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FPE IAT 1 Scheme & Solution
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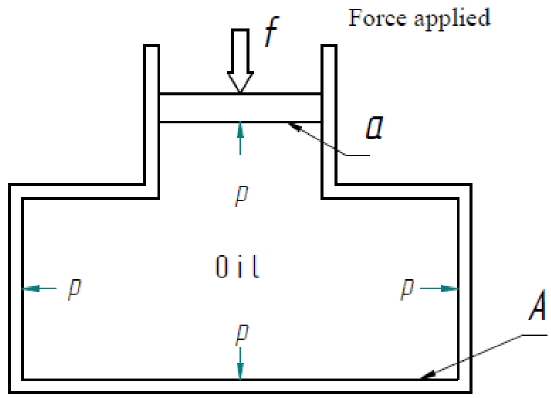
7. A gear pump has a 7.5 cm outside diameter a 5 cm inside diameter and a 2.5 cm width. If the volumetric efficiency is 90% at rated pressure, what is the corresponding actual flow rate? The pump speed is 1000 rpm. V_D Value 4M Q_T Value 3M Q_A Value 3M

Solutions

1. State Pascal's law. Explain with a neat sketch its application to simple hydraulic jack. 10M

Pascal's law reveals the basic principle of how fluid power systems perform useful work. This law can be stated as follows: "Pressure applied to a confined fluid is transmitted undiminished in all directions throughout the fluid and acts perpendicular to the surfaces in contact with the fluid".



Pressure in an enclosed fluid can be considered uniform throughout a practical system. There may be small differences arising from head pressures at different heights, but these will generally be negligible compared with the system operating pressure. This equality of pressure is known as *Pascal's law,* and is illustrated in the Figure above.

The applied force develops a pressure, given by the expression:

$$p = f/a$$

The force on the base is:

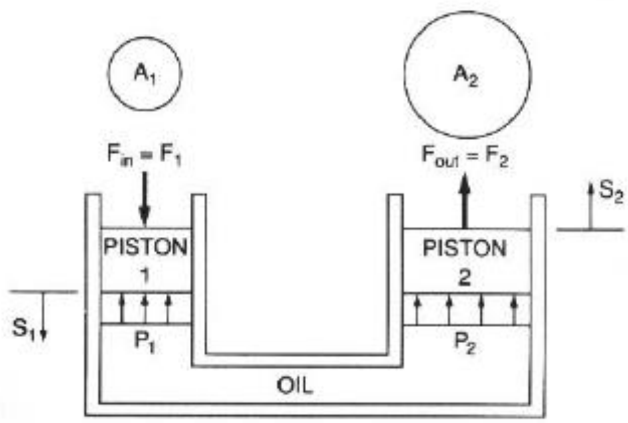
$$F = p \times A$$

from which F can be derived as:

$$F = f \times A/a$$

The above Expression shows an enclosed fluid may be used to magnify a force.

Pascal's law applied to hydraulic jack.



As shown downward input force F_1 is applied to small-diameter piston 1, which has an area A_1. This produces an oil pressure p_1 at the bottom of piston 1. This pressure is transmitted through the oil to the large-diameter piston 2 which has an area A_2. The pressure p_2 at piston 2 pushes up on the piston to create an output force F_2.

By Pascal's law,

$$p_1 = p_2.$$

Since pressure equals force divided by area, we have

$$F_1/A_1=F_2/A_2$$
OR
$$F_2/F_1=A_2/A_1$$

Thus a force multiplication occurs from the input to the output of the jack if the piston area is greater than the input piston area. The force multiplication ratio F_2/F_1 equals the piston area ratio A_2/A_1. However, the output piston does not move as far as does the input piston. The ratio of the piston movements can be determined by assuming the oil to be incompressible. Thus, the cylindrical volume of oil displaced by the input piston equals the cylindrical volume displaced by the output piston:

$$V_1=V_2$$

Since the volume of a cylinder equals the product of its cross-sectional area and its height we have

$$A_1S_1=A_2S_2$$

Where S1 = the downward movement of piston 1,

S_2 = the upward movement of piston 2.

