out of the air. These liquids are then drained.

Figure 9(a) is the control panel on the top of the small refrigerated air dryer shown in Figure 9(b).

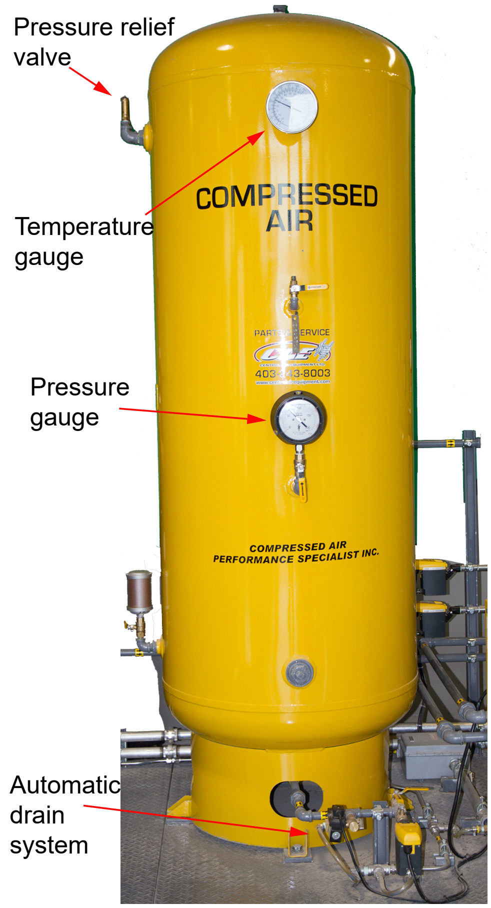
Figure 9 – Refrigerated Air Dryer

(a) (b)

Air Compressor Receivers

An air receiver is a pressure vessel used as an air reservoir in a compressed air system. In addition to acting as a reservoir, it acts to dampen pulsations in the discharge pressure of a reciprocating compressor. Another function of the receiver is to allow moisture and oil to settle out from the air. These liquids collect at the bottom of the receiver, and they are drained.

Figure 10 – Air Receiver



Air receivers may be either horizontal or vertical. Their specifications must conform to the **ASME BPVC Section VIII, Division 1**. They are fitted with a:

- Safety valve
- Pressure gauge
- Drain valve
- Openings for inspection and cleaning
- Regulator connection

There have been instances of air receiver failure because of either defective safety valves, or weakening of the vessel material due to corrosion. To ensure proper operation, safety valves should be tested regularly by lifting the valve off the seat with the hand lever. The receiver should also be kept drained to minimize corrosion.

Receivers should be inspected and hydrostatically tested periodically by proper authorities. After opening an air receiver for inspection, the interior should be thoroughly ventilated, so there is no accumulation of carbon monoxide gas, which can be formed from deposits within the vessel. Naked lights, and other possible sources of ignition, should be kept away from the vicinity, since carbon monoxide is a combustible gas.

Overpressure Protection

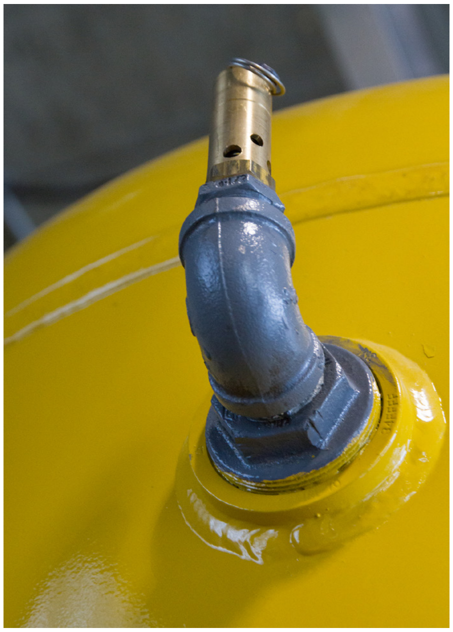
A E

Air receivers must have pressure relief valves, in accordance with **ASME BPVC Section VIII, Division 1 Part UG 125**. However, the whole system needs safety valves located at various points on a compressed gas (air) system, including the compressor discharge, intercooler, aftercooler, and separators.

Overpressure conditions can result when the discharge valve is closed between the compressor and air receiver. In most cases, the high pressure shut down will activate in these situations, and the compressor will stop.

