LECTURE NOTES

HYDRAULIC MACHINES & INDUSTRIAL FLUID POWER

5TH SEMESTER

DIPLOMA IN MECHANICAL ENGINEERING

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HYDRAULIC MACHINES

Hydraulic machines are defined as those machines which convert either hydraulic energy (energy possessed by water) into mechanical energy (which is further converted to electrical energy) or mechanical energy into hydraulic energy.

Types of hydraulic machines:

- Turbines
- Pumps

TURBINES: The hydraulic machines which convert hydraulic energy into mechanical energy.

PUMPS: The hydraulic machines which convert mechanical energy into hydraulic energy.

Turbines are rotary machines that convert kinetic energy and potential energy of water into mechanical work. A turbine consists of a circular wheel called rotor/runner to which series of blades are attached.

When water at very high velocity strike on the blades, a force is acts on the blades, the rotor rotates, thus energy is transferred from water flow to turbine.

HYDROELECTRIC POWER PLANT

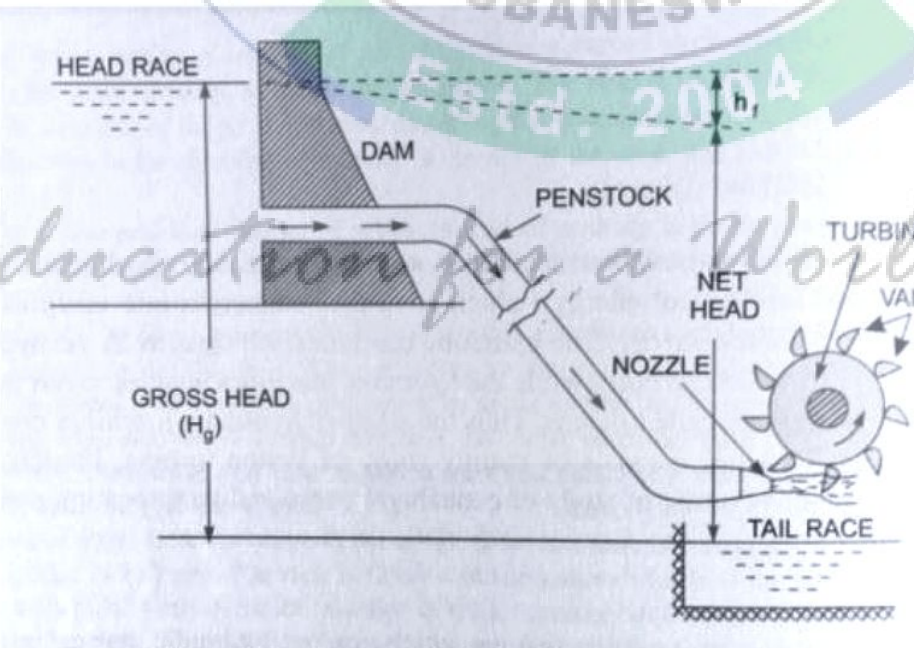


Fig. 18.1 *Layout of a hydroelectric power plant.*

1

COMPONENTS:

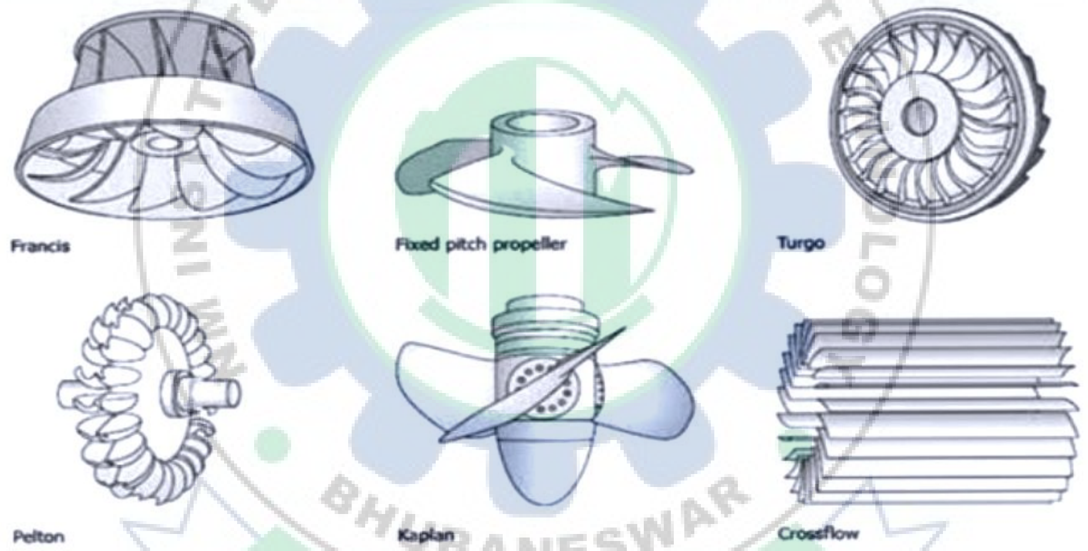
- GROSS HEAD: the difference between head race level and tail race level when no water is flowing. (H_g).
- NET HEAD (H): it is the effective head available at inlet of the turbine.

$$H = H_g - h_f$$

h_f = head loss due to friction between penstocks and water.

- PENSTOCK: large diameter pipes which carry water from dam to turbine.
- HEAD RACE: The surface of water at dam.
- TAIL RACE: these are pipes which carry water from turbine after passing through it.

CLASSIFICATION OF HYDRAULIC TURBINES:



The hydraulic turbines are classified according to:

1. According to type energy available at inlet.
   - Impulse turbine
   - Reaction turbine
2. According to direction of flow through the runner/vanes.
   - Tangential flow turbine
   - Radial flow turbine
   - Axial flow turbine
   - mixed flow turbine
3. According to head at the inlet of turbine.
   - High head turbine
   - Medium head turbine
   - low head turbine
4. According to specific speed of turbine.
   - Low specific speed turbine

2

- Medium specific speed turbine
- High specific speed turbine

❖ According to type energy available at inlet.

IMPULSE TURBINE: at the inlet of the turbine the energy available is only kinetic energy .ex pelton wheel.

REACTION TURBINE: at the inlet of turbine, the water possesses some part of kinetic energy and some part of pressure energy. as water flows through runner, water is under pressure. The pressure energy goes on changing into kinetic energy. Thus inlet pressure is higher than outlet. Ex francis , Kaplan turbine.

❖ According to head at the inlet of turbine.

TANGENTIAL FLOW TURBINE: the water flows along the tangent of the runner (tangent to the path of rotation of runner).pelton
RADIAL FLOW TURBINE: water flows through the runner along radial direction & remains wholly normal to the axis of rotation.
AXIAL FLOW TURBINE: water flows through the runner along a direction parallel to the axis of rotation of runner .kaplan.
MIXED FLOW TURBINE: water flows through the runner in radial direction but leaves in the direction parallel to axis of rotation of runner. Modern Francis turbine.

❖ According to head at the inlet of turbine.

- **HIGH HEAD TURBINE**: the turbines are capable of working under high heads between 250 m to 1770 m. It requires less quantity of water. Pelton wheel
- **MEDIUM HEAD TURBINE**: the turbines are capable of working under heads between 60 m to 250 m. it requires relatively large quantity of water. ex francis
- **LOW HEAD TURBINE**: the turbines are capable of working under low heads less than 60m.it requires large quantity of water .kaplan, propeller.

❖ According to specific speed of turbine.

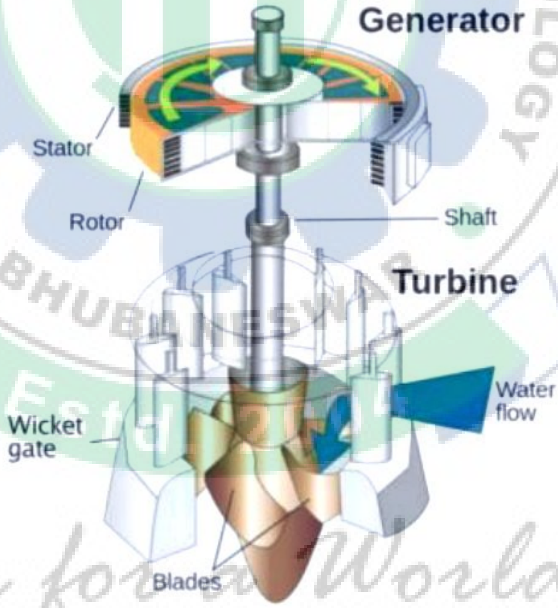
Specific speed: the speed at which a turbine can produce 1Kw power under unit head.

$$N_S = \frac{N\sqrt{P}}{H^{5/4}} \qquad H = \text{head available}$$

- Low specific speed turbine :the speed varies from 8.5 to30 or 10-35.ex pelton wheel with single jet
- Medium specific speed turbine: :the speed varies from 50 to340 or 60- 400. Ex francis
- High specific speed turbine: :the speed varies from 255 to866 or 300-1000.kaplan

IMPULSE TURBINE:

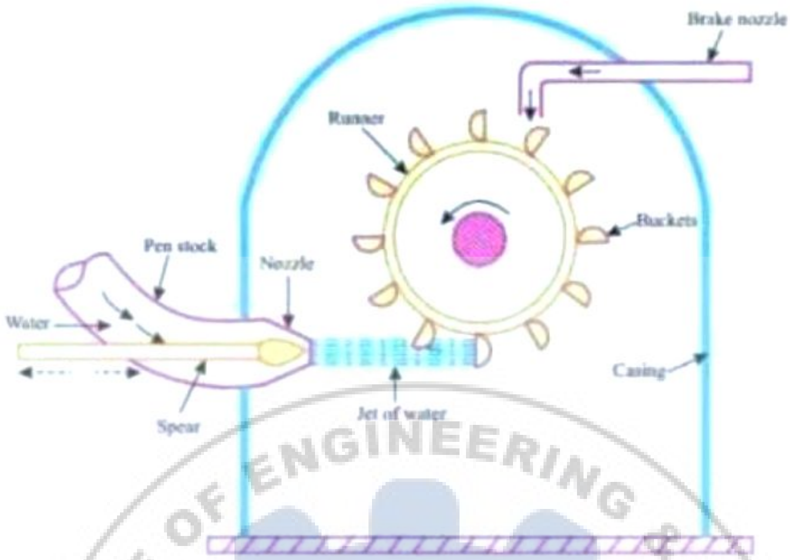
It is run by impulse of water. The entire available energy of the water is converted to kinetic energy, by passing it through the nozzles. The jet of water impinges on the buckets with high velocity and after flowing over the vanes leaves with low velocity, imparting energy to runner.The pressure of water at both inlet and outlet is atmospheric.



PELTON WHEEL TURBINE:

It is a tangential flow impulse turbine where water flows tangentially to runner (water strikes the bucket along the tangent of the runner).Water possesses only KE at the inlet of turbine. Pressure at the inlet and outlet of the turbine is atmospheric.

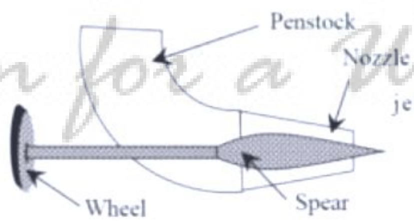
It is a high head turbine and requires less quantity of water .it is a low specific turbine.



COMPONENTS OF PELTON WHEEL TURBINE

- Nozzle
- Runner and buckets
- Casing
- Breaking jet

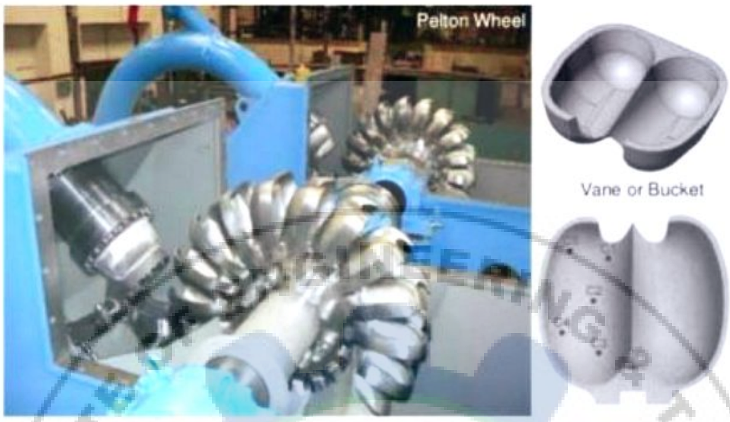
NOZZLE WITH SPEAR: The amount of water striking the vanes of the runner is controlled by a spear in the nozzle. Spear is a conical needle operated in horizontal direction either by hand wheel or automatically. When the spear is pushed forward into nozzle the amount of water striking the runner is decreased and when it is moved back wards the amount of water striking the runner increases.