Thus,

$$S_2/S_1 = A_1/A_2$$

The above equation shows that large output piston does not travel as far as the small input piston. Note that the piston stroke ratio S_2/S1 equals the piston area ratio A_1/A_2. Thus, for a piston area ratio of 2, the output force increases by a factor of 2, but the output motion decreases by a factor of 2. Hence, in a hydraulic jack we do not get something for nothing. The output force is greater than the input force, but the output movement is less than the input movement.

Combining Eqs. yields the corresponding relationship

$$F_2/F_1 = S_1/S_2$$

Hence,

$$F_1S_1 = F_2S_2$$

Recall that work energy equals the product of force and the distance moved by the force. Thus equation ($F_1S_1 = F_2S_2$) states that the energy input to the hydraulic jack equals the energy output from the jack. This result occurs because the force multiplication factor equals the motion reduction factor.

2. What are the four primary functions of a hydraulic fluid? Name any six fluid properties that a fluid should possess? 10M

A hydraulic fluid has the following four primary functions:

1. Transmit power.
2. Lubricate moving parts.
3. Seal clearances between mating parts.
4. Dissipate heat.

The desirable properties of a hydraulic fluids are listed below:

1. Ideal viscosity.
2. Variation of viscosity with temperature (viscosity Index); must be minimal viscosity change with temperature change.
3. Good lubrication capability.
4. Good chemical stability.
5. High specific heat and thermal conductivity to dissipate heat.

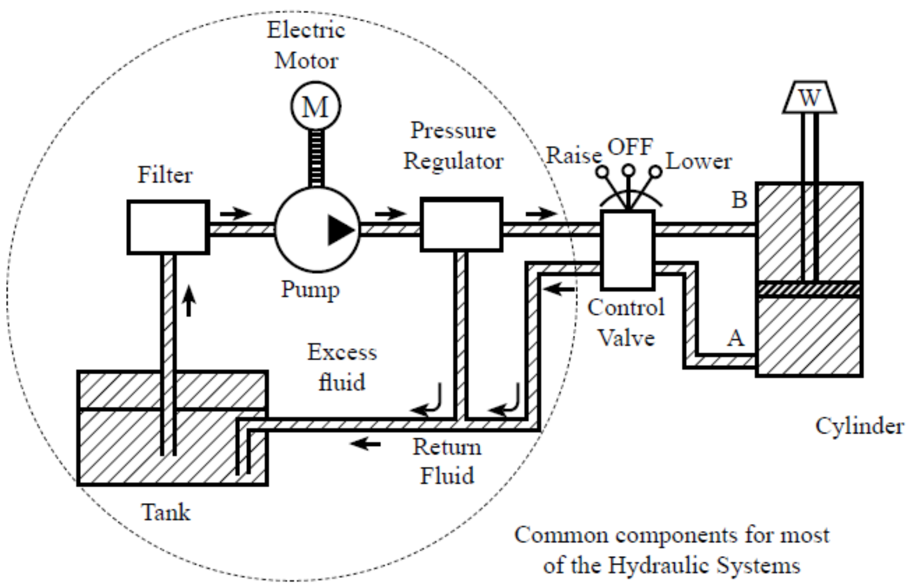
6. Low compressibility.
7. Fire resistance property.
8. System compatibility.
9. Foam resistant properties.
10. Environmental Compatibility.

3. Sketch and explain the structure of a hydraulic control system. 10M

A hydraulic control system is a group of hydraulic components arranged in an order to transmit hydraulic power using oil to perform useful work.

There are eight basic components required in a hydraulic system.

1. A reservoir is used to hold the hydraulic oil.
2. An actuator to convert the fluid power into mechanical power to perform useful work.
3. A pump is used to force the fluid from the reservoir.
4. An electric motor is required to drive the pump.
5. Valves are used to control the direction, pressure and flow rate of a fluid.
6. Piping system carries the hydraulic oil from one place to another.
7. Filters are used to remove any foreign particles so as keep the fluid system clean and efficient.
8. Pressure regulator regulates (i.e. maintains) the required level of pressure in the hydraulic fluid.



