24. FLUID SYSTEMS

Topics:

Objectives:

24.1 SUMMARY

• Fluids are a popular method for transmitting power (hydraulics). Basically, by applying a pressure at one point, we can induce flow through a pipe/value/orifice.

24.2 MATHEMATICAL PROPERTIES

• Fluids do work when we have a differential pressure on a surface. The pressure may be expressed as an absolute value. More correctly we should consider atmospheric pressure (gauge pressure).

• When we deal with fluids we approximate them as incompressible.

• Fluids observe some basic laws,

w = flow rate

p = pressure

24.2.1 Resistance

• If fluid flows freely, we say it is without resistance. In reality, every fluid flow experiences some resistance. Even a simple pipe has resistance. Of similar interest is the resistance of a value.

$$w = K\sqrt{\Delta p}$$

where,

w = flow rate through the pipe

Δp = pressure difference across valve/pipe

K = a constant specific to the pipe/valve/orifice

NOTE: In this case the relationship between pressure drop and flow are non-linear. We have two choices if we want to analyze this system.
1. We can do a non-linear analysis (e.g. integration)
2. We can approximate the equation with a linear equation. This is only good for operation near the chosen valve position. As the flow rate changes significantly the accuracy of the equation will decrease.

$$\Delta p \approx R(w - \bar{w})$$

$$R \approx \frac{\Delta(\Delta p)}{\Delta w} \qquad R = 2\frac{w}{K^2}$$

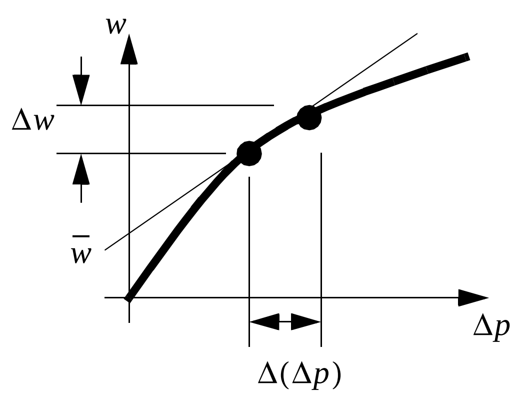
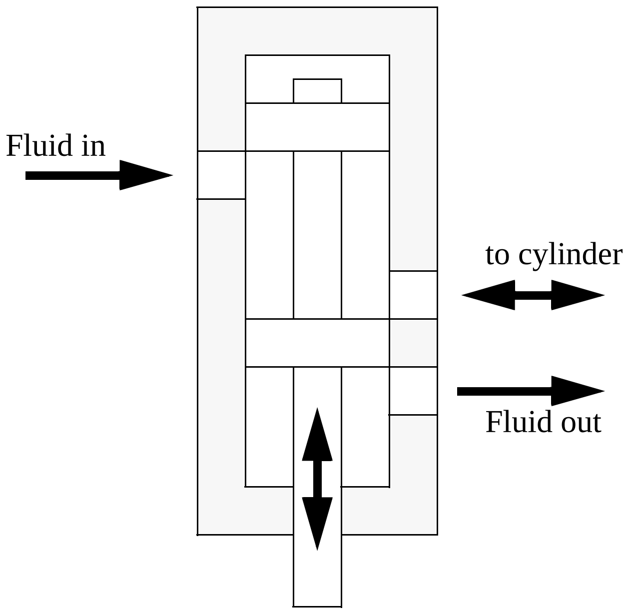


Figure 24.1 Fluid flow resistance

• Resistance may also result from valves. Valves usually restrict flow by reducing an area for fluid to flow through.

• A simple form of valve is a sliding plunger. The valve below is called a two way valve because it will allow fluid to flow in or out.



NOTE: For this type of valve the fluid in is typically under pressure. When the valve slide is up the pressure is applied to the cylinder, and causes it to actuate. The fluid out is typically not under pressure, and just returns fluid to a reservoir tank. When used this way a cylinder needs a spring, or some other force to return it and force the fluid out.

Figure 24.2 Fluid servo valve

• Four way valve allow fluid force to be applied in both directions of a cylinder motion.