Spear

RUNNER WITH BUCKETS (VANES): A runner is a circular disc on the periphery of which a number of buckets are evenly spaced and fixed. The buckets are of double hemispherical bowl type. Each bucket is divided into two symmetrical parts by a wall called **splitter.**

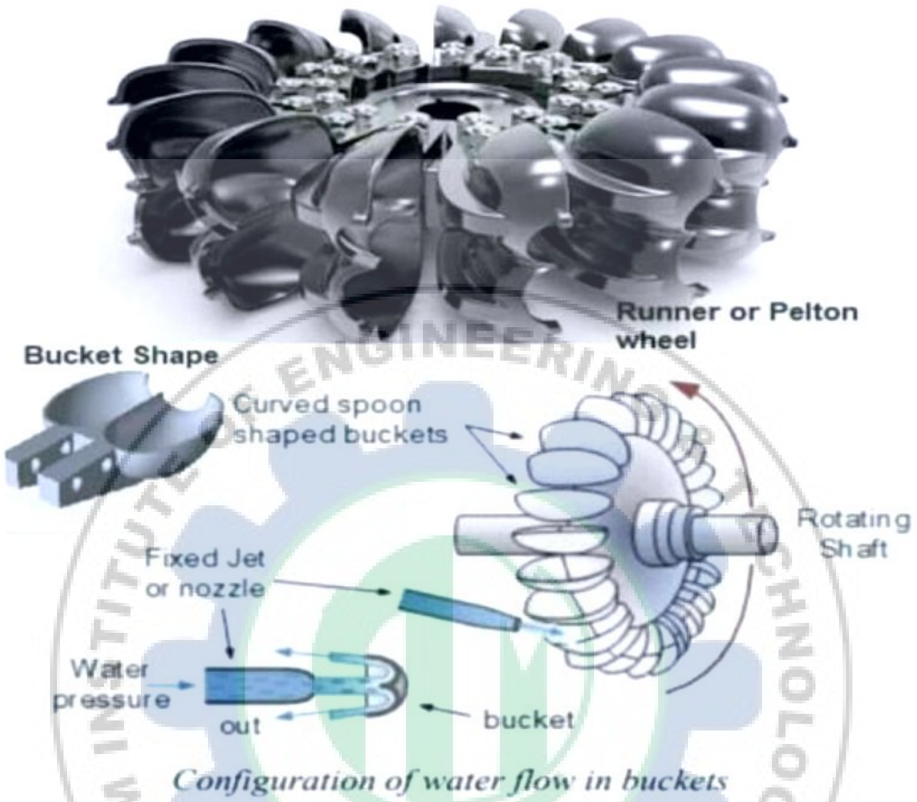
The water strikes on the splitter, which divides the jet into two equal parts and the jet comes out at the outer edge of the bucket. The shape of bucket is such that jet is deflected through (α) 160° or 170°.depending upon head and inlet buckets are made of cast iron, steel, bronze or stainless steel.



CASING: It is made of cast iron or fabricated steel plates .it prevents splashing of water and discharges water into tail race. It also acts as safeguard against accidents. It doesn't perform any hydraulic function**.**

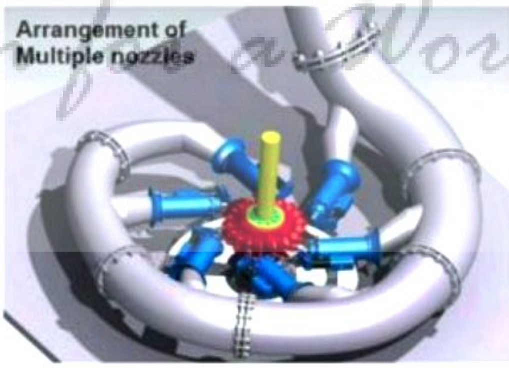
BREAKING JET: in order to stop the the runner in a short time interval, a small nozzle is provided which directs the jet of water on the back of the vanes.

As when nozzle is completely closed by spear, the amount of water striking the runner reduces to zero. But due to inertia runner goes on revolving for a long time. Breaking jet stops this rotation.



Pelton wheel runner, blade shape design

ARRANGEMENT OF JETS: In most pelton wheel plants ,a single jet with horizontal shaft is used. The number of jets used depends on specific speed required.



multiple nozzle arrangement for Pelton wheel turbine

GOVERNING MECHANISM: The speed of turbine runner is required to be maintained constant so that electric generator can be directly coupled to the turbine .thus governor measures and regulate the speed of turbine runner.

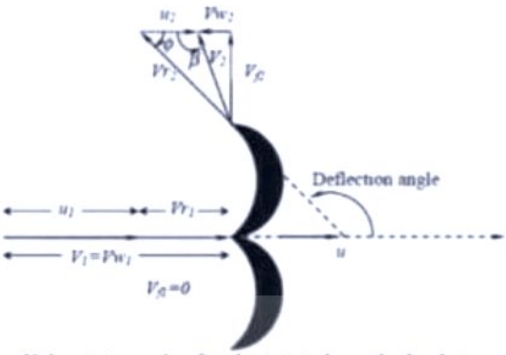
WORKING OF PELTON WHEEL TURBINE:

- The water stored at high head is made to flow through the penstock and reaches the nozzle of pelton wheel.
- The nozzle increases the KE of the water and directs the water in form of jet .this water from the nozzle strikes the bucket at its splitter.
- The splitter then splits the jet into two parts. One part glides over the inner surface of one portion of vane and leaves at its extreme edge, other part glides over other part of vane on other side of splitter.
- The water quantity is controlled by spear in the nozzle. When water jet strikes the bucket at high velocity, the vanes rotates due to the force and as vanes are attached to runner, the runner rotates thus turbine shaft rotates. As armature of generator is attached to turbine shaft it rotates resulting in electricity generation.

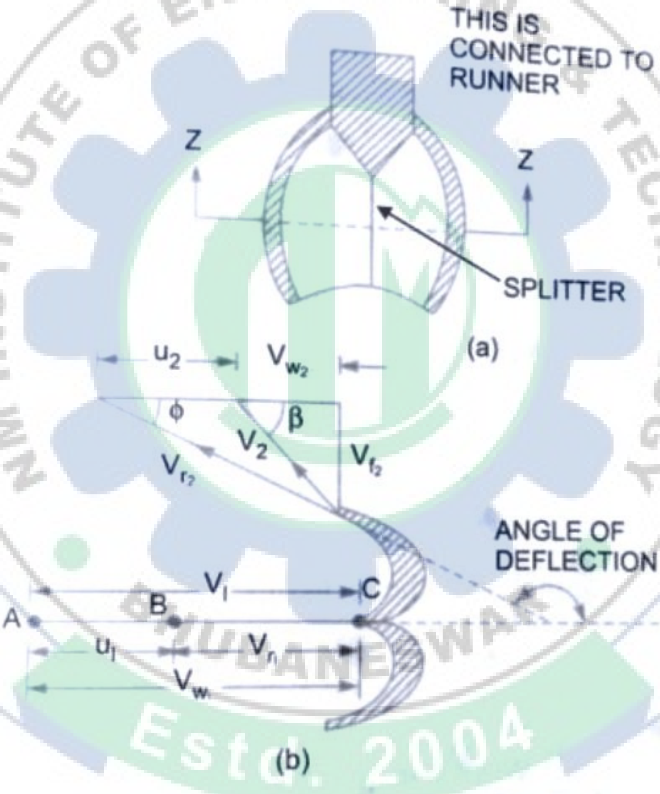
VELOCITY TRIANGLES AND WORK DONE FOR PELTON WHEEL

The jet of water from the nozzle strikes the bucket at splitter, which splits the jet into two parts. These parts glide over the inner surfaces and come out at the outer edge.

The inlet velocity triangle diagram is drawn at splitter (inlet tip) and the outlet velocity triangle diagram is drawn at outer edge of bucket (outlet tip). As vane is moving in different direction to jet, the relative velocity at inlet will be equal to the vector difference of jet velocity vane velocity at inlet.



Velocity triangles for the jet striking the bucket



V_1 = velocity of the water jet at inlet

u_1= velocity of the vane at inlet

V_{r1}= relative velocity of jet with respect to vane at inlet

α = angle between velocity of jet $V_1$and direction of motion of the plate u_1 (guide blade angle

θ=angle between relative velocity with direction of motion of vane at inlet (vane angle at inlet

V_{w1} = whirl velocity at inlet (horizontal component of V_1. It is parallel to the direction of motion of vane

V_{f1} = flow velocity at inlet (vertical component of V_1. It is perpendicular to direction of motion of vane.

Outlet velocity triangle

V_2 = velocity of the water jet at outlet

u_2= velocity of the vane at outlet

V_{r2}= relative velocity of jet with respect to vane at outlet

β = angle between velocity of jet V_2 and direction of motion of the plate at outlet (guide blade angle

ϕ=angle between relative velocity V_{r2} with direction of motion of vane at outlet (vane angle at outlet

V_{w2} = whirl velocity at outlet (horizontal component of V_1. It is parallel to the direction of motion of vane

V_{f2} = flow velocity at outlet (vertical component of V_1. It is perpendicular to direction of motion of vane.

The vane is smooth with velocity in direction of motion at inlet and outlet equal

$u_1 = u_2$ = u = velocity of vane in the direction of motion.

$$U = \frac{\pi DN}{60}$$

The velocity triangle at inlet will be a straight line

$$V_{r1} = V_1 - u_1 = V_1 - u$$

$$V_{w1} = V_1$$

$$\alpha = 0 \; and \; \theta = 0$$

From velocity triangle at outlet,

$$V_{r2} = V_{r1}$$

$$V_{w2} = V_{r2} \cos\phi - u_2$$

Force exerted by jet of water in direction of motion

$$F_x = \rho a V_1 [V_{w1} + V_{w2}]$$

As β is acute angle, +ve sign. If β is obtuse angle, -ve sign

As series of vanes, mass of water striking is $\rho a V_1$ not $\rho a V_{r1}$

$$\text{Area of jet (a)} = \frac{\pi}{4} d^2$$

Work done by jet on runner/second.

$$= F_x \times u$$

$$= \rho a V_1 [V_{w1} + V_{w2}] \times u$$

$$\text{Power given to the runner by jet.} = \frac{\text{Work done by jet on runner/second}}{1000} \text{ Kw}$$

$$= \frac{\rho a V_1 [V_{w1} + V_{w2}] \times u}{1000} \text{ Kw}$$

Work done/second/unit weight of water striking/second

$$= \frac{\rho a V_1 [V_{w1} + V_{w2}] \times u}{weight\ of\ water\ striking/second}$$

$$= \frac{\rho a V_1 [V_{w1} + V_{w2}] \times u}{\rho a V_1 \times g}$$

$$= \frac{1}{g} [V_{w1} + V_{w2}] \times u$$

The energy supplied to the jet at inlet is in the form of kinetic energy ($\frac{1}{2} m V^2$)

$$\text{K.E of jet per second} = \frac{1}{2} (\rho a V_1) V_1^{\ 2}$$

HYDRAULIC EFFICIENCY(η_h)

$$\eta_h = \frac{Work\ done\ per\ second}{K.E\ of\ jet\ per\ second}$$

$$= \frac{\rho a V_1 [V_{w1} + V_{w2}] \times u}{\frac{1}{2} (\rho a V_1) V_1^{\ 2}}$$

$$= \frac{2 [V_{w1} + V_{w2}] \times u}{V_1^{\ 2}}$$

$$V_{r1} = V_1 - u_1 = (V_1 - u)$$

$$V_{w1} = V_1$$

$$V_{r2} = (V_1 - u)$$

$$V_{w2} = V_{r2} \cos \phi - u_2$$

$$= V_{r2} \cos\phi - u$$

$$= (V_1 - u) \cos\phi - u$$

Put values of V_{w1} and V_{w2}

$$\eta_h = \frac{2[V_1 + (V_1 - u)\cos\phi - u] \times u}{V_1^2}$$

$$= \frac{2(V_1 - u)[1 + \cos\phi] \times u}{V_1^2}$$

Condition for maximum efficiency.

$$U = \frac{V_1}{2}$$

$$= \frac{(1+\cos\phi)}{2}$$

Points to be remembered for pelton wheel

The velocity of jet at inlet = $V_1 = C_V\sqrt{2gH}$ $\quad C_V = Coefficient\ of\ velovity\ (0.98/0.99)$

The velocity of pelton wheel

$u = \phi\sqrt{2gH}$ $\quad \phi$ = speed ratio (0.43 to 0.48)

Angle of deflection of jet through bucket (165°).

Mean diameter /pitch diameter D of pelton wheel.

$$u = \frac{\pi DN}{60} \text{ or } D = \frac{60u}{\pi N}$$

Jet ratio (m) : ratio of pitch diameter (D) of pelton wheel to diameter of the jet (d)

$$m = \frac{D}{d}$$

Number of buckets on a runner.

$$Z = 15 + \frac{D}{2d} = 15 + 0.5m$$ **(m) = Jet ratio**

Number of jets it is obtained by dividing total rate of flow through the turbine by rate of flow of water through a single let

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EFFICIENCIES OF A TURBINE :

1. HYDRAULIC EFFICIENCY (η_h)

It is defined as ratio of power given by water to the runner of a turbine to the power supplied by the water at the inlet of the turbine.

Power delivered to runner will be less than the power available at the inlet of the turbine because of Hydraulic loss , as vanes are not smooth, power goes on decreasing as water flows over the vanes.

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{power supplied at the inlet}}$$

$$= \frac{RP}{WP}$$

RP = Runner power

$$RP = \frac{w}{g}\frac{[V_{w1} \pm V_{w2}] \times u}{1000} \quad \text{For pelton turbine}$$

$$RP = \frac{w}{g}\frac{[V_{w1}\,u_1 \pm V_{w2}\,u_2]}{1000} \quad \text{For radial flow turbine}$$

WP = Water power $= \frac{W \times H}{1000}$ kW

W = Weight of water striking the vannes of the turbine per second

[$W = \rho g \times Q$] Q = volume of water discharged per second

$$WP = \frac{\rho g Q H}{1000} \quad \text{(for fluid other than water)}$$

As $\rho = 1000\ kg/m^3$ for water

$$\textbf{WP = g×Q×H} \quad \text{(for water as fluid)}$$

2. MECHANICAL EFFICIENCY (η_m)

The ratio of power available at shaft of turbine (SP or BP) to the power delivered to the runner.