The hydraulic system requires a liquid fluid to operate; this is expensive and messy. The piping must act as a closed loop, with fluid transferred from a storage tank to one side of the cylinder, and returned from the other side of the cylinder to the tank.

Fluid is drawn from the tank by a pump which produces fluid flow at the required pressure. A prime move generally an electric motor is required to run the pump. Cylinder movement is controlled by a three-position direction control valve (DCV). To extend the cylinder, port A is connected to the pressure line and port B to the tank. To reverse the motion, port B is connected to the pressure line and port A to the tank. In its centre position the valve locks the fluid into the cylinder.

4. Using a neat diagram, explain the construction and functioning of a hydraulic unbalanced vane pump.

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.

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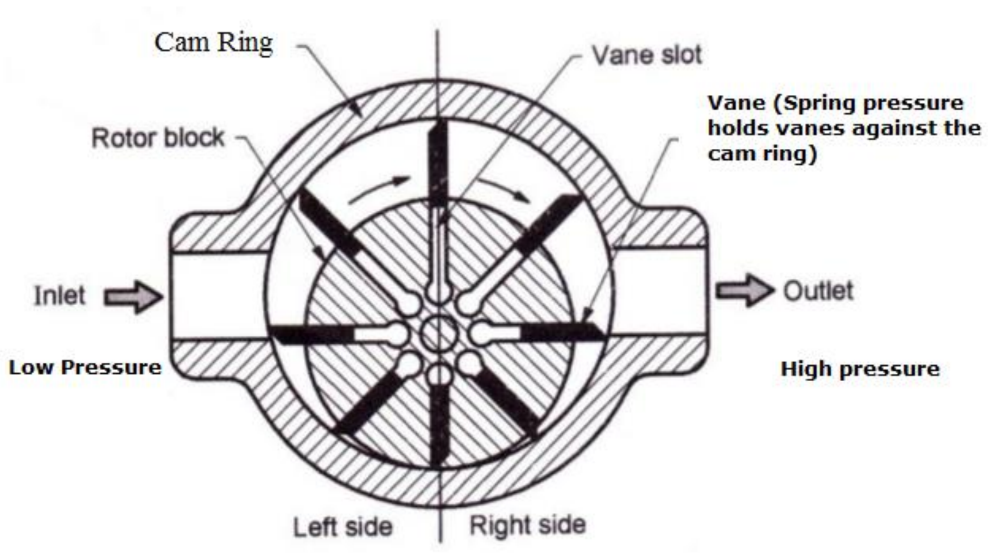
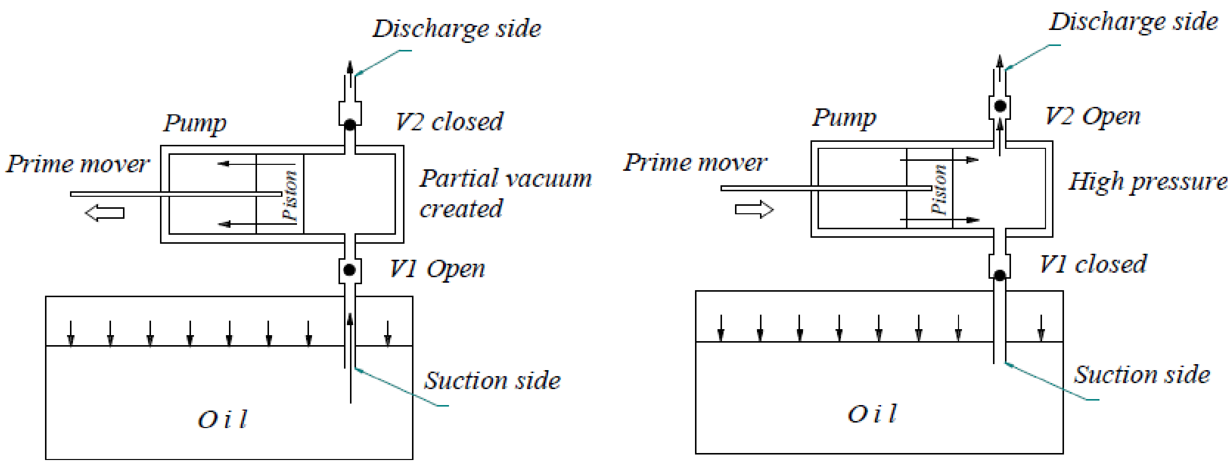