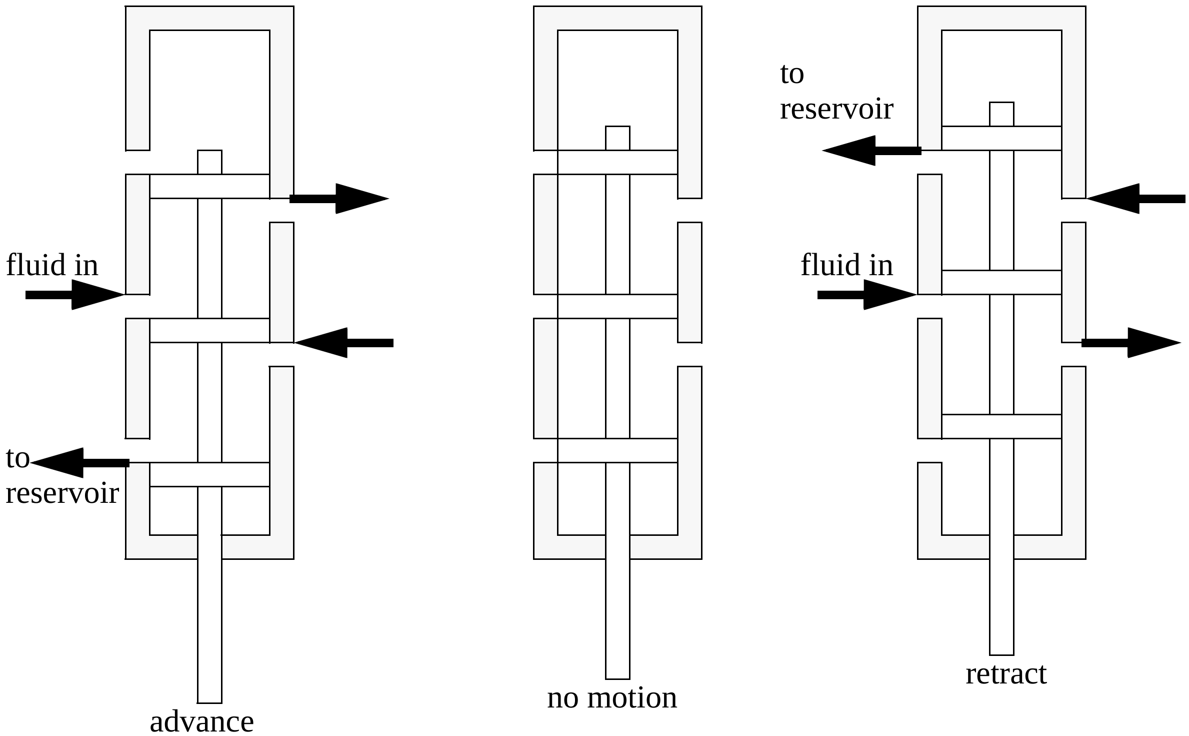
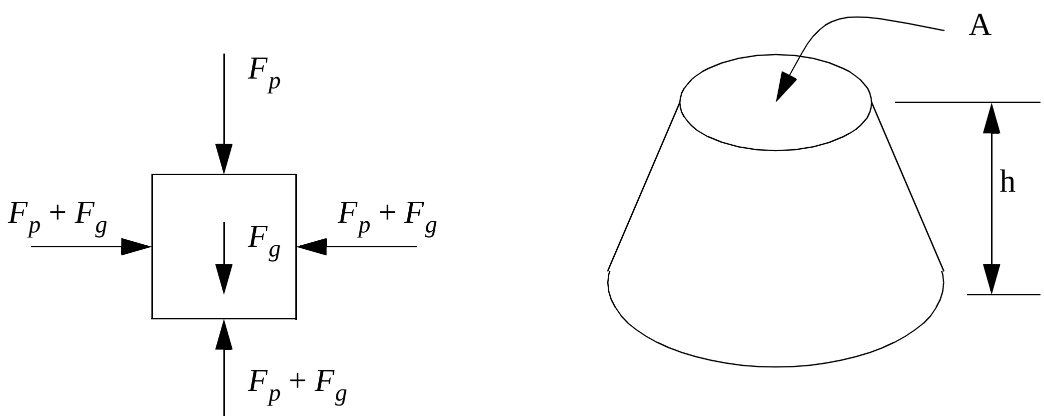