Due to mechanical losses, power available at shaft of turbine is less than power delivered by water to runner.

$$\eta_m = \frac{\text{power available at shaft of turbine}}{\text{power delivered by water to runner}}$$

$$= \frac{SP}{RP}$$

3. **VOLUMETRIC EFFICIENCY (η_v)**

The ratio of volume of water actually striking the runner to the volume of water supplied to the turbine.

As some volume of water is discharged to the tail race without striking the runner, thus volume of water striking the runner is less than volume of water supplied to the turbine.

$$\eta_v = \frac{\text{volume of water actually striking the runner}}{\text{volume of water supplied to the turbine.}}$$

4. **OVERALL EFFICIENCY (η_o)** The ratio of power available at shaft of turbine (SP or BP) to the power supplied by the water at the inlet of the turbine(WP).

$$\eta_o = \frac{\text{power available at shaft of turbine}}{\text{power supplied by the water at the inlet of the turbine}}$$

$$= \frac{SP}{WP}$$

$$= \frac{SP}{WP} \times \frac{RP}{RP}$$

$$= \frac{SP}{RP} \times \frac{RP}{WP}$$

$$\eta_o = \eta_m \times \eta_h$$

$$\eta_o = \frac{P}{\left(\frac{\rho g Q H}{1000}\right)} \qquad \text{P= Shaft power}$$

PNEUMATIC CONTROL SYSTEM

Introduction:

Pneumatic systems are the power systems which are using compressed air as a working medium for the power transmission. The air compressor used in the Pneumatic system converts the mechanical energy of the prime mover into pressure energy of the compressed air. After compression, the compressed air obtained from the compressor is prepared and used to perform useful work. The air preparation includes filtration, cooling, water separation, drying, and adding lubricating oil mist. The compressed air is stored in compressed air reservoirs and transmitted through transmission lines: pipes and hoses. The pneumatic power is controlled by means of a set of valves such as the pressure, flow and directional control valves. Then, the pressure energy is converted to the required mechanical energy by means of the pneumatic cylinders and motors.

Advantages of Pneumatic Systems:

- Air is used as a working medium in Pneumatic system which is unlimited in the atmosphere.
- Compressed air can easily be stored and transmitted through pipe lines. It can be easily released into the atmosphere without further processing.
- Pneumatic parts are proven to last longer and require less maintenance.
- Pneumatic system components are relatively simple, which makes them suitable for less complicated automatic control systems.
- Pneumatic systems can work in inflammable environments without the risk of fire or explosion.
- Pneumatic system components are relatively inexpensive. So, it is cost-effective.

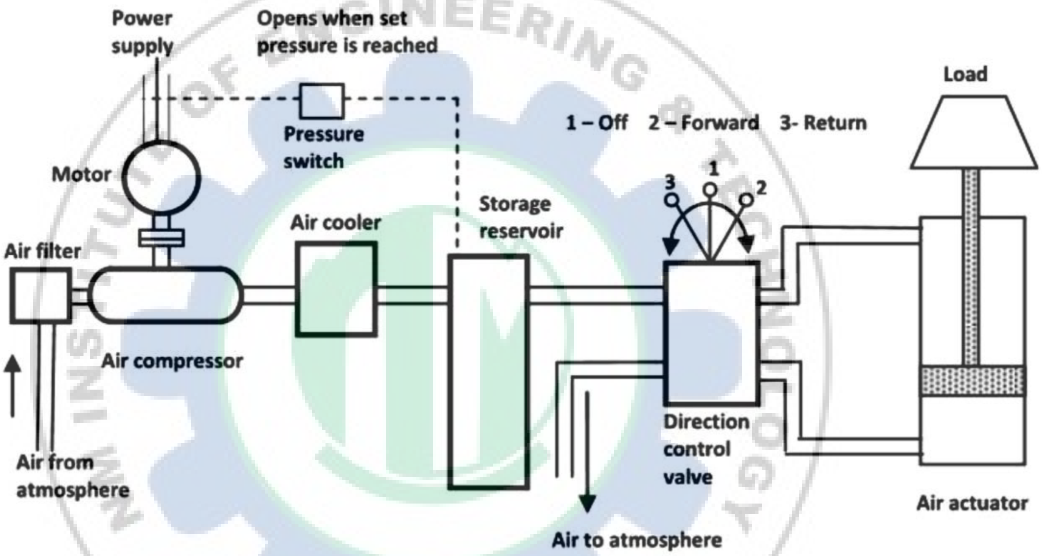
Disadvantages of Pneumatic Systems:

- Air is a compressible gas. So, control and speed in a pneumatic system is more difficult in comparison to electric or hydraulic systems.
- Pneumatic systems are less durable than hydraulic systems.
- Pneumatic systems cannot operate underwater and are sensitive to changing temperatures and vibrations. Devices are known to fail over long periods of time.
- Pneumatic systems are the loudest type of designs that other machines. Actuators that run the system are the source of the noise.

Basic Components of a Pneumatic System:

The functions of various components of a Pneumatic system are as follows:

- Pneumatic actuator: It converts the fluid power into mechanical power to perform useful work.
- Compressor: It is used to compress the fresh air drawn from the atmosphere.
- Storage reservoir: It is used to store a given volume of compressed air.
- Valves: These are used to control the direction, flow rate and pressure of compressed air.
- External power supply (motor): It is used to drive the compressor.
- Piping system: It carries the pressurized air from one location to another.



(Components of a Pneumatic System)

When the air compressor starts, it draws the air from the atmosphere through an air filter and raised required pressure and temperature of air. A cooler is provided to cool the air and moisture from the air is removed. This pressurized air is stored in a storage reservoir. A pressure switch is fitted with the storage reservoir to start and stop the electric motor when pressure falls and reaches the required level respectively. The pressurized air is transferred from the storage tank to one side of the piston and returned back from the other side of the piston to the tank. The direction of flow of air is controlled by the valve, which controls the motion in the actuator. The actuator is used to convert the fluid power into mechanical power to do useful work.

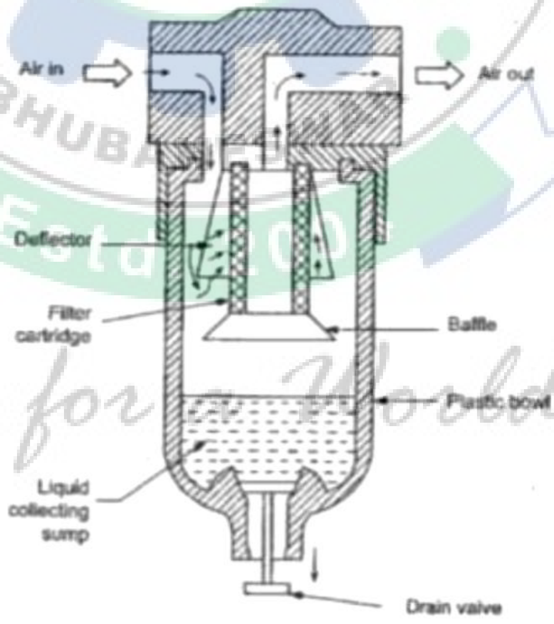
Comparison between a hydraulic and a pneumatic system:

Hydraulic System	Pneumatic System
1. It uses a pressurized liquid as a fluid.	1. It uses compressed air as a fluid
2. Pumps are used to provide pressurized liquids.	2. Compressors are used to provide compressed air.
3. It is generally employed as closed system.	3. It is generally employed as open system.
It operates at pressures up to 700 bar.	4. It operates at pressures at 5-10 bar.
5. This system is heavy in weight.	5. This system is light in weight.
6. Leakage of fluid affects the performance.	6. There is no such effect of leakage.
7. Valve operations are difficult.	7. Valve operations are easy.
8. There may be chance of fire hazards.	8. This is free from fire hazards.
9. No special lubrication is required.	9.Special lubrication is important

AIR FILTER

Function:

- To prevent entrance of solid contaminants to the system.
- To condensate and remove the water vapour that is present in the air.
- To arrest submicron particles that may pose a problem in the system components.



(Air Filter)

The construction and operation of a typical cartridge-type filter system is illustrated in Figure. It consists of the filter cartridge, deflector, plastic bowl, baffle, water drain valve.

Working:

The air to be filtered is allowed downward with a swirling motion that forces the moisture and the heavier particles to fall down. The deflector used in the filter mechanically separates the contaminants before they pass through the cartridge filter. The filter cartridge provides a random zig-zag passage for the airflow. This type of airflow arrests the solid particles in the cartridge passage. The water vapor gets condensed inside the filter and is collected at the bottom of the filter bowl. Also, heavier foreign particles that are separated from the air are collected at the bottom of the bowl. Then the accumulated water and other solid particles at the bottom of the filter bowl are drained off with the use of an on-off drain valve located at the bottom of the filter bowl.

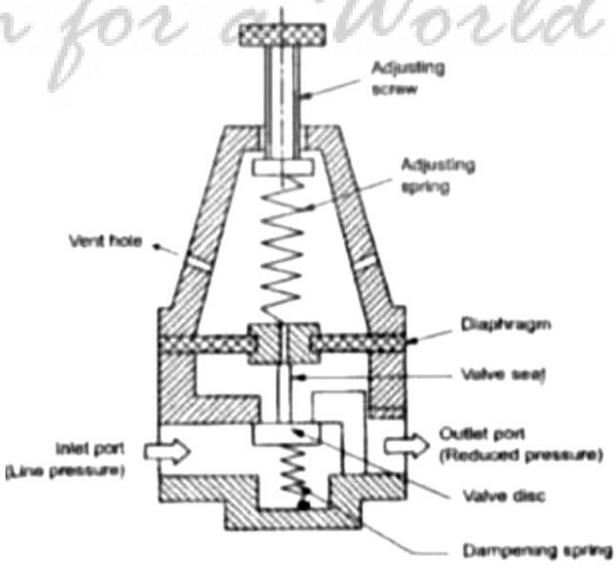
AIR REGULATOR

Function:

The function of the air pressure regulator is to maintain working pressure virtually constant regardless of fluctuations of the line pressure and air consumption. When the pressure is too low, it results in poor efficiencies and when the pressure is too high, energy is wasted and equipment's performance decay faster. In pneumatic system, pressure fluctuations occur due to variation in supply pressure or load pressure. It is therefore essential to regulate the pressure to match the requirement of load regardless of variation in supply pressure or load pressure.

Generally, pressure is regulated in pneumatic system at two places.

> At the receiver tank and in the load circuits Pressure regulation at the receiver tank is required as a safety measure for the system. In the load circuits, pressure regulator is used to regulate the pressure for downstream components such as valves and actuators.



(Air Regulator)

There are two types of Pressure regulators:

1) Diaphragm type regulator.
2) Piston type regulator.

AIR LUBRICATOR

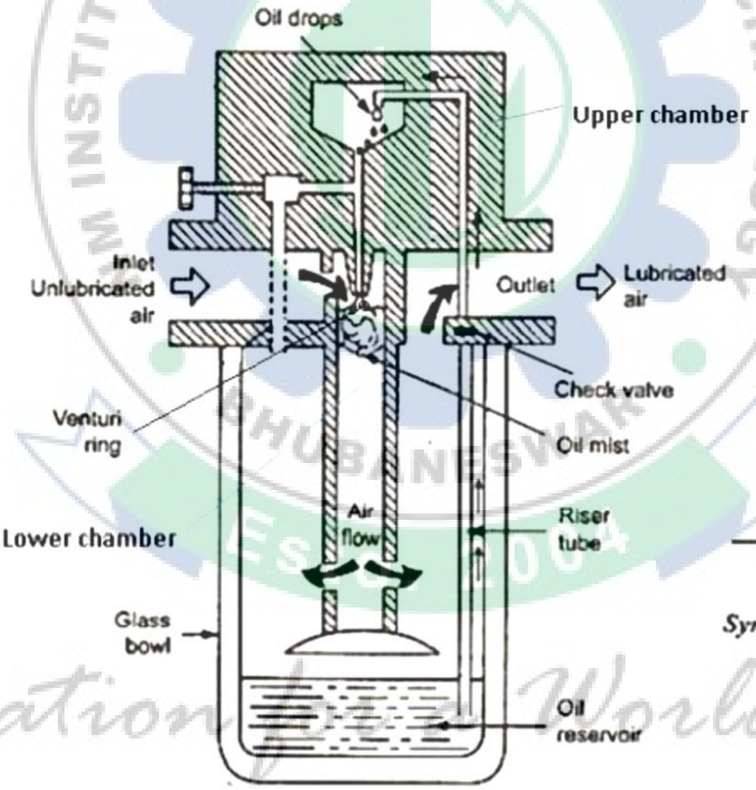
Function:

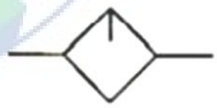
The function of air lubricator is to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.

Lubricants are used to

- To reduce the wear of the moving parts
- Reduce the frictional losses
- Protect the equipment form corrosion

The lubricator adds the lubricating oil in the form of fine mist to reduce the friction and wear of moving parts of pneumatic components such as valves, packing used in air actuators.