Safety valves through the system will prevent the rupture of piping or equipment due to excessive pressure in the system.

Figure 11 – PRV



Check Valves

Check valves are designed to allow air to flow in one direction only. They are normally fitted between the compressor and the receiver to prevent high-pressure air in the receiver from blowing back into the compressor. Check valves are also used in other applications in a compressed air distribution system.

Instruments

A pressure gauge and thermometer should always be connected to the delivery (discharge) side of an air compressor, and between stages when more than one stage is used.

Pressure gauges are fitted to receivers and intercoolers. Thermometers are installed in the discharge lines from the cylinders of a reciprocating compressor.

These instruments will indicate variations from normal operation; thus, the conditions responsible for abnormal readings can be traced and corrected.

Pressure gauges and pressure regulators should be installed at locations where the required air pressure is lower than the pressure supplied by the compressor. Approved safety valves should be provided to relieve pressure, in case of a pressure regulator malfunction.

OBJECTIVE 3

Describe the capacity control of compressors.

COMPRESSOR CONTROL

The discharge flow of air from the compressor must be varied to suit load requirements and maintain a constant pressure in the system. Several methods are used to control the compressor output:

1. Start and stop control
2. Load/unload control
3. Dual control
4. Variable speed control
5. Constant speed control

Start and Stop Control

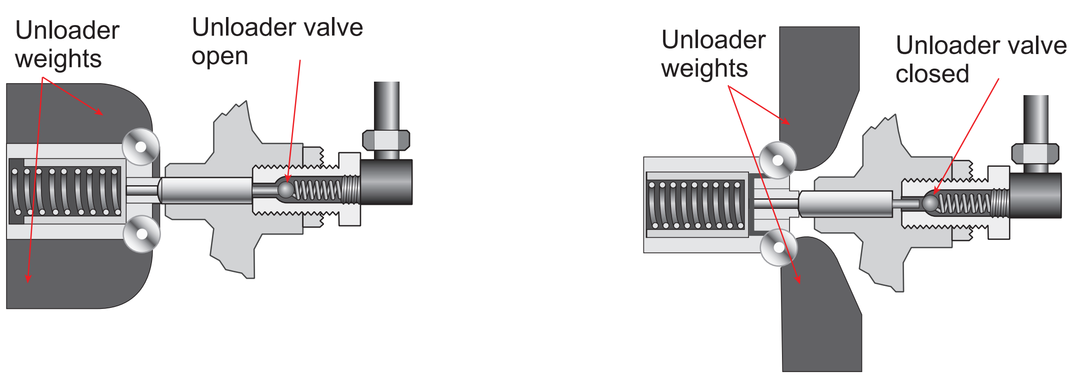
In this method, the compressor is shut down when little or no air is required by the system, and started when the demand increases. This starting and stopping can be done by means of a pressure switch sensing the pressure in the receiver.

The start and stop method is only used on electric motor driven units. A sufficiently large receiver should be installed so that the compressor does not continuously start and stop, and operates less than 50 percent of the time. The compressor should be automatically unloaded during the startup period to protect the motor from overloading.

A suitable unloader operates as a function of speed, independent of a pressure switch. It unloads the compressor when it stops, and loads it when it reaches operating speed after starting.

Figure 12 shows a centrifugal type loader. When the compressor stops, the unloader weights move to a closed position and open the unloader valve. Compressed air trapped in the compressor escapes (Figure 12(a)). When the compressor reaches operating speed after starting, the weights automatically close the unloader valve, and compression takes place (Figure 12(b)).

Figure 12 – Compressor Unloader



(a) Unloaded position (b) Loaded position

The discharge of a reciprocating compressor connects to the air receiver through a pipe.

When the compressor stops, the pressure in this pipe is reduced to atmospheric pressure by the unloader.

This venting of the pressure is the hissing sound that is heard when the compressor stops. The check valve in the line ensures that the air receiver pressure is maintained.

The reduced pressure in this pipe makes it possible for the electric motor to start the compressor with minimal load on the compressor.

