**Introductory Motion and Control**
**Simple Hydraulic Circuits**

Reference: *Parker Design Engineers Handbook: Volume 1-Hydraulics,* Bulletin 0292-B1-H.
*Parker Industrial Hydraulic Technology*, 2nd Ed., Bulletin 0232-B1.

## Pumps and Cavitation

Pumps are used in hydraulic circuits to ***supply pressurized fluid***, and in turn, the pressurized fluid can be used to ***perform work***. Pumps and hydraulic fluids both have ***limitations*** as to the amount of work that can be done. An example of this is the phenomenon known as ***cavitation***. Cavitation is the ***formation*** and ***collapse*** of gaseous vapor cavities in a liquid.

***Cavitation*** can be brought about in a hydraulic pump when the rotating group of the pump moves so rapidly that pressure inside the pumping mechanism reaches the ***liquid's vapor pressure***. The hydraulic fluid ***boils***, resulting in cavitation, which causes harmful effects to the pump. Cavitation causes the pump to emit a steady high-pitched squeal and gravel-like rattle.

The ***hydraulic trainers*** often have a vacuum gage connected to the tank outlet to monitor this possibility. The gage will read a low (negative) pressure as the fluid is being sucked from the tank into the pump. If cavitation should occur the system should be shut down to prevent damage.

## Pumps and Pressure Relief

As discussed in previous notes, if a pump has fixed displacement, it will output the same volume of fluid with each revolution. This fixed volume of fluid is called the pump's displacement. The maximum volumetric flow rate of a pump it determined by its displacement and rotational rate. The volumetric flow rate and pressure at any point in a hydraulic system can be related to the power using the following equation.

$$\boxed{P = F \cdot v = p \cdot A \cdot v = p \cdot Q}$$

The symbols used in this equation are defined as follows: $P$ is ***power***, $p$ is ***pressure***, $A$ is flow rate ***area***, $v$ is ***velocity***, and $Q$ is the ***volumetric flow rate***.

The above equation can be used to find the ***maximum pressure*** that a pump and motor combination can develop. For example, if a 3 GPM, fixed-displacement pump is driven using a 1 HP electric motor, the ***maximum pressure*** allowed before the motor will stall can be calculated as follows.

Motor: $1(HP) = 550\left(\frac{\text{ft-lb}}{\text{sec}}\right) = 6600\left(\frac{\text{in-lb}}{\text{sec}}\right)$

Pump: $3(GPM) = 3\left(\frac{\text{gal}}{\text{min}}\right) \cdot 231\left(\frac{\text{in}^3}{\text{gal}}\right) \cdot \frac{1}{60}\left(\frac{\text{min}}{\text{sec}}\right) = 11.55\left(\frac{\text{in}^3}{\text{sec}}\right)$

Using these values, the maximum pressure is

$$p_{\max} = 6600\left(\frac{\text{in-lb}}{\text{sec}}\right) \cdot \frac{1}{11.55}\left(\frac{\text{sec}}{\text{in}^3}\right) = 571 \text{ (psi)}$$

If the pressure relief valve is set above this value, the flow rate will slow until the motor ***stalls***.

Dead-heading a System

The circuit in Fig. 1 has an ***electric motor*** coupled with a ***hydraulic pump*** that pressurizes the fluid. A ***pressure gage***, a variable ***pressure relief valve***, a ***vent valve***, and a ***reservoir*** (tank) are located down-stream from the pump.

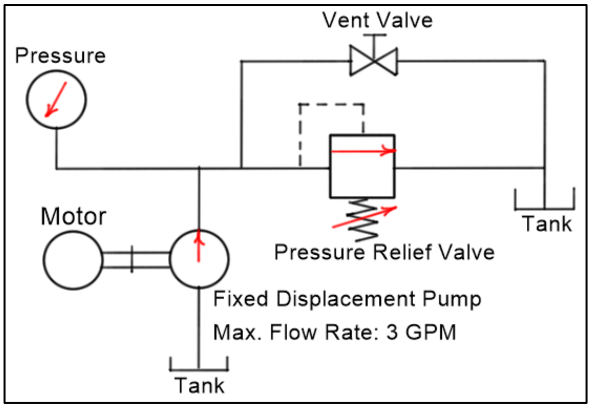


Fig. 1: Circuit diagram for the motor, pump, tank, vent valve, and relief valve.