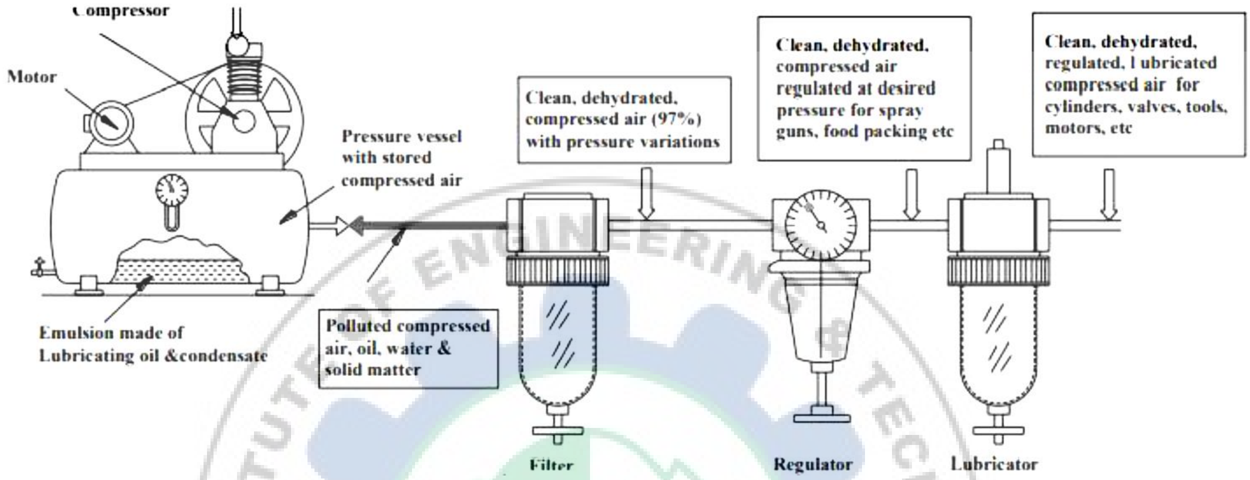
Symbol for lubricator

(Air Lubricator)

The air lubricator is shown in figure. As air enters the lubricator its velocity is increased by a venture ring. The pressure at the venture ring will be lower than the atmospheric pressure and the pressure on the oil is atmospheric. Due to this pressure difference between the upper chamber and lower chamber,oil will be drawn up in a riser tube. Oil droplets mix with the incoming air and form a fine mist. The needle valve is used adjust the pressure differential between across the oil jet and hence the oil flow rate. The air – oil mixture is forced to swirl as it leaves the central cylinder so that large particles of oil is goes back to bowl and only the mist goes to outlet.

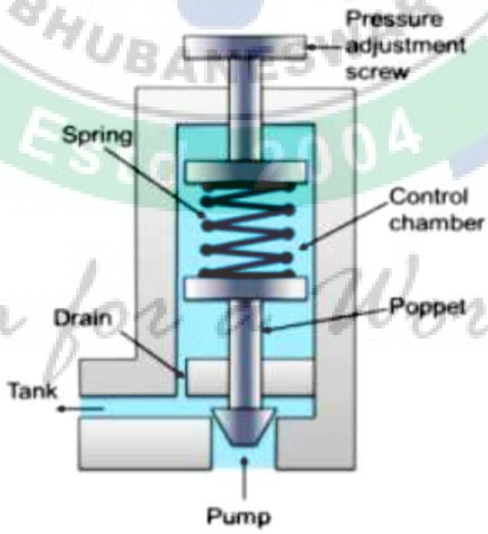
Filter-Regulator-Lubricator Unit:

Filter, Pressure Regulator, and Lubricator are combined in a unit. These three units together are called FRL units or Service units. Compressed air from compressor comes in FRL unit wherein, the air is filtered, controlled, and lubricated. Such prepared and controlled air is delivered to the pneumatic system.



In most pneumatic systems, the compressed air is first filtered and then regulated to the specific pressure and made to pass through a lubricator for lubricating the oil. Thus, usually a filter, regulator and lubricator are placed in the inlet line to each air circuit. They may be installed as separate units, but more often they are used in the form of a combined unit.

Pressure Relief valve:



The pressure relief valves are used to protect the system components from excessive pressure. Its primary function is to limit the system pressure within a specified range. It is normally a closed type and it opens when the pressure exceeds a specified maximum value by diverting pump flow back to the tank. The simplest type valve contains a poppet held in a seat against the spring force as shown in Figure.

This type of valves has two ports; one of which is connected to the pump and another is connected to the tank. The fluid enters from the opposite side of the poppet. When the system pressure exceeds the preset value, the poppet lifts and the fluid is escaped through the orifice to the storage tank directly. It reduces the system pressure and as the pressure reduces to the set limit again the valve closes.

HYDRAULIC CONTROL SYSTEM

Hydraulic System:

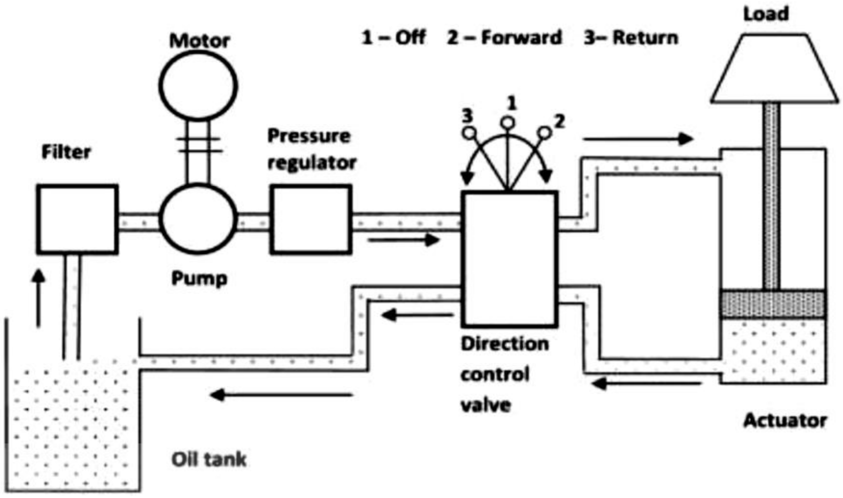
The hydraulic systems are used to employ pressurized liquid for transmitting energy and perform useful work. A hydraulic fluid is the transmitting medium of a hydraulic system. It performs the following functions.

- ❖ Power transmission
- ❖ Cooling and Lubrication
- ❖ Sealing
- ❖ Removal of impurities

Basic Components of a Hydraulic System:

The functions of various components of a Hydraulic system are as follows:

- ❖ Hydraulic actuator: It converts the fluid power into mechanical power to perform useful work. It may be of linear or rotary type.
- ❖ Pump: It is used to produce pressurized liquid. It forces the liquid into the different components of hydraulic circuit.
- ❖ Reservoir: It is used to store the hydraulic liquid.
- ❖ Valves: These are used to control the direction, flow rate and pressure of liquid.
- ❖ External power supply (motor) It is used to drive the pump.
- ❖ Piping system: It carries the liquid from one location to another.
- ❖ Filter: Filters are used to remove contaminants.
- ❖ Pressure regulator: It regulates the required level of pressure in the hydraulic fluid.



(Components of a Hydraulic System)

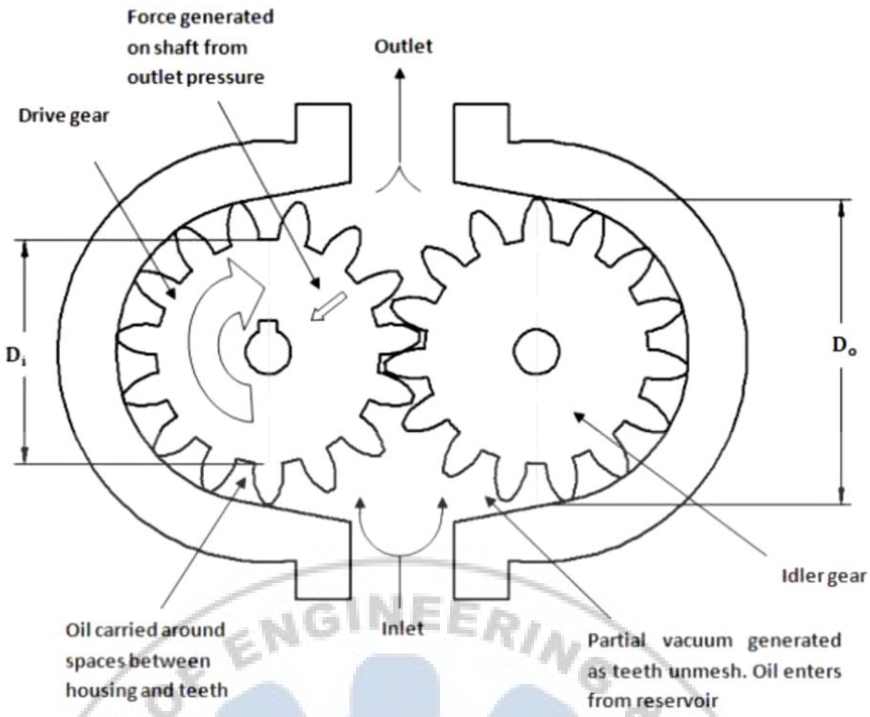
When the pump starts, it draws the oil from the oil tank through an oil filter and raised required pressure and temperature of oil. The oil pressure is regulated by the pressure regulator. The direction of flow of oil is controlled by the valve, which controls the motion in the actuator. The actuator is used to convert the fluid power into mechanical power to do useful work.

Gear Pumps

Gear pumps are less expensive but limited to pressures below 140 bar. It is noisy in operation than either vane or piston pumps. Gear pumps are invariably of fixed displacement type, which means that the amount of fluid displaced for each revolution of the drive shaft is theoretically constant. There are two types of gear pumps.

External Gear Pumps:

External gear pumps are the most popular hydraulic pumps in low-pressure ranges due to their long operating life, high efficiency and low cost. They are generally used in a simple machine. The most common form of external gear pump is shown in Figure. It consists of a pump housing in which a pair of precisely machined meshing gears runs with minimal radial and axial clearance. One of the gears, called a driver is driven by a prime mover. The driver drives another gear called a follower. As the teeth of the two gears separate, the fluid from the pump inlet gets trapped between the rotating gear cavities and pump housing. The trapped fluid is then carried around the periphery of the pump casing and delivered to outlet port. The teeth of precisely meshed gears provide almost a perfect seal between the pump inlet and the pump outlet. When the outlet flow is resisted, pressure in the pump outlet chamber builds up rapidly and forces the gear diagonally outward against the pump inlet. When the system pressure increases, imbalance occurs. This imbalance increases mechanical friction and the bearing load of the two gears. Hence, the gear pumps are operated to the maximum pressure rating stated by the manufacturer.



(Working of External Gear pump)

The advantages of external gear pump are as follows:

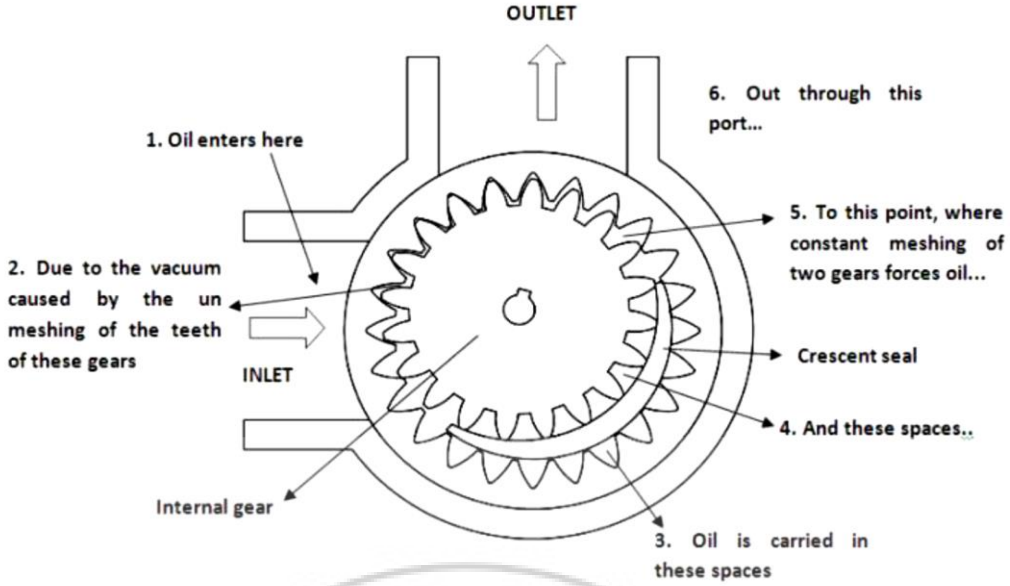
1. They are self-priming.
2. They give constant delivery for a given speed.
3. They are compact and light in weight.
4. Volumetric efficiency is high.

The disadvantages of external gear pump are as follows:

1. The liquid to be pumped must be clean, otherwise it will damage pump.
2. Variable speed drives are required to change the delivery.
3. If they run dry, parts can be damaged because the fluid to be pumped is used as lubricant.

Internal Gear Pumps

Another form of gear pump is the internal gear pump, which is illustrated in the figure. They consist of two gears: An external gear and an internal gear. The crescent placed in between these acts as a seal between the suction and discharge. When a pump operates, the external gear drives the internal gear and both gears rotate in the same direction. The fluid fills the cavities formed by the rotating teeth and the stationary crescent. Both the gears transport the fluid through the pump. The crescent seals the low-pressure pump inlet from the high-pressure pump outlet. The fluid volume is directly proportional to the degree of separation and these units may be reversed without difficulty. The major use for this type of pump occurs when a through shaft is necessary, as in an automatic transmission. These pumps have a higher-pressure capability than external gear pumps.