Load/Unload Control or Constant Speed Control

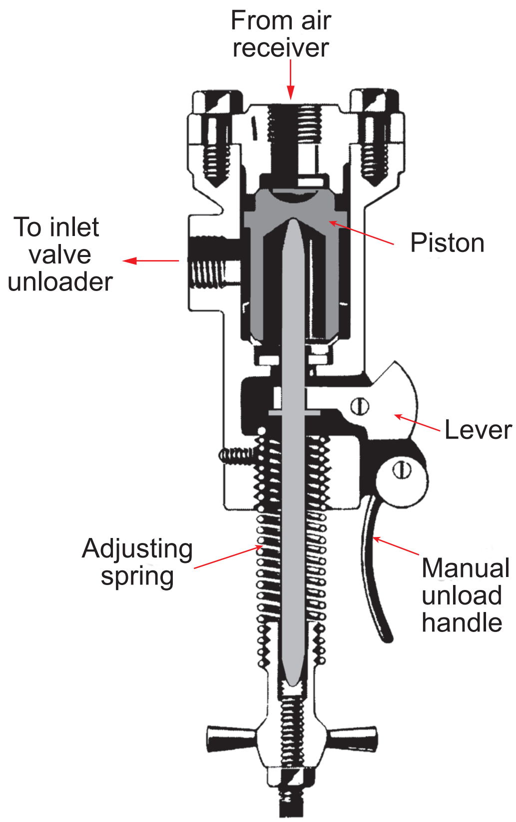
In this method, the compressor drive (usually an electric motor) runs at a constant speed at all times. However, a pilot type unloader varies the output from the compressor, according to the air demand. The electric motor will have less starts than the on-off type control system. This type of control is used if the compressor is very large, or if the compressor is running at greater than 50% of the time.

This type of unloader may operate in one of three ways:

1. It may hold the inlet valves open.
2. It may close the compressor intake valve.
3. It may open a bypass valve in the discharge back to the compressor intake. This method is inefficient and is seldom use.

Figure 13 illustrates a type of pilot valve used to operate the compressor inlet valve unloader.

Figure 13 – Pilot Valve



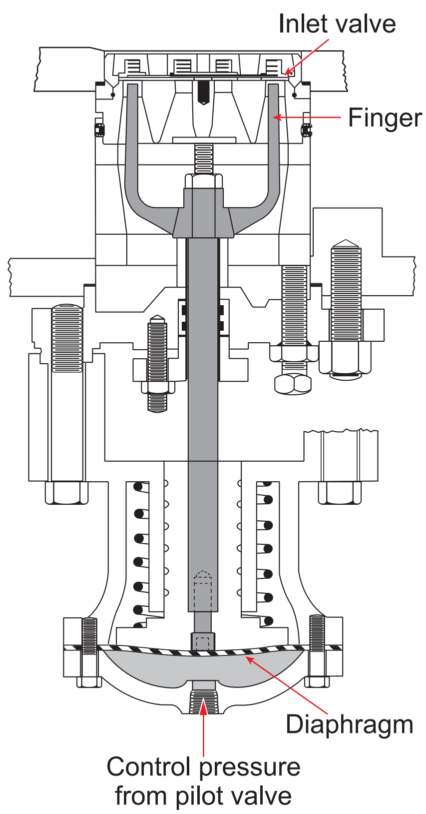
The piston of the pilot valve is held down on its seat by a spring. Air pressure from the air receiver is connected to the underside of the piston. When the air pressure is high enough, it lifts the piston off its seat and allows air to flow to the inlet valve unloader.

The piston in the unloader then moves against a spring. Pressure and the legs on the unloader lift the plates of the compressor inlet valve off their seats. Now unloaded, the inlet valve becomes completely ineffective, and air passes freely in and out of the compressor cylinder, without gaining any compression at all.

When the pressure in the air receiver falls low enough, the reduced air pressure from the receiver will allow the spring to reseat the pilot valve. The inlet valve unloader retracts and allows the compressor inlet valve plates to be seated again. The compressor is now "loaded" and it resumes normal operation.

Figure14 shows an inlet valve unloader operated by pressure from the pilot valve shown in Figure 13.

Figure 14 – Inlet Air Unloader



Variable Speed Control

The variable speed control method can be used when the compressor is driven by a variable frequency drive AC motor, a steam turbine, or an internal combustion engine.

In order to maintain the system pressure at a constant value, the compressor speed is increased or decreased according to the system demand. This adjustment is done by varying the motor speed, regulating the steam supply to the turbine, or regulating the fuel supply to the internal combustion engine.

For example, if the demand for air decreases, the receiver pressure will increase, which will cause a pressure-actuated control to slow down the driving engine or turbine. On an increased demand for air, the receiver pressure will drop, and the pressure-actuated control will speed up the motor, engine, or turbine.