Figure 24.3 Fluid flow control valves

24.2.2 Capacitance

• Fluids are often stored in reservoirs or tanks. In a tank we have little pressure near the top, but at the bottom the mass of the fluid above creates a hydrostatic pressure. Other factors also affect the pressure, such as the shape of the tank, or whether or not the top of the tank is open.

• To calculate the pressure we need to integrate over the height of the fluid.



$$P = \frac{F_g}{A}$$

$$F_g = \rho V = \rho g A h$$

$$P = \frac{\rho g A h}{A} = \rho g h$$

Figure 24.4 Pressures on fluid elements

• Consider a tank as a capacitor. As fluid is added the height of the fluid rises, and the hydrostatic pressure increases. Hence we can pump fluid into a tank to store energy, and letting fluid out recovers the energy. A very common application of this principle is a municipal water tower. Water is pumped into these tanks. As consumers draw water through the system these tanks provide pressure to the system. When designing these tanks we should be careful to keep the cross section constant (e.g. a cylinder). If the cross section varies then the fluid pressure will not drop at a linear rate and you won't be able to use linear analysis techniques (eg., Laplace).

• The mathematical equations for a constant cross section tank are,

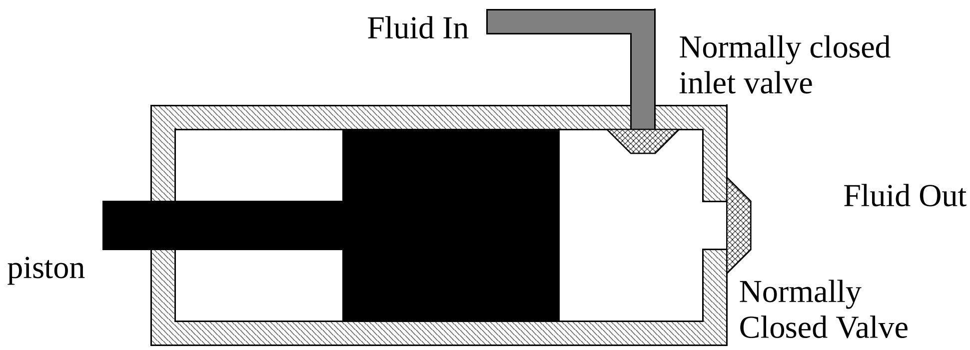
$$C = \frac{A}{\rho g}$$

$$w = C\frac{d}{dt}p$$

24.2.3 Power Sources

• As with most systems we need power sources. In hydraulics these are pumps that will provide pressure and/or flow to the system.

• One type of pump uses a piston.



In this common form of piston pump, the piston rod is drawn back creating suction that holds the valve closed, and pulls fluid into the chamber. When the cylinder is full of fluid the piston motion is reversed, creating a pressure, and forcing the inlet vale closed, and the outlet valve open, and the fluid is pumped out. The fluid volume can be controlled by using the cylinder size, and piston strokes

Figure 24.5 A piston driven hydraulic pump

• A geared hydraulic pump is pictured below. Other types use vanes and pistons.