(Working of Internal Gear pump)

Vane Pumps

There are two types of vane pumps:

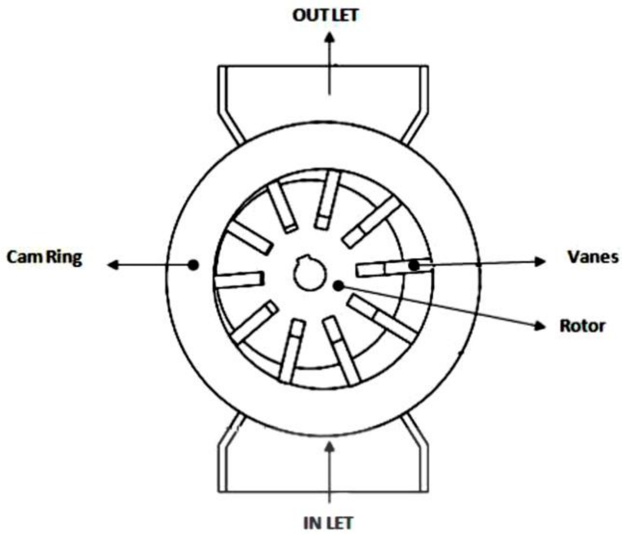
1. Unbalanced vane pump
2. Balanced vane pump

Unbalanced vane pumps are of two varieties:

a) Unbalanced vane pump with fixed delivery.
b) Unbalanced vane pump with pressure-compensated variable delivery.

Unbalanced Vane Pump with Fixed Delivery:

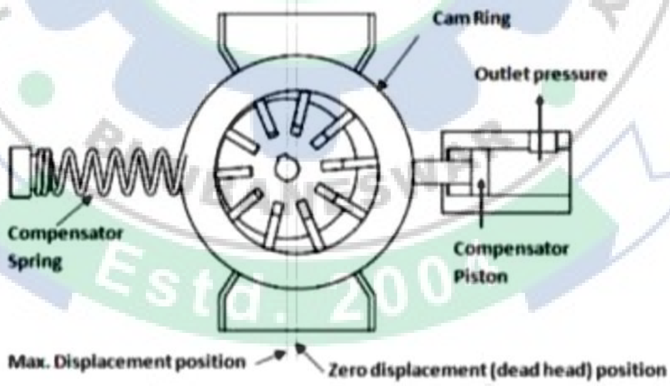
A simplified form of unbalanced vane pump with fixed delivery and its operation are shown in Figure. The main components of the pump are the cam surface and the rotor. The rotor contains radial slots splined to drive shaft. The rotor rotates inside the cam ring. Each radial slot contains a vane, which is free to slide in or out of the slots due to centrifugal force. The vane is designed to mate with surface of the cam ring as the rotor turns. The cam ring axis is offset to the drive shaft axis. When the rotor rotates, the centrifugal force pushes the vanes out against the surface of the cam ring. The vanes divide the space between the rotor and the cam ring into a series of small chambers. During the first half of the rotor rotation, the volume of these chambers increases, thereby causing a reduction of pressure. This is the suction process, which causes the fluid to flow through the inlet port. During the second half of rotor rotation, the cam ring pushes the vanes back into the slots and the trapped volume is reduced. This positively ejects the trapped fluid through the outlet port. In this pump, all pump action takes place in the chambers located on one side of the rotor and shaft, and so the pump is of an unbalanced design. The delivery rate of the pump depends on the eccentricity of the rotor with respect to the cam ring.



(Simple Vane pump)

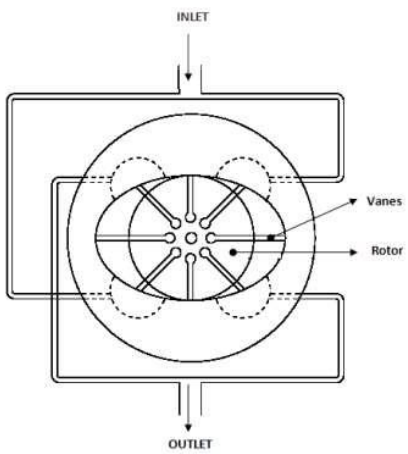
Unbalanced Vane Pump with Pressure-Compensated Variable Delivery:

Schematic diagram of variable displacement vane pump is shown in Figure. The Variable displacement feature can be brought into vane pumps by varying eccentricity between the rotor and the cam ring. Here in this pump, the stator ring is held against a spring-loaded piston. The system pressure acts directly through a hydraulic piston on the right side. This forces the cam ring against a spring-loaded piston on the left side. If the discharge pressure is large enough, it overcomes the Compensated spring force and shifts the cam ring to the left. This reduces the eccentricity and decreases the flow. If the pressure continues to increase, there is no eccentricity and pump flow becomes zero.



(Working of Variable displacement Vane pump)

Balanced Vane Pump with Fixed Delivery:



(Working of Balanced Vane pump)

A balanced vane pump is a very versatile design that has found widespread use in both industrial and mobile applications. The basic design principle is shown in Figure. The rotor and vanes are contained within a double eccentric cam ring and there are two inlet segments and two outlet segments during each revolution. This double pumping action not only gives a compact design, but also leads to another important advantage: although pressure forces acting on the rotor in the outlet area are high, The forces at the two outlet areas are equal and opposite, completely cancelling each other. As a result, there are no net loads on shaft bearings. Consequently, the life of this type of pump in many applications has been exceptionally good. Operating times of 24000 h or more in industrial applications are widespread. In more severe conditions encountered in mobile vehicles, 5000–10000h of trouble-free operation is frequently achieved.

The advantages of vane pumps are as follows:

1. Vane pumps are self-priming, robust and supply constant delivery at a given speed.
2. They provide uniform discharge with negligible pulsations.
3. Their vanes are self-compensating for wear and vanes can be replaced easily.
4. These pumps do not require check valves.
5. They are light in weight and compact.
6. They can handle liquids containing vapors and gases.
7. Volumetric and overall efficiencies are high.
8. Discharge is less sensitive to changes in viscosity and pressure variations.

The disadvantages of vane pumps are as follows:

1. Relief valves are required to protect the pump in case of sudden closure of delivery.
2. They are not suitable for abrasive liquids.
3. They require good seals.
4. They require good filtration systems and foreign particle can severely damage pump.

Piston Pumps:

Piston pumps are of the following two types:

1. Axial piston pump
2. Radial piston pump

Axial Piston pumps are of two designs:

a) Bent-axis-type piston pump

b) Swash-plate-type piston pump

HYDRAULIC ACTUATORS:

Hydraulic systems are used to control and transmit power. A pump driven by a prime mover such as an electric motor creates a flow of fluid, in which the pressure, direction and rate of flow are controlled by valves. An actuator is used to convert the energy of fluid back into the mechanical power. The amount of output power developed depends upon the flow rate, the pressure drop across the actuator and its overall efficiency. Thus, hydraulic actuators are devices used to convert pressure energy of the fluid into mechanical energy.

Depending on the type of actuation, hydraulic actuators are classified as follows:

1. Linear actuator: For linear actuation (hydraulic cylinders).
2. Rotary actuator: For rotary actuation (hydraulic motor).
3. Semi-rotary actuator: For limited angle of actuation (semi-rotary actuator).

CONTROL VALVES:

In fluid power, controlling elements are called valves.

There are three types of valves:

1. **Directional control valves (DCVs):** They determine the path through which a fluid transverses a given circuit.
2. **Pressure control valves:** They protect the system against overpressure, which may occur due to a sudden surge as valves open or close or due to an increase in fluid demand.
3. **Flow control valves:** Shock absorbers are hydraulic devices designed to smooth out pressure surges and to dampen hydraulic shock.

Directional Control Valves:

A valve is a device that receives an external signal (mechanical, fluid pilot signal, electrical or electronics) to release, stop or redirect the fluid that flows through it. The function of a DCV is to control the direction of fluid flow in any hydraulic system. A DCV does this by changing the position of internal movable parts.

A DCV is mainly required for the following purposes:

- To start, stop, accelerate, decelerate and change the direction of motion of a hydraulic actuator.
- To permit the free flow from the pump to the reservoir at low pressure when the pump's delivery is not needed into the system.
- To vent the relief valve by either electrical or mechanical control.
- To isolate certain branch of a circuit.

Classification of DCVs:

Based on fluid path, DCVs can be classified as follows:

- Check valves.
- Shuttle valves.
- Two-way valves.
- Three-way valves.
- Four-way valves

Based on design characteristics, DCVs can be classified as follows:

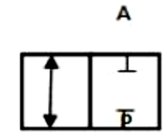
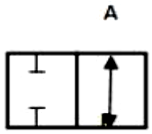
- An internal valve mechanism that directs the flow of fluid. Such a mechanism can either be a poppet, a ball, a sliding spool, a rotary plug or a rotary disk.
- Number of switching positions (usually 2 or 3).
- Number of connecting ports or ways.
- Method of valve actuation that causes the valve mechanism to move into an alternate position.

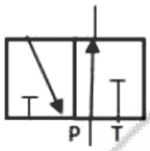
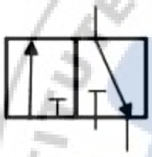
Based on the control method, DCVs can be classified as follows:

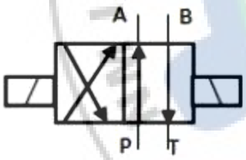
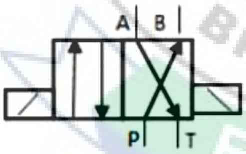
- **Direct controlled DCV**: A valve is actuated directly on the valve spool. This is suitable for small sized valves.
- **Indirect controlled DCV**: A valve is actuated by a pilot line or using a solenoid or by the combination of electrohydraulic and electro-pneumatic means. The use of solenoid reduces the size of the valve. This is suitable for large-sized valves.

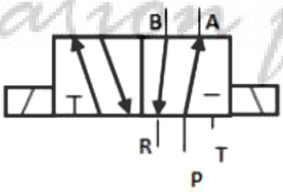
Based on the construction of internal moving parts, DCVs can be classified as follows:

- **Rotary spool type**: In this type, the spool is rotated to change the direction of fluid. It has longitudinal grooves. The rotary spools are usually manually operated.
- **Sliding spool type**: This consists of a specially shaped spool and a means of positioning the spool. The spool is fitted with precision into the body bore through the longitudinal axis of the valve body. The lands of the spool divide this bore into a series of separate chambers. The ports of the valve body lead into these chambers and the position of the spool determines the nature of inter-connection between the ports.

2/2-way valve: 2-ports and 2-position DCV	
	Normally closed position: P is not connected to A. When the valve is not actuated, the way is closed.
	Normally open position: P is connected to A. When the valve is not actuated, the way is open.

3/2 way valve : 3ports and 2 position DCV	
	Normally open position: P is connected to A. When the valve is not actuated, the way is open.
	Normally open position: P is connected to A. When the valve is actuated, the way is closed

4/2-way valve – 4-port and 2-position DCV	
	P is connected to A B is connected to T
	Position 2: P is connected to B A is connected to T

5/2-way valve – 5-port and 2-position DCV	
	Normal position: P is connected to B A is connected to R

3/2-Way DCV (Normally Closed):

Three-way valves either block or allow flow from an inlet to an outlet. They also allow the outlet to flow back to the tank when the pump is blocked, while a two-way valve does not. A three-way valve has three ports, namely, a pressure inlet (P), an outlet to the system (A)and a return to the tank(T). Figure 1.10 shows the operation of a 3/2-way valve normally closed. In its normal position, the valve is held in position by a spring as shown in Fig. 1.10(a).

In the normal position, the pressure port P is blocked and outlet A is connected to the tank. In the actuated position shown in Fig. 1.10(b), the pressure port is connected to the tank and the tank port is blocked.

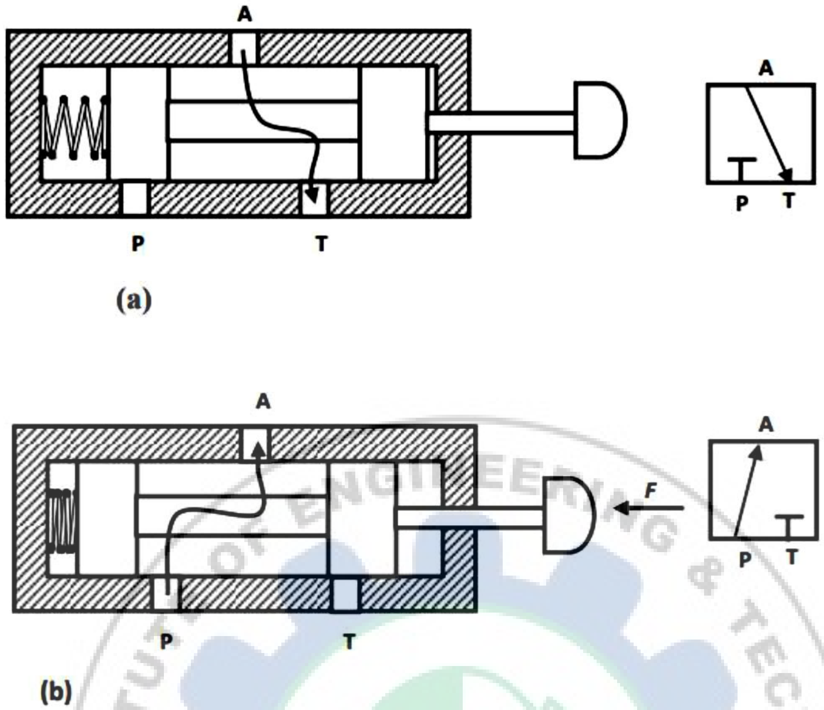
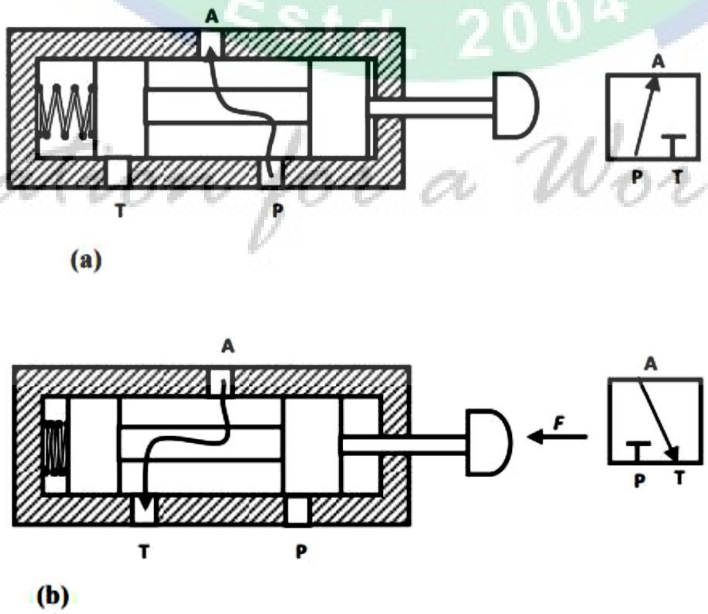


Figure 1.10 3/2-way DCV (normally closed). (a) Ports A and T are connected when force is not applied (valve unactuated). (b) Ports A and P are connected when force is applied (valve actuated).