Dual Control

Dual capacity control uses two systems to match compressor output to system demand. The compressor's first control method is the load/unload method, but if it runs a set time without loading, it will shut down. This method is used with small reciprocating compressors and rotary screw compressors (not oil-free type).

Protective Controls

In addition to those controlling the output of a compressor, other systems of protective controls or interlocks should be used to protect the compressor from damage or catastrophic failure. A typical two-stage compressor might have automatic shutdown devices that would operate in the following conditions:

a) High lubricating oil temperature
b) High intercooler temperature
c) High discharge air temperature
d) High discharge air pressure
e) Low lubricating oil pressure
f) Low lubricating oil level
g) Excessive vibration
h) Cylinder lubricator failure

Objective 4

Describe preventative maintenance and routine procedures for compressors.

Preventive Maintenance

One of the most important items for continuous, trouble-free, and economic operation is the maintenance of the correct working temperature within a compressor cylinder. Temperatures do not become high until the point of maximum compression is reached. At this point, near the end of the stroke, the temperature under normal conditions will be approximately 90°C. In very exceptional circumstances, the temperature may rise as high as 200°C.

The cooling water for cylinder jackets and heads must always be turned on before the compressor is started. While in operation, frequent temperature readings of the water should be taken, at both the inlet and outlet. A change will indicate an irregularity, possibly in the action or wearing of the discharge valves.

Scale in the water jackets, intercooler pipes, and other water-cooled parts may accumulate if cooling water that contains impurities or deposit-forming salts is used. Such accumulations may seriously interfere with the heat transfer from the compressed air to the circulating water. These water-cooled parts should be thoroughly cleaned as often as necessary. The frequency of cleaning required will depend on the quality of water being used.

The condition of the air entering a compressor is also an important consideration. The correct treatment of this air has a marked effect on the operation of a compressor, and on the extent to which its moving parts will need to be repaired or replaced.

Filters must remove impurities in the intake air before it enters the cylinder of the compressor. Air should be drawn from as clean a source as possible, outside the engine room and away from any engine exhaust. It should also be as cool as possible.

Abrasion, produced from the lubricating oil and dust entering with the air, causes wear. This requires early replacement of parts, shutdowns, and needless labour charges. Sticky accumulations form behind the piston rings, and quickly bake into hard deposits that interfere with the free action of the rings, and impair the piston seal.

How often air filters need cleaning is influenced by the:

- Local conditions
- Type and capacity of the filter
- Volume of air handled
- Amount of dust in the atmosphere

A clean filter imposes very little restriction on the flow of air passing through it. Contaminants should never be allowed to accumulate to an extent that will seriously impede the airflow. The manufacturer of the particular filter in use should be consulted to ascertain the correct method of determining when a filter needs cleaning, and the best method to clean it.

Routine Checks

The startup and shut down of a compressor will depend on the type of compressor and the process. Both the manufacturer and the plant will have standard operating procedures (SOPs) for the operators to follow. Other SOPs list the checks an operator will be expected to do on a routine basis.

Operators perform routine checks on the equipment that monitors the operation of compressors and related equipment. This is to detect developing problems before they become serious, or to prepare a controlled management of the problem. Here is list of some of the main items on the operator checklist.

Daily:

1. Review control panel for process pressures, temperatures, and all supervisory feedback.
2. Check lubricating oil and coolant levels.
3. Check operation of all coolers and traps.
4. Listen for unusual noises.
5. Check for leaks and loose parts.
6. Check differential pressures across filters, intercoolers, and aftercoolers.

Weekly:

1. Depending on the quality of supply air, clean or replace air intake filters.
2. Inspect and clean cooling coils.
3. Resolve any warning alarms that arose over the week that could not be resolved while running.

Monthly:

1. Assess the performance of all intercoolers, aftercoolers, and oil coolers.
2. Lubricate the linkage, pins, and slide bars of all control valves, valve positioners, and guide vane positioners.
3. Analyze oil samples from lubricating and seal oil reservoirs.

Major shutdown checks:

1. Inspect couplings.
2. Drain and clean each lubrication and coolant system.
3. Check the calibration of all instruments, and alarm and trip devices.

Chapter Summary

Compressor operation and maintenance were the focus of this chapter. This chapter discussed the auxiliary equipment, such as lubrication pumps, air unloaders, scrubbers, and others associated with gas compression in different compressed gas units.