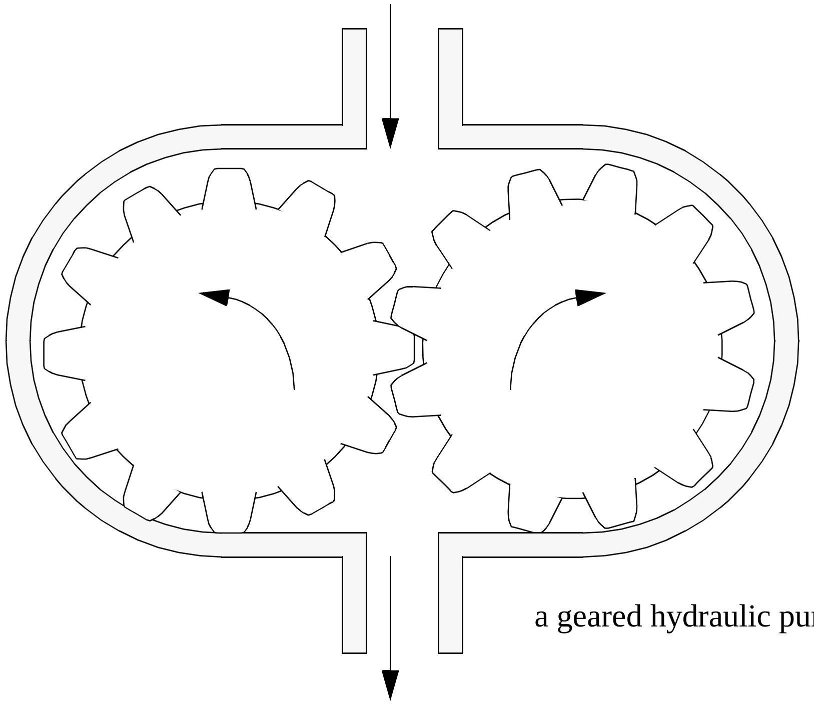


Figure 24.6 A gear driven hydraulic pump

• Vane based pumps can be used to create fluid flow. As the pump rotates the vanes move to keep a good seal with the outer pump wall. The displacement on the advance and return sides are unequal (aided by the sliding vanes). The relative displacement across the pump determines the fluid flow.

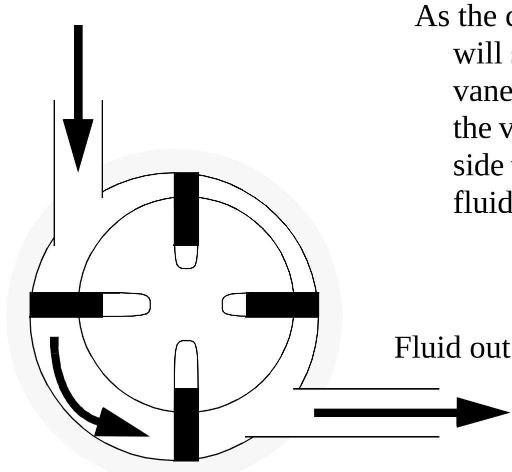


Figure 24.7 A vaned hydraulic pump

• As with the resistance of valves, these are not linear devices. It is essential that we linearize the devices. To do this we look at the pressure flow curves. (Note: most motors and engines have this problem)

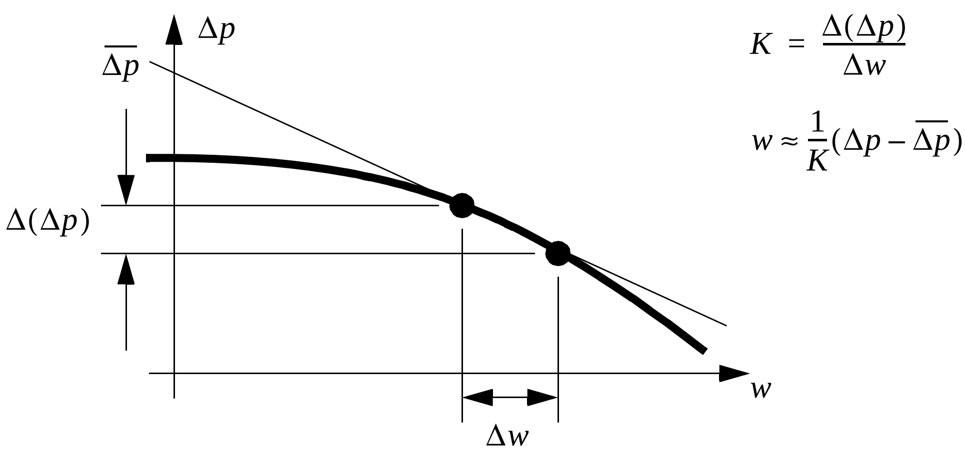


Figure 24.8 Linearizing a hydraulic valve ?????