If the ***vent valve*** is ***open***, fluid will flow freely from the pump to the tank. If the ***vent valve*** is ***closed***, the fluid has no place to flow and the system pressure will rise to a ***maximum value*** before the ***relief valve opens*** and maintains that pressure. "***Dead-heading***" the system occurs when the fluid in a system is prevented from flowing and the pressure in the system reaches a maximum value.

Pumps, Pressure, and Flow Rate

All hydraulic pumps have a flow rate limit. ***Fixed-displacement hydraulic pumps*** develop a reasonably constant fluid flow into the system. Generally, higher system pressures occur where the system has ***higher resistance*** to flow, and lower system pressures occur where the system has ***lower resistance*** to flow. When a system experiences its lowest level of resistance, the pump will operate at full capacity. The circuit in Fig. 2 is designed to determine the ***pump's maximum flow rate***. The circuit simply routes fluid through the flow meter, a filter, and then back to tank.

If a circuit is not providing the required amount of work, it is usually due to a ***lack of pressure*** in the system. An inadequate pump can cause the lack of pressure. The circuit may require a pump with a ***greater displacement*** or a pump with a ***higher speed***. Another solution to this problem is to ***supercharge*** the existing pump with another pump by coupling them together.

In Fig. 3, a ***flow control valve*** is placed in front of a flow meter. The function of the ***flow control valve*** is to place a restriction in the flow path and reduce the pump's flow rate in that particular portion of a hydraulic circuit. ***As the flow restriction area is made smaller and smaller***, the ***pressure*** in the system upstream of the restriction will ***increase*** until the pressure relief valve activates to divert the flow.

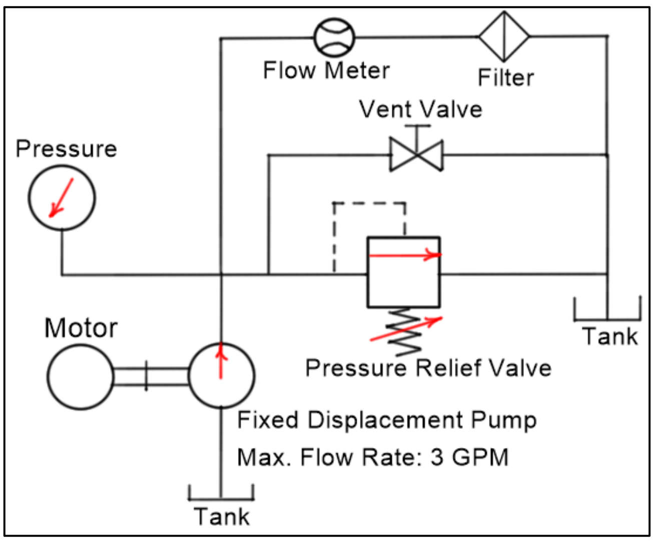


Fig. 2: A circuit to measure the maximum flow rate of the pump.

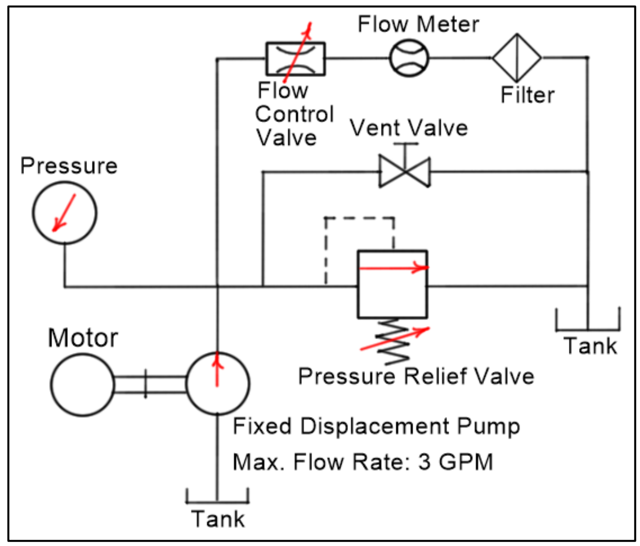


Fig. 3: A circuit to control the flow rate of hydraulic fluid.

## Simple Hydraulic Actuation Circuits

The circuit in Fig. 4 is an example of a ***standard actuation circuit***. Two components have been added to the circuit shown in Fig. 1, a ***three-position, four connection (way), spring-offset, mechanical control valve*** and a ***double-acting, single-rod cylinder***. The mechanical control valve ***allows flow*** into the system in ***two directions***, depending on which direction the lever is moved. This system ***cannot*** be ***dead-headed*** when the control valve is in the default, or centered, position because the mechanical valve allows the fluid to flow internally from the pressure port P to the return port T. The valve gives control over the ***direction*** of ***flow*** and ***some control*** over the ***flow rate***. The operator can adjust the lever slightly in either direction. This action will allow a little fluid to pass through the orifice of the valve and slowly move the piston inside the cylinder. If the lever is moved ***completely left*** (or ***right***), the piston velocity will increase to a maximum value.