The new Power Engineer should understand compressed gas quality, how it is achieved, and why it is important. Some general aspects of routine maintenance and operation were reviewed.

A Power Engineer works with compressed gases on a daily basis. The knowledge acquired in this chapter provides a practical awareness of the various systems – pneumatic controls, cooling, and natural gas transportation – associated with them.

The understanding of pressure, heat, compression process, lubrication, and cooling covered by this chapter will be repeated throughout continued studies of Power Engineering. They will also be reflected in the plants where Power Engineers are employed.

UNIT SUMMARY

Power Engineers are responsible for the safe and efficient operation of pumps and compressors, two essential parts of an energy plant. This unit provided the learner with a basic understanding of a variety of pumps and compressors, and their operation.

Pumps and compressors are at the heart of their systems. To fully understand the role this equipment has in a process, many concepts in thermodynamics need to be considered. These explain how fluids behave in relation to volume, pressure, velocity, and temperature. Because of these principles, equipment is needed to manage the resulting heat, pressure, and flow. The end use process will also determine what equipment is installed, and how that equipment will operate.

This unit introduced the applied scientific principles under which pumps and compressors work. A variety of designs were identified, and simple descriptions of their operation were presented. A short overview of some troubleshooting recommendations finalizes this unit's treatment of this topic.

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

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UNIT B-2

KNOWLEDGE EXERCISES AND UNIT GLOSSARY

Knowledge Exercises – Chapter 1

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. List seven applications where pumps are used in energy plants.

Objective 2

2. Briefly define each of the following terms:

   a) Total Static Head

   b) Static Discharge Head

   c) Static Suction Lift

   d) Static Suction Head

Chapter 1 (Cont.)

e) Pressure Head

f) Total Dynamic Head

g) Friction Head

h) Velocity Head

i) Dynamic Head

Objective 3

3. Pumps are classified as either dynamic or positive displacement. What is the major difference between these two classifications?

Chapter 1 (Cont.)

4. Explain cavitation and its impact on centrifugal pump impellers.

Knowledge Exercises – Chapter 2

Name: ____________________ Date: ____________________

Instructor: ____________________ Course: ____________________

Objective 1

1. Name three important purposes of wear rings.

2. Explain the importance of the following pump parts:
   a) Coupling
   b) Shaft sleeve
   c) Stuffing box
   d) Base

Objective 2

3. Why must there always be leakage from a pump stuffing box?

Chapter 2 (Cont.)

4. What is the purpose of a lantern ring?

5. A pump shaft has a diameter of 63.5 mm. The stuffing box inside diameter is 88.9 mm. What size of packing should be used?

Objective 3

6. Name four advantages mechanical seals have over compression packing.

7. Name two disadvantages of mechanical seals.

Objective 4

8. What types of bearings are used in pumps?

9. Name two ways that pump and driver shafts can be misaligned.

10. State three reasons shafts may not stay aligned when pumps are in operation.

Chapter 2 (Cont.)

Objective 5

11. What is the purpose of a foot valve?

12. Describe a method of priming a centrifugal pump, when the pump is located above the surface of the fluid being pumped.

13. What may show that a pump suction strainer is plugging?

Objective 6

14. What feature makes positive displacement pumps self-priming?

15. What safety device must be located in the discharge piping from a positive displacement pump, prior to the discharge line shut-off valve? Why?

Knowledge Exercises – Chapter 3

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Compressors are used in energy plants in a number of applications. List three applications where compressors are used.

2. Name the two classes of compressors, and explain their main differences.

3. List the major types of compressors found in energy plants.

Objective 2

4. Name five uses of compressed air.

Chapter 3 (Cont.)

5. What are the advantages of pneumatic tools over electric tools?

6. What makes a refrigeration compression system different from air or gas compression systems?

Knowledge Exercises – Chapter 4

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. What are the most common compressor drives?

2. Name a typical application for compressors driven by gas turbines.

3. When are internal combustion engines used to power air compressors?

Objective 2

4. Describe each of the following components of a compressed air system:

   a) Air intake

   b) Air filter

   c) Intercooler

Chapter 4 (Cont.)

d) Aftercooler

e) Receiver

5. What is the importance of dryers in a compressed air system?

6. Describe the safety features found on air compressor systems.

7. Why are water vapour and oil vapour removed from compressed air and gases?

Chapter 4 (Cont.)