24.3 EXAMPLE SYSTEMS

• We can model a simple hydraulic system using the elements from before. Consider the example below,

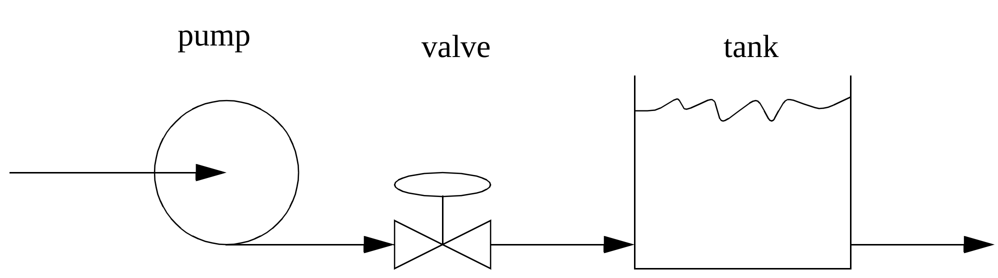
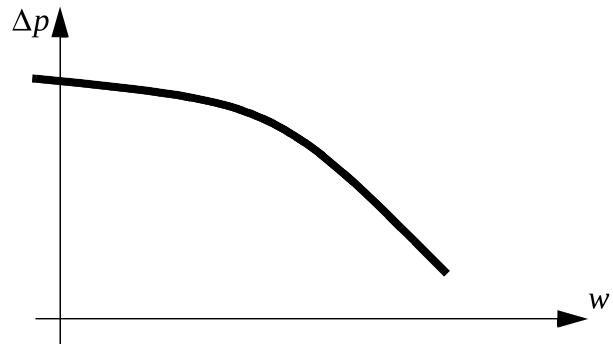
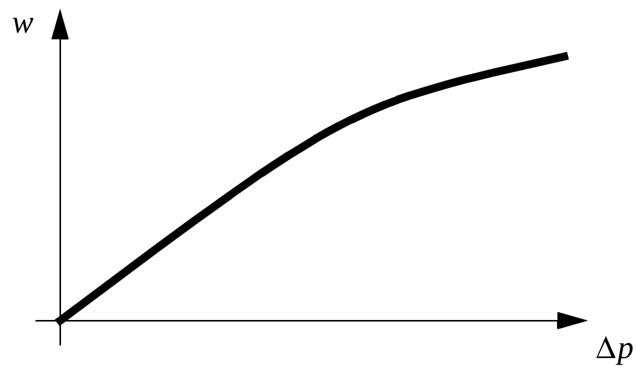


Figure 24.9 A hydraulic system example

For the pump the relationship is shown in the graph, and it will operate at the point marked.



For the valve the relationship is given below



The pipes are all equal length and have the relationships shown below.

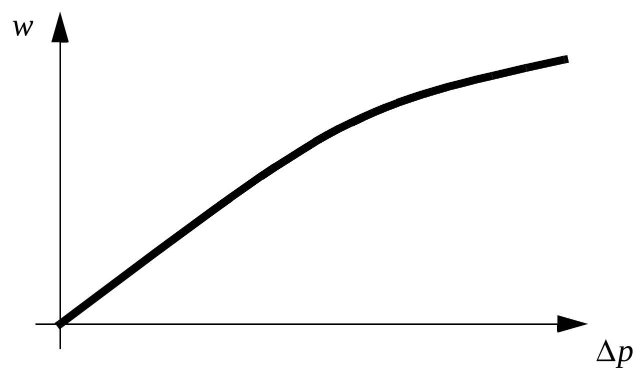


Figure 24.10 A hydraulic system example (continued)

24.4 SUMMARY

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24.5 PRACTICE PROBLEMS

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24.6 PRACTICE PROBLEMS SOLUTIONS

24.7 ASSIGNMENT PROBLEMS