3/2-Way DCV (Normally Opened):

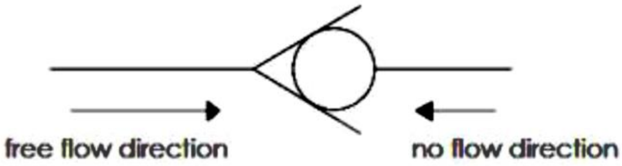
Figure 1.11 shows a three-way two-position DCV (normally open) with push button actuation and spring return. In the normal position, shown in Fig. 1.11(a), the valve sends pressure to the outlet and blocks the tank port in the normal position. In the actuated position, the pressure port is blocked and the outlet is vented to the tank.



(a) **Figure 1.11** 3/2-way DCV (normally opened). (a) Ports A and P are connected when force is not applied (valve unactuated). (b) Ports A and T are connected when force is applied (valve actuated).

Check Valve

The simplest DCV is a check valve. A check valve allows flow in one direction, but blocks the flow in the opposite direction. It is a two-way valve because it contains two ports. The following figure shows the graphical symbol of a check valve along with its no-flow and free-flow directions.



Pressure-control valves:

Pressure-control valves are used in hydraulic systems to control actuator force (force = pressure ×area) and to determine and select pressure levels at which certain machine operations must occur.

Pressure controls are mainly used to perform the following system functions:

- Limiting maximum system pressure at a safe level.
- Regulating/reducing pressure in certain portions of the circuit.
- Unloading system pressure.
- Assisting sequential operation of actuators in a circuit with pressure control.
- Any other pressure-related function by virtue of pressure control.
- Reducing or stepping down pressure levels from the main circuit to a lower pressure in a sub-circuit.

The various pressure control valves are:

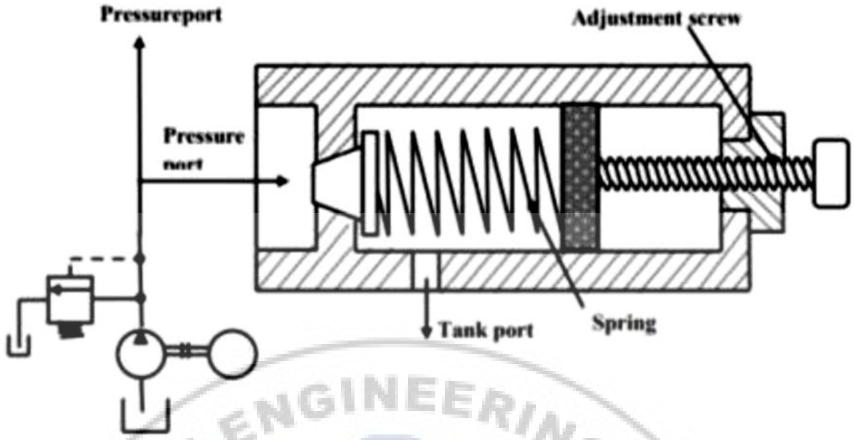
- Pressure-relief valve
- Pressure-reducing valve
- Unloading valve
- Counterbalance valve
- Pressure-sequence valve
- Brake valve.

Pressure-Relief Valves:

Pressure-relief valves limit the maximum pressure in a hydraulic circuit by providing an alternate path for fluid flow when the pressure reaches a pre-set level. In a hydraulic circuit, a relief valve opens and bypasses fluid when pressure exceeds its setting.

Schematic diagram of simple relief valve is shown in Figure. It is normally a closed valve whose function is to limit the pressure to a specified maximum value by diverting pump flow back to the tank. A poppet is held seated inside the valve by a heavy spring.

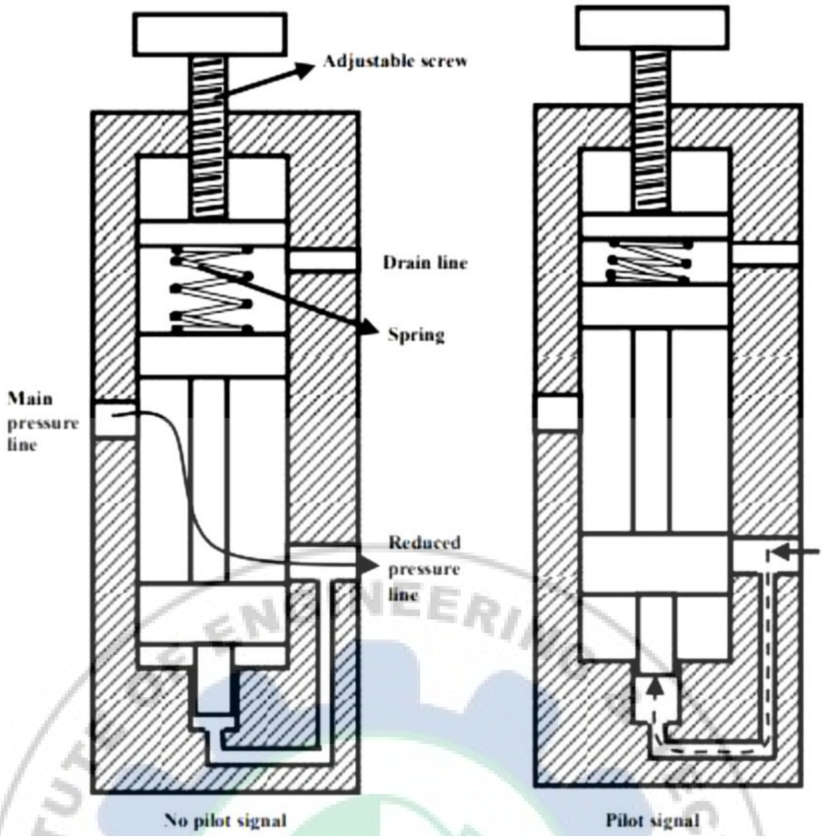
When the system pressure reaches a high enough value, the poppet is forced off its seat. This permits flow through the outlet to the tank as long as this high-pressure level is maintained. Note the external adjusting screw, which varies spring force and, thus, the pressure at which the valve begins to open.



(A simple Pressure relief valve)

Pressure-Reducing Valve:

This is another type of pressure control valve. This type of valve (which is normally open) is used to maintain reduced pressures in specified locations of hydraulic systems. It is actuated by downstream pressure and tends to close as this pressure reaches the valve setting. Schematic diagram of pressure reducing valve is shown in Figure. A pressure-reducing valve uses a spring-loaded spool to control the downstream pressure. If the downstream pressure is below the valve setting, the fluid flows freely from the inlet to the outlet. Note that there is an internal passageway from the outlet which transmits outlet pressure to the spool end opposite the spring. When the outlet (downstream) pressure increases to the valve setting, the spool moves to the right to partially block the outlet port. Just enough flow is passed to the outlet to maintain its preset pressure level. If the valve closes completely, leakage past the spool causes downstream pressure to build up above the valve setting.



(A Pressure reducing valve)

Flow-control valves:

Flow-control valves control the rate of flow of a fluid through a hydraulic circuit. Flow-control valves accurately limit the fluid volume rate from fixed displacement pump to or from branch circuits. Their function is to provide velocity control of linear actuators, or speed control of rotary actuators.

Flow-control valves can be classified as follows:
1. Non-pressure compensated
2. Pressure compensated

Non-Pressure-Compensated Valves:
Non-pressure-compensated flow-control valves are used when the system pressure is relatively constant and motoring speeds are not too critical. The operating principle behind these valves is that the flow through an orifice remains constant if the pressure drops across it remains the same. In other words, the rate of flow through an orifice depends on the pressure drop across it.
The main disadvantage of this valve is that, the speed of the piston cannot be defined accurately using non-pressure-compensated flow-control valves when the working load varies. Schematic diagram of non-pressure-compensated needle-type flow-control valve is shown in Fig. 1.3.It is the simplest type of flow-control valve. It consists of a screw (and needle) inside a tube like structure.

It has an adjustable orifice that can be used to reduce the flow in a circuit. The size of the orifice is adjusted by turning the adjustment screw that raises or lowers the needle.

For a given opening position, a needle valve behaves as an orifice. Usually, charts are available that allow quick determination of the controlled flow rate for given valve settings and pressure drops. Sometimes needle valves come with an integrated check valve for controlling the flow in one direction only. The check valve permits easy flow in the opposite direction without any restrictions.

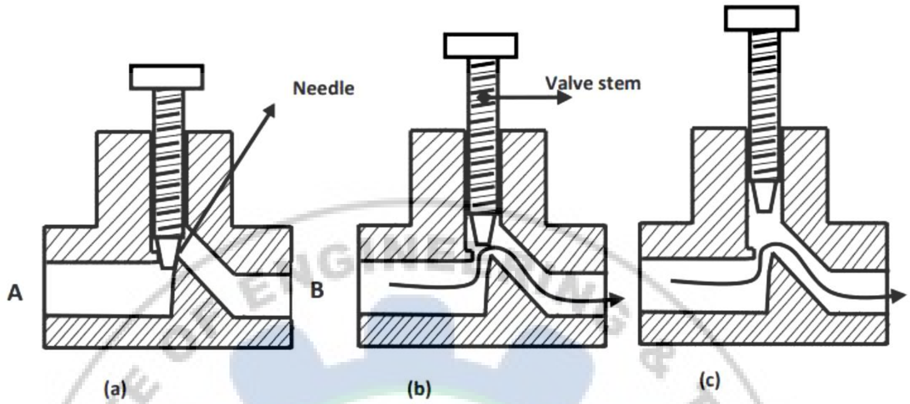


Figure 1.3 Non-pressure-compensated needle-type flow-control valve. (a) Fully closed; (b) partially opened; (c) fully opened.

Pressure-Compensated Valves:

Pressure-compensated flow-control valves overcome the difficulty caused by non pressure compensated valves by changing the size of the orifice in relation to the changes in the system pressure. This is accomplished through a spring-loaded compensator spool that reduces the size of the orifice when pressure drop increases. Once the valve is set, the pressure compensator acts to keep the pressure drop nearly constant. Schematic diagram of a pressure compensated flow-control valve is shown in Fig. 1.5. A pressure compensated flow-control valve consists of a main spool and a compensator spool. The adjustment knob controls the main spool's position, which controls the orifice size at the outlet. The upstream pressure is delivered to the valve by the pilot line A. Similarly, the downstream pressure is ported to the right side of the compensator spool through the pilot line B. The compensator spring biases the spool so that it tends toward the fully open position. If the pressure drops across the valve increases, that is, the upstream pressure increases relative to the downstream pressure, the compensator spool moves to the right against the force of the spring. This reduces the flow that in turn reduces the pressure drop and tries to attain an equilibrium position as far as the flow is concerned.