Objective 3

8. Identify five methods of air compressor capacity control.

9. What kind of protective controls are on a compressed air/gas system?

Objective 4

10. List six routine daily checks that should be performed on an air compression system.

11. List three routine monthly checks that should be performed on an air compression system.

Unit B-2 Glossary

Term	Definition
Absorbent	A substance capable of extracting one or more constituents from a mixture of gases and/or liquids. It undergoes a physical or chemical change while performing the extraction.
Adsorbent	A substance with tremendous surface area, capable of extracting one or more constituents from a mixture of gases or liquids by the physical attraction of the extracted material to the exposed surface area. No physical or chemical change of the adsorbent results.
Axial flow pump	A type of dynamic pump that uses a propeller instead of an impeller, and directs its discharge parallel to the pump shaft.
Cavitation	The sudden vapour cavity formation, growth, and subsequent collapse, that occurs in a saturated liquid. Cavitation is caused by local pressure fluctuations.
Centrifugal pump	A dynamic pump, which uses a spinning impeller to accelerate a fluid, and a volute-shaped housing to convert fluid velocity into pressure.
Coalescer	A vessel that uses either an electric field or demister pad to combine small droplets of liquid, which are carried in gas, into larger droplets. This enables the large droplets to be knocked out.
Compression packing	Braided or woven material placed in single rings in a stuffing box, to control leakage along a pump or compressor shaft, or a valve stem.
Coupling (mechanical)	A device that connects two shafts mechanically.
Diffuser centrifugal pump	A centrifugal pump which, instead of having a volute, is equipped with a series of convergent discharge vanes that convert fluid velocity into pressure.
Diffuser vane	In a pump or fan, blades positioned to provide a fluid pathway of increasing cross-sectional area. Diffuser vanes are designed to convert high-speed fluid flow into low-speed flow at an increased pressure.
Double acting	A pump or compressor in which fluid is moved or compressed on both strokes (and both sides) of the pressure-imposing element.
Duplex pump	A two-cylinder double-acting reciprocating pump driven directly by the action of two steam cylinders.
Dynamic head	The pressure of a pumping system that varies with changes in fluid velocity. This includes velocity head and friction head.
Dynamic pump	A pump that continuously increases a liquid's kinetic energy, and then converts the kinetic energy to potential energy.
External gear pump	A positive displacement pump with a housing containing a driving gear and an idler gear. As the gears rotate, they convey pockets of liquid to the discharge side of the pump by trapping the fluid in the pockets between the gear teeth and the housing.
Foot valve	A check valve placed at the terminus of a suction line, to prevent reverse flow.
Friction head	The pressure a pump must provide to overcome the friction of piping and fittings, expressed in equivalent metres of head.
Gland	A machinery component used to seal a rotating or reciprocating shaft against fluid leakage. Also, see Packing Gland.
Impeller	The rotating element of a dynamic pump or compressor, used to transfer mechanical energy to a fluid.

Term	Definition
Impeller eye	The inlet of an impeller.
Lantern ring	A metallic ring with radial holes, placed in a pump stuffing box, to allow entry of sealing or lubricating fluid to the packing.
Laser	Narrow spectrum, highly focused, and intense light. Laser is an acronym for "light amplification by stimulated emission of radiation."
Mechanical seal	Mechanical device to seal the flow of liquid along a centrifugal pump shaft by using a fixed and rotating element of two different materials.
Mixed flow pump	A dynamic pump, with a distinctively shaped impeller and casing, which combines features of an axial pump and a centrifugal pump.
Multiplex pump	A reciprocating positive displacement pump with multiple pumping stages connected in series, used to provide small volumes of very high-pressure fluid.
Net positive suction head (NPSH)	The absolute pressure of a fluid, measured at the inlet of a pump.
Net positive suction head available ($NPSH_A$)	The absolute fluid pressure at the suction port of a pump, calculated during the design and construction of a pumping system.
Net positive suction head required ($NPSH_R$)	The amount of pressure that is required on the suction side of a pump to prevent cavitation.
NPSH	See *net positive suction head* (NPSH).
$NPSH_A$	See *net positive suction head available* ($NPSH_A$).
$NPSH_R$	See *net positive suction head required* ($NPSH_R$).
Packing	See *compression packing*.
Packing gland	A metal device that encircles a shaft or valve stem, and applies force to compression packing, in order to control leakage along a shaft or valve stem.
Pascal's paradox	The fact that, in different shaped containers, with the same base area, and filled with a liquid of the same height, the applied force by the liquid on the base of each container is exactly the same.
Peristaltic pump	A positive-displacement pump that moves fluid through a flexible tube that is squeezed progressively by a roller. The roller moves around the housing, pushing trapped liquid toward the discharge of the pump.
Positive displacement pump	A pump in which pressure energy is added to a liquid by action of the pump that causes a definite movement of the liquid into the discharge area.
Pressure head	The pressure produced by a column of liquid due to its height and density.
Priming	The filling of a pump with liquid before commencing pumping.
Progressing cavity pump	A progressive cavity pump.
Progressive cavity pump	A positive displacement pump that has a single helical stainless steel rotor fit tightly within an elastomer-lined stator. It is used for transferring viscous, abrasive, or delicate fluids.
Propeller	A high-speed, rotating, pressure-imposing element used in axial and mixed flow pumps.
Reciprocating pump	A pump in which the pressure-imposing element consists of a piston, plunger, or diaphragm that moves back and forth, thus displacing liquid.