Fig. 5 shows the circuit of Fig. 4 with the mechanical control valve replaced with a ***solenoid-operated control valve***. Because this valve does not allow internal flow from the pressure port P to the return port T, the system ***can*** be ***dead-headed*** by simply centering the valve. The solenoid valve also ***does not give control*** over the ***flow rate***, because once the solenoid is activated in either direction, it moves the valve spool into the extreme left or right positions. However, like the mechanical valve, the ***direction*** of ***flow can be controlled***.

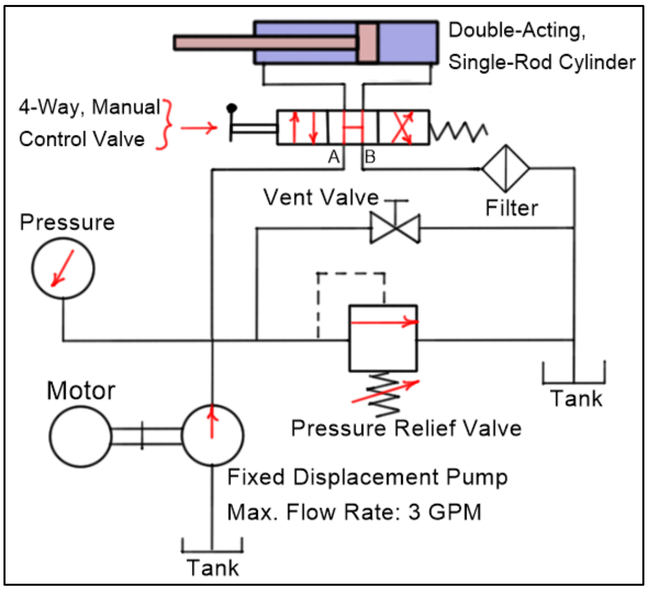


Figure 4: Simple actuation circuit with a double-acting cylinder and manual 4-way valve.

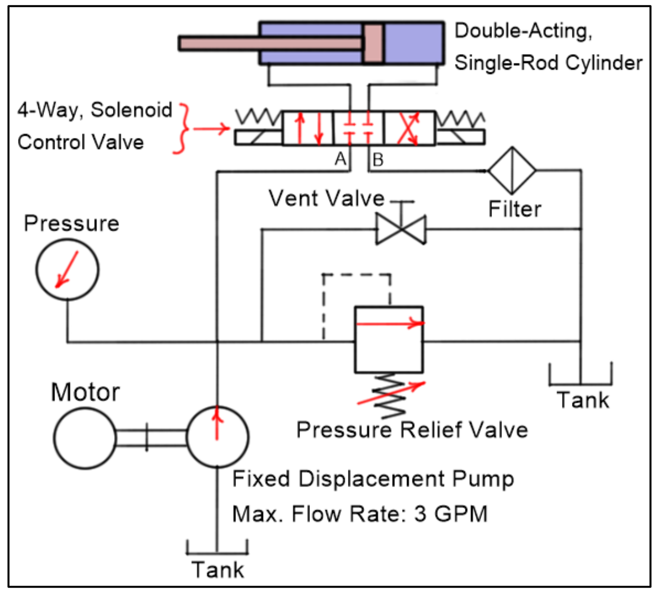


Figure 5: Simple actuation circuit with a double-acting cylinder and 4-way solenoid valve.

The ***cylinder*** in both systems is said to be ***double-acting***, because it is actuated in both directions by pressurized fluid. When the ***solenoid*** is ***activated*** to the ***right***, fluid flows from port P into port A and ***retracts*** the cylinder. When the ***solenoid is activated*** to the ***left***, the cross configuration to the right is enabled and ***extends*** the cylinder.

When the piston reaches the end of the cylinder, the ***system*** will be ***dead-headed***. This is because the fluid that is pushing the piston has nowhere to go once the piston has extended or retracted completely. If the ends of the cylinder are "***cushioned***", the motion of the cylinder will slow as it reaches the end of its stroke due to a ***hydraulic damping circuit*** incorporated into the ends of the cylinder.