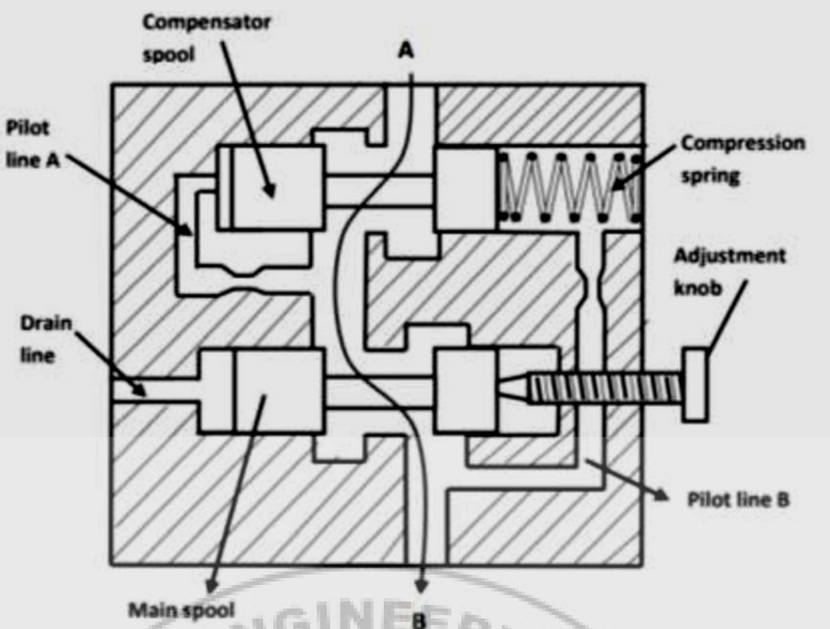


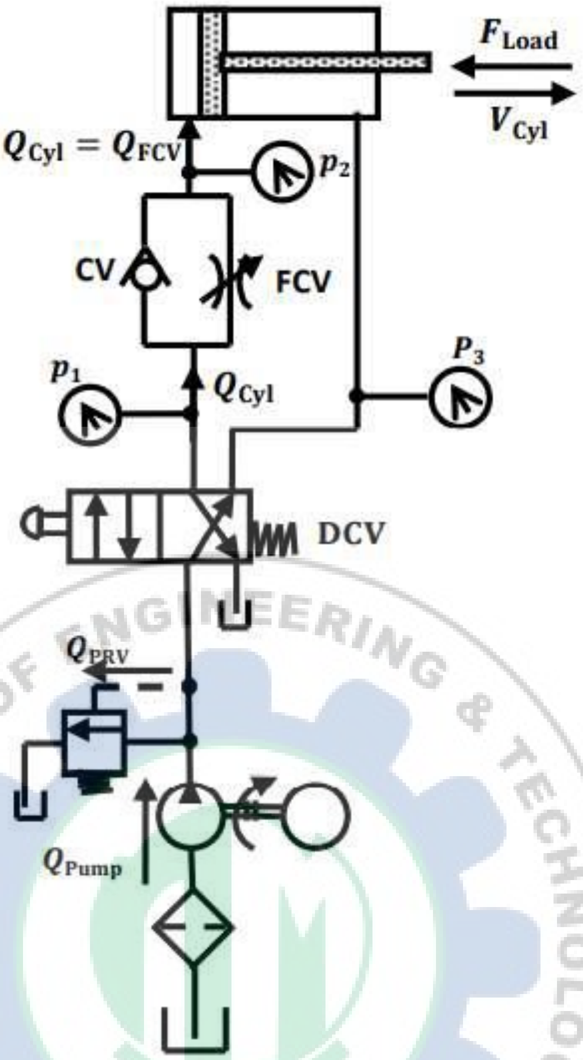
Figure 1.5 Sectional view of a pressure-compensated flow-control valve.

Speed-Controlling Circuits:

In hydraulic operations, it is necessary to control the speed of the actuator so as to control the force, power, timing and other factors of the operation. Actuator speed control is achieved by controlling the rate of flow into or out of the cylinder. Speed control by controlling the rate of flow into the cylinder is called meter-in control. Speed control by controlling the rate of flow out of the cylinder is called meter-out control.

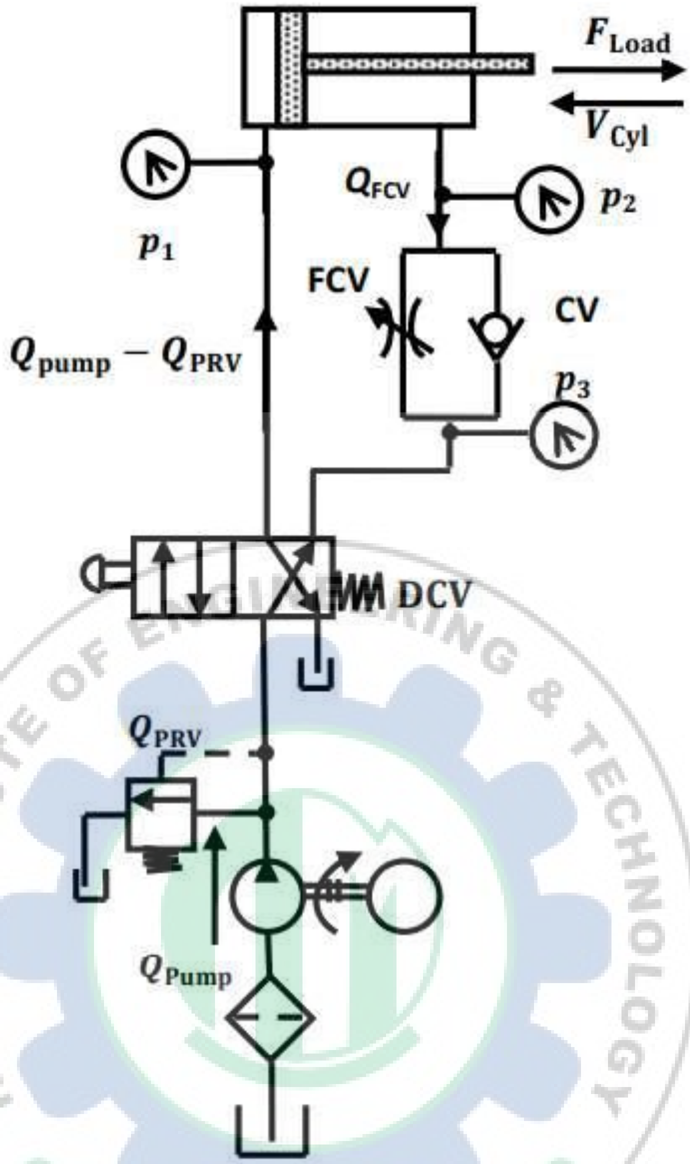
Meter-In Circuit:

The following figure shows a meter-in circuit with control of extend stroke. The inlet flow into the cylinder is controlled using a flow-control valve. In the return stroke, however, the fluid can bypass the needle valve and flow through the check valve and hence the return speed is not controlled. This implies that the extending speed of the cylinder is controlled whereas the retracing speed is not.



Meter-Out Circuit:

The following figure shows a meter-out circuit for flow control during the extend stroke. When the cylinder extends, the flow coming from the pump into the cylinder is not controlled directly. However, the flow out of the cylinder is controlled using the flow-control valve (metering orifice). On the other hand, when the cylinder retracts, the flow passes through the check valve unopposed, bypassing the needle valve. Thus, only the speed during the extend stroke is controlled. Both the meter-in and meter-out circuits mentioned above perform the same operation (control the speed of the extending stroke of the piston), even though the processes are exactly opposite to one another.



Bleed-Off Circuit:

Compared to meter-in and meter-out circuits, a bleed-off circuit is less commonly used. Figure 1.10 shows a bleed-off circuit with extend stroke control. In this type of flow control, an additional line is run through a flow-control valve back to the tank. To slow down the actuator, some of the flow is bleed off through the flow-control valve into the tank before it reaches the actuator. This reduces the flow into the actuator, thereby reducing the speed of the extend stroke. The main difference between a bleed-off circuit and a meter-in/meter-out circuit is that in a bleed-off circuit, opening the flow control valve decreases the speed of the actuator, whereas in the case of a meter-in/meter-out circuit, it is the other way around.

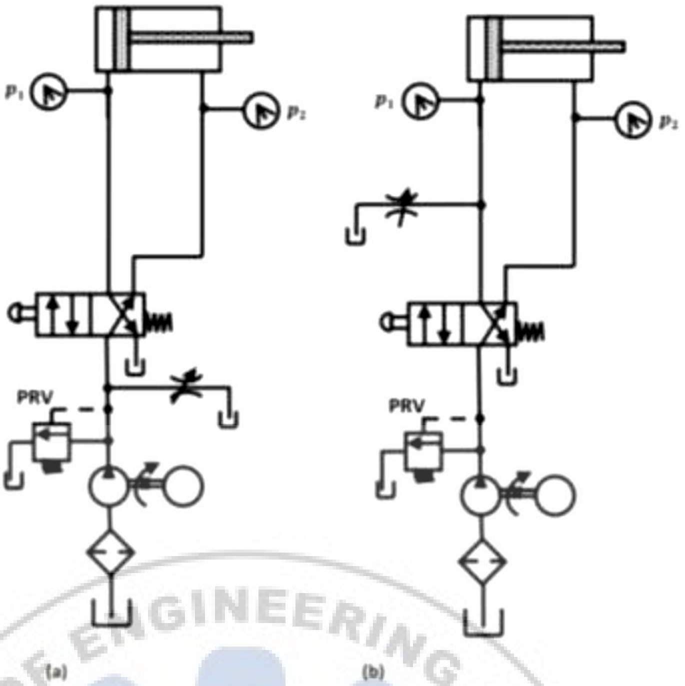


Figure 1.10 Bleed-off circuits:(a) Bleed-off for both directions and (b) bleed-off for inlet to the cylinder or motor.

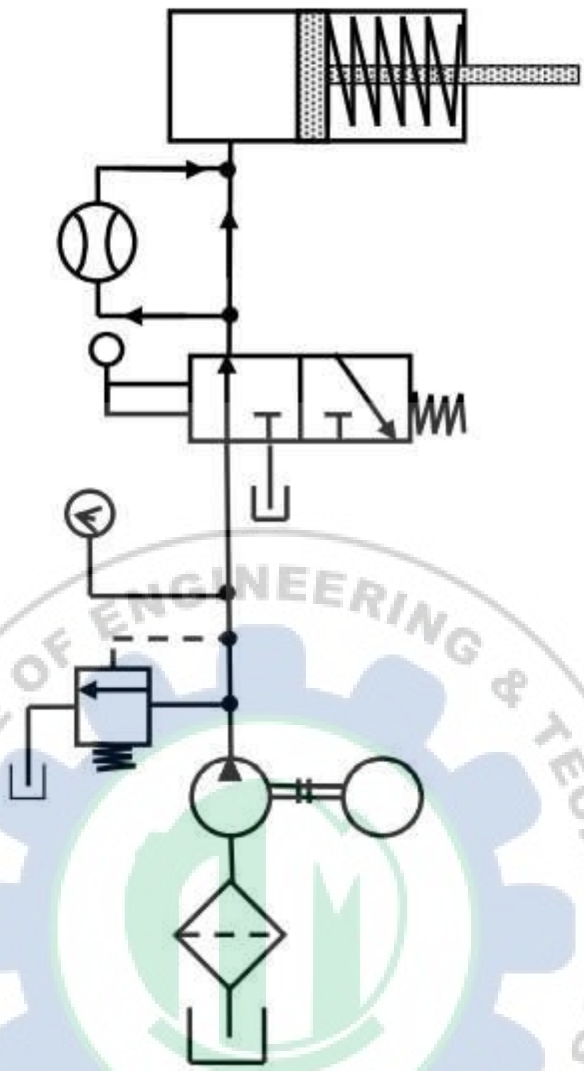
Hydraulic Circuit:

A hydraulic circuit is a group of components such as pumps, actuators, control valves, conductors and fittings arranged to perform useful work. There are three important considerations in designing a hydraulic circuit:

- ❖ Safety of machine and personnel in the event of power failures.
- ❖ Performance of given operation with minimum losses.
- ❖ Cost of the component used in the circuit.

Control of a Single-Acting Hydraulic Cylinder:

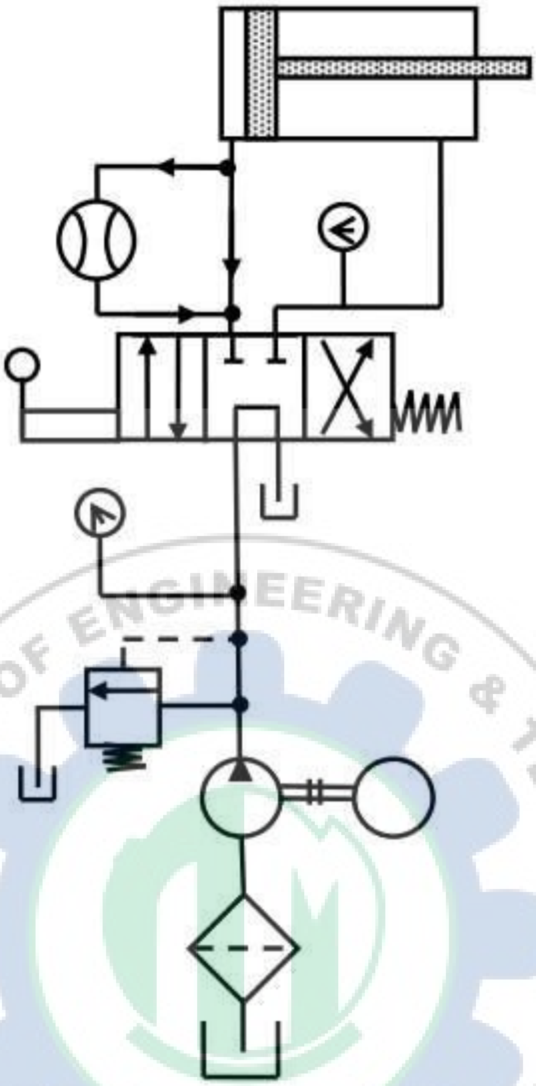
The following figure shows that the control of a single-acting, spring return cylinder using a three way two-position manually actuated, spring offset direction-control valve (DCV). In the spring offset mode, full pump flow goes to the tank through the pressure-relief valve (PRV). The spring in the rod end of the cylinder retracts the piston as the oil from the blank end drains back into the tank. When the valve is manually actuated into its next position, pump flow extends the cylinder. After full Extension, pump flow goes through the relief valve. Deactivation of the DCV allows the cylinder to retract as the DCV shifts into its spring offset mode.