Term	Definition
Regenerative pump	A dynamic pump with a high-speed rotating element that repeatedly imparts impulse forces on a liquid to raise its pressure.
Rotary lobe pump	A positive displacement pump comprised of a housing containing rotors with intermeshing lobes. As the lobes rotate, they convey pockets of liquid to the discharge side of the pump by trapping the fluid in the pocket of the lobe and the pump housing.
Rotary pump	Positive displacement pumps with various rotating parts, whose rotation creates voids that move liquid from the pump's suction port to its discharge port.
Roto-dynamic pump	A dynamic pump that uses rotating pressure-imposing elements.
Saturant	Lubricant contained within pump or valve packing.
Seal cage	See *lantern ring*.
Shut-off head	The head developed by a dynamic pump when running with its discharge valve shut. This is the maximum discharge head a centrifugal pump can develop.
Simplex pump	A single-stage, reciprocating, positive displacement, plunger-style pump, often used for chemical metering.
Single acting	A pump or compressor in which fluid is moved or compressed on only one stroke (and on one side) of the pressure-imposing element.
Sliding vane pump	A positive displacement rotary pump, which consists of a casing and sliding vanes, held within an eccentric rotor. As the rotor rotates, the vanes capture pockets of liquid and move them from the suction port to the discharge port of the pump.
Slinger	A ring of leather or rubber placed around a pump shaft behind the stuffing box. Slingers protect bearings or attached equipment from water leakage out of the stuffing box.
Sorbent	A material capable of absorbing or adsorbing liquids or gases.
Spur gear pump	See *external gear pump*.
Static discharge head	The distance above the centre line of a pump and the liquid level of an elevated discharge tank, or to the point of free liquid discharge, measured in metres.
Static head	The pressure exerted at the base of a column of liquid, measured in metres.
Static suction head	The distance between the centre line of a pump and the surface of the liquid level in an elevated supply tank.
Static suction lift	The distance between the surface of the liquid level of a supply source located below a pump and the centre line of the pump.
Stuffing box	The part of a pump or valve body that houses compression packing.
Total dynamic head	The sum of the total static head and the dynamic head. It takes into account dynamic suction head, dynamic discharge head, static suction head, static discharge head, and pressure head.
Total static head	The vertical distance between the liquid surface of the supply tank to the liquid surface in a discharge tank, or to the highest liquid level of the free end of the discharge pipe. If pumping into a pressurized vessel, total static head also includes the discharge pressure head. If pumping from a pressurized vessel, total static head also includes the suction pressure head.
Triplex pump	A reciprocating positive displacement pump with three pumping stages connected in series; used to provide small volumes of very high-pressure fluid.

Term	Definition
Turbine pump	See *regenerative pump*.
Velocity head	The equivalent height of fluid equal to its velocity pressure.
Volute casing	The spiral-shaped pump casing. A volute increases in cross-sectional area from the point of impeller discharge to the pump discharge nozzle, to convert fluid velocity to pressure.
Wear rings	Replaceable metallic rings installed on a centrifugal pump impeller, casing, or both, to prevent impeller and casing wear.

Additional Workspace

Additional Workspace

Additional Workspace

Additional Workspace