Figure Unbalanced Vane Pump

5. With a neat diagram explain pumping theory. 10M

A positive displacement hydraulic pump is a device used for converting mechanical energy into hydraulic energy. It is driven by a prime mover such as an electric motor. It basically performs two functions. First, it creates a partial vacuum at the pump inlet port. This vacuum enables atmospheric pressure to force the fluid from the reservoir into the pump. Second, the mechanical action of the pump traps this fluid within the pumping cavities transports it through the pump and forces it into the hydraulic system. It is important to note that pumps create flow not pressure. Pressure is created by the resistance to flow.

All pumps operate by creating a partial vacuum at the intake, and a mechanical force at the outlet that induces flow. This action can be best described by reference to a simple piston pump shown in Fig.



(a) Suction stroke (b) Return stroke

1. As the piston moves to the left, a partial vacuum is created in the pump chamber that holds the outlet valve in place against its seat and induces flow from the reservoir that is at a higher (atmospheric) pressure. As this flow is produced, the inlet valve is temporarily displaced by the force of fluid, permitting the flow into the pump chamber (suction stroke).

2. When the piston moves to the right, the resistance at the valves causes an immediate increase in the pressure that forces the inlet valve against its seat and opens the outlet valve thereby permitting the fluid to flow into the system. If the outlet port opens directly to the atmosphere, the only pressure developed is the one required to open the outlet valve (delivery stroke).

6. A Vane pump is to have a volumetric displacement of 82 cm^3. It has a rotor dia of 5 cm, a cam ring dia 7.5 cm, and a vane width of 4 cm. what must be the eccentricity? What is the maximum volumetric displacement possible? 10M

$$Volumetric\ displacement, V_D = 82\ {cm^3}/{rev}$$

$$Rotor\ dia, D_r = 5\ cm$$

$$Cam\ ring\ dia, D_c = 7.5\ cm$$

$$Width, L = 4\ cm$$

Eccentricity is given by,

$$e = \frac{2 \times V_D}{\pi(D_c + D_r)L}$$

$$e = \frac{2 \times 82}{\pi(5 + 7.5)4}$$

$$e = 1.04\ cm$$

$$e_{max} = \frac{D_c - D_r}{2} = 1.25\ cm$$

$$V_{D\,max} = \frac{\pi}{2} \times (5 + 7.5) \times 1.25 \times 4$$

Maximum possible volumetric displacement,

$$V_{D\,max} = 98.214\ cm^3$$

7. A gear pump has a 75mm outside diameter a 50 mm inside diameter and a 25 mm width. If the volumetric efficiency is 90% at rated pressure, what is the corresponding actual flow rate? The pump speed is 1000 rpm.

Given Data:

External dia: D_o = 75 mm

Inside dia: D_i = 50 mm

Width of teeth: L= 25 mm

Efficiency: 0.9

Speed: 1000 rpm

Volumetric displacement is given by $V_D = \frac{\pi}{4}({D_o}^2 - {D_i}^2)\ L$

$$V_D = 61383.98\ mm^3$$

Theoretical flow rate is given by $Q_T = V_D \times N$

$$Q_T = 61383.98 \times 1000$$

$$Q_T = 613839800\ {mm^3}/{m}$$

Now, actual flow rate is given by $Q_A = \eta_V \times Q_T$

$$Q_A = 55245528\ {mm^3}/{m}$$

$$= 0.0553\ {m^3}/{m}$$

$$Q_A = 55.3\ Lpm$$