(Control of a single-acting cylinder)

Control of a Double-Acting Hydraulic Cylinder:

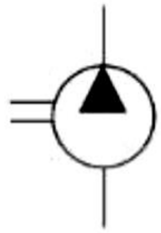
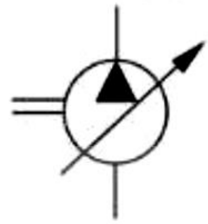
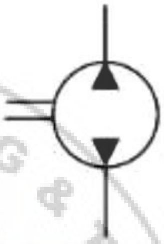
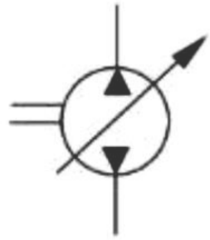
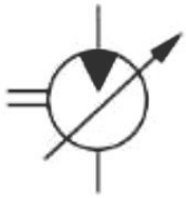
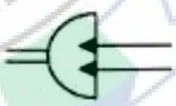
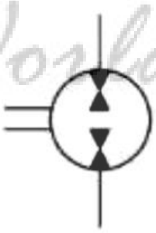
The circuit diagram to control double-acting cylinder is shown in the following figure. The control of a double-acting hydraulic cylinder is described as follows: 1. When the 4/3 valve is in its neutral position (tandem design), the cylinder is hydraulically locked and the pump is unloaded back to the tank. 2. When the 4/3 valve is actuated into the flow path, the cylinder is extended against its load as oil flows from port P through port A. Oil in the rod end of the cylinder is free to flow back to the tank Through the four-way valve from port B through port T. 3. When the 4/3 valve is actuated into the right-envelope configuration, the cylinder retracts as oil flows from port P through port B. Oil in the blank end is returned to the tank via the flow path from port A to port T. At the ends of the stroke, there is no system demand for oil. Thus, the pump flow goes through the relief valve at its pressure level setting unless the four-way valve is deactivated.

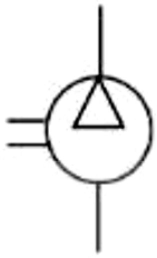
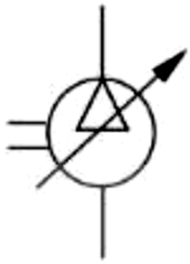
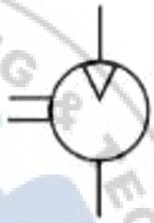
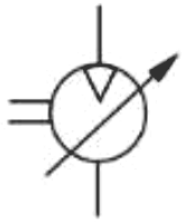
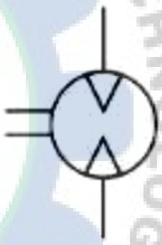
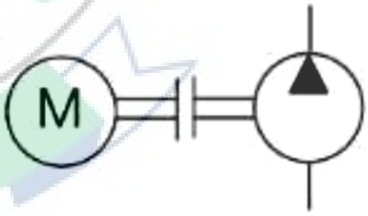
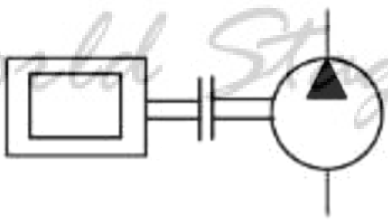


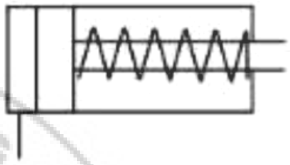
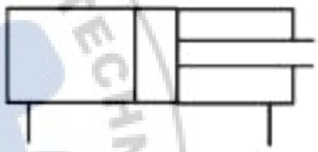
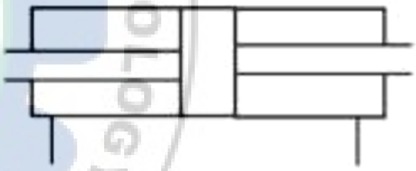
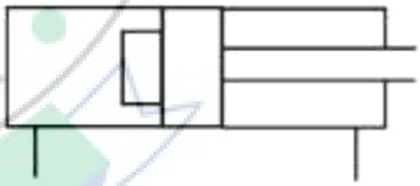
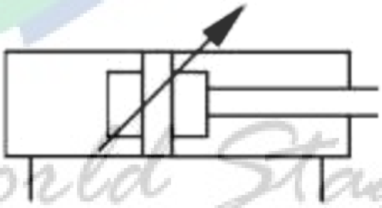
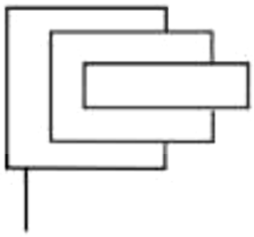
(Control of a double-acting cylinder)

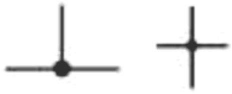
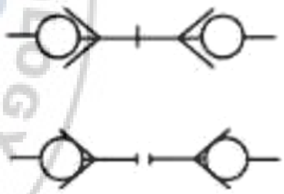
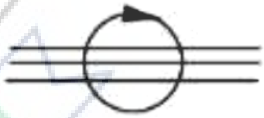
HYDRAULIC PNEUMATIC SYMBOLS

Hydraulics pneumatics symbols play very important role in design and implementation of the systems. These symbols designate the components and way they should be interconnected. Without hydraulics pneumatics symbols it would have very difficult to represent and express a hydraulic circuit.

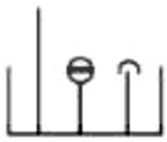
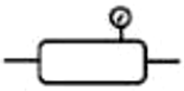
Elements	Description	Symbol — Displacement: Fixed	Symbol — Displacement: Variable
Hydraulic Pumps Conversion of Mech.energy to hyd. energy.	a) With one directional flow		
	b) With two directional flow		
Hydraulic Motor Conversion of hyd. energy to Mech. energy.	a) With one directional flow		
	b) With two directional flow		
	c) Limited rotation motor		
Pump / Motor	Components which can operate both as Pump and Motor		

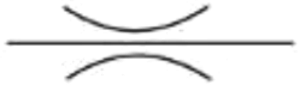
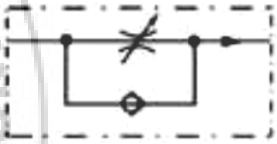
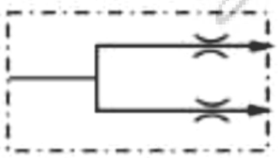
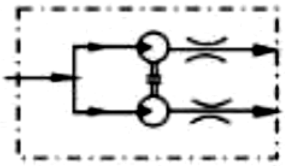
Elements	Description	Symbol Displacement	
		Fixed	Variable
Compressors Conversion of Mech. energy to pressure energy.			
Air Motors Conversion of pressure energy into Mech. energy.	a) With one directional flow		
	b) With two directional flow		
Drives Provide mechanical energy to system	Electric Motor		
	Internal Combustion Engine		

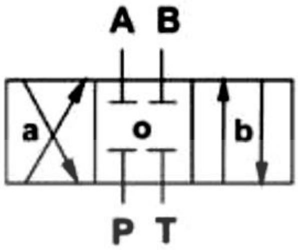
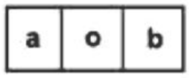
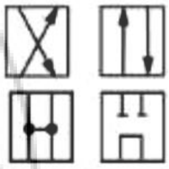
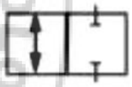
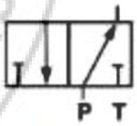
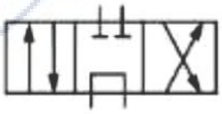
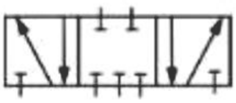
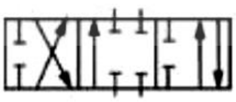
Elements	Description	Symbol
Cylinders	Conversion of pressure energy into Mechanical energy.	
a) Single acting	Fluid exerts pressure on one side only.	
b) Single acting with Spring return	Return action caused by Spring .	
c) Double acting cylinder with single piston rod.	Two different piston areas	
d) Double acting cylinder with double piston rod.	Two identical piston areas	
e) Cylinder with end cushioning		
f) Adjustable cushion at both ends		
g) Telescopic Cylinder		

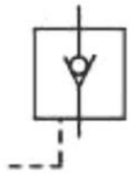
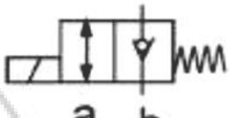
Elements	Description	Symbol
Conduct Lines	Main working line	
	Pilot (control)	
	Drain line	
	Flexible connection lines	
Line Junction	Dot at cross point	
Crossed Line with no connection	No dot at cross point	
Pressure Line with plug		
Quick acting coupling	Note that in connected position both check valves are open & when disconnected they are closed by spring force.	
Rotating joint		

d) Fluid Storage Elements

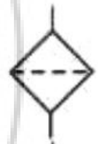
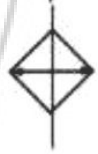
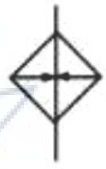
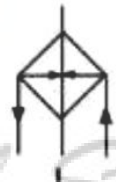
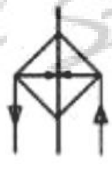
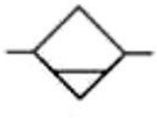
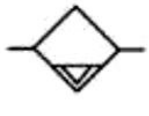
Storage Tank	A vented reserve oil	
	A Pressurised reseroil	
	Tank with Piping oil level indicator and air bleeding	
	Air Tank or reservoil	

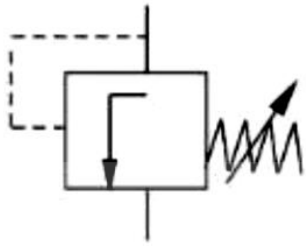
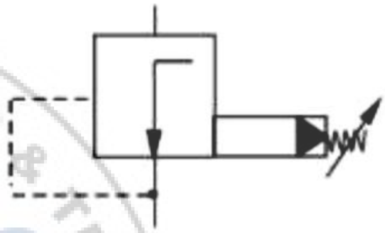
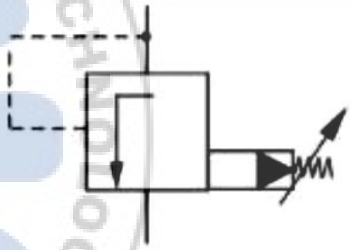
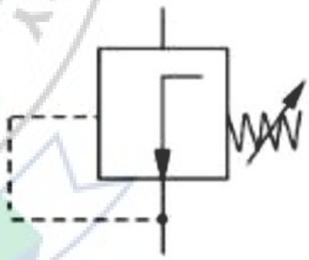
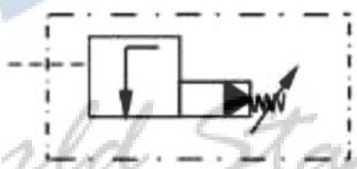
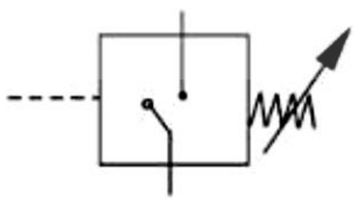
Elements	Description	Symbol
a) Orifice Valve	Short throttle segment	
b) Throttle valve	Fixed	
Flow depends on thepressure difference	Variable	
c) Throttle and check valve in one consturction		
d) Flow control Valve	Pressure Compensated	
	Pressure & temperature Compensated	
	Pressure & temperature flow control valve with by pass check valve.	
e) Flow divider	Divides flow into two equal parts.	
	Flow divider with two coupled motors.	

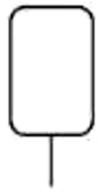
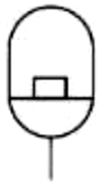
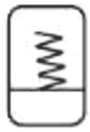
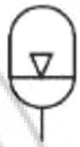
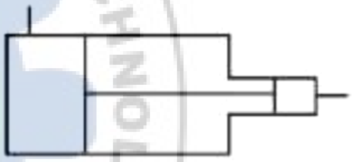
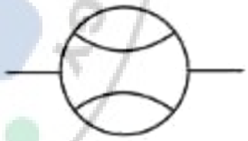
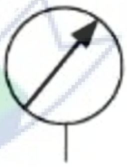
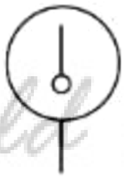
Elements	Description	Symbol
	Parts of Valves are named with letters P - Pump, Pressrue T - Tank, Return A,B - Load, Consumer X,Y,Z - Pilot Ports L- Leakage Oil Port R- Return line	
	Designation **4/3** directional control valve └ Number of switching position └ Number of Ports	
	Switching Positions shown by blocks	
	Internal connections shown by arrows and lines	
	2/2 directional control valve	
	3/2 directional control valve	
	4/2 directional control valve	
	4/3directional control valve	
	5/2 directional control valve	
	5/3 directional control valve	
	6/3 directional control valve	

Elements	Description	Symbol
a) Non-return valves	With /without closing spring	
b) Pilot Operated check valve	Opens in One direction only when set pressure is reached at pilot line	
c) Solenoid operated check valve	Position a) allows flow in both direction b) allows flow in only one direction	

h) Fluid Conditioning elements

a) Filter		
b) Cooler	Outside arrows indicates heat flowing out of system	
c) Heater	Inside arrow indicates heat flowing into the system.	
	Heater with liquid heating medium	
	Heater with gaseous heating medium	
d) Separator [removing water from air]	Separator with a manual drain	
	Separator with automatic drain	

Elements	Description	Symbol
a) Directly operated pressure relief valve.	Normally closed (Open on actuation)	
b) Pilot operated pressure relief valve.		
c) Directly operated pressure reducing valve.	Normally open (Closes on actuation) See difference in symbol.	
d) Pilot operated pressure reducing valve.		
e) Pilot operated sequence valve with external signal input	The valve switches & opens flow when set value of pressure is reached.	
f) Pressure switchs		

Elements	Description	Symbol
a) Accumulators.		
	Weight loaded	
	Spring loaded	
	Gas charged	
b) Intensifier [Pressure booster]		
c) Flow meter		
d) Pressure gauge		
e) Temperature gauge.		

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