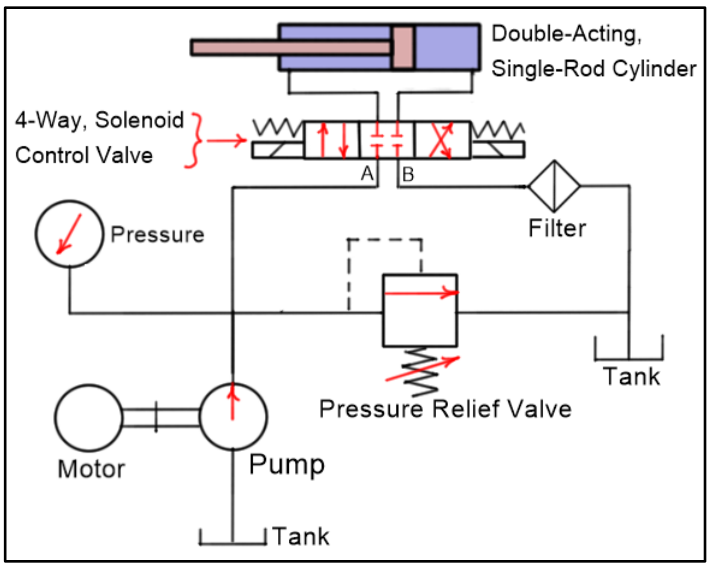
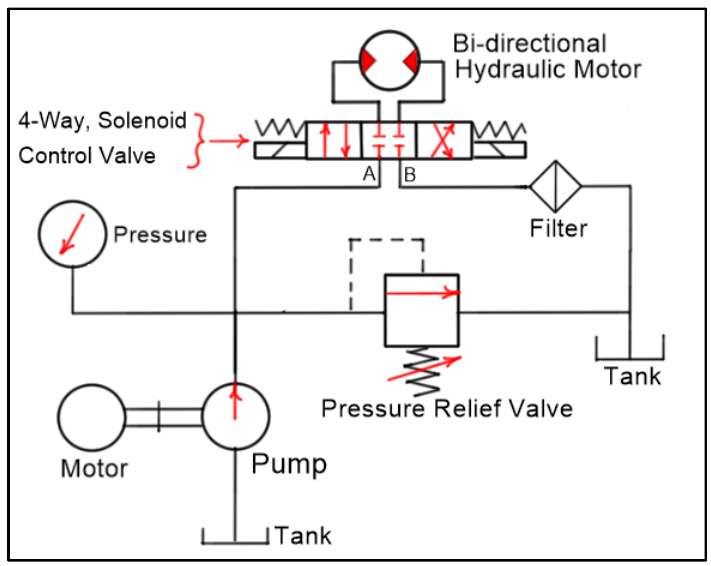
Introductory Motion and Control
Hydraulic Actuation System Components

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

Hydraulic actuation systems convert ***mechanical power*** (provided by a motor or engine) into ***fluid power***, transmit the fluid power to some location, and convert fluid power back into mechanical power to do ***useful work***. The figures below depict ***two typical systems***. The one on the left produces ***translational*** (or linear) motion, while the one on the right produces ***rotational*** motion. Even though power is lost each time it is converted to a different form or transmitted over some distance, these systems are still widely used, especially when it is required to control the motion of large loads.



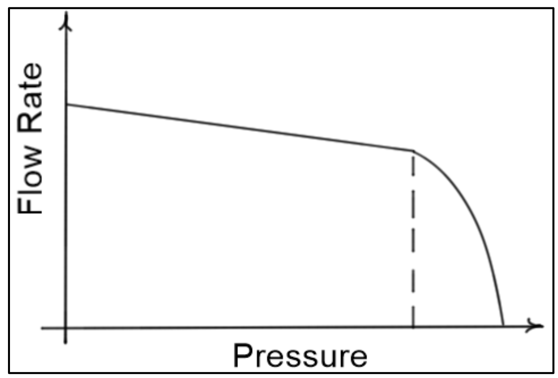


In each case shown, an ***electric motor*** drives a ***pump*** to produce ***pressurized fluid***. In the system on the left, the fluid is used to extend or retract the piston in a ***hydraulic cylinder***. In the system on the right, the fluid is used to rotate the ***hydraulic motor*** either clockwise or counter-clockwise. The ***directional control valves*** determine whether the cylinder extends or retracts, which direction the hydraulic motor rotates, and in each case how quickly. For safety purposes, both systems also use a ***pressure relief valve***.

Pumps

There are many different types of pumps used in industrial applications. The most common types are ***vane*** pumps, ***gear*** pumps, and ***piston*** pumps. Each of these can provide a ***fixed*** or ***variable volume*** of fluid to the system per revolution of the motor or engine. Fixed volume (fixed displacement) pumps are shown in the systems above.

Fixed volume pumps move a ***fixed volume*** of fluid into the system ***irrespective of system pressure***. As system pressure rises beyond a specified limit, a ***pressure relief valve*** is used to divert unneeded flow back to the tank. Unfortunately, this tends to heat the hydraulic fluid. Conversely, ***pressure compensated, variable volume pumps*** will decrease the volume of flow into the system when system pressure goes beyond a set limit. As the pressure continues to increase, the flow from the pump will eventually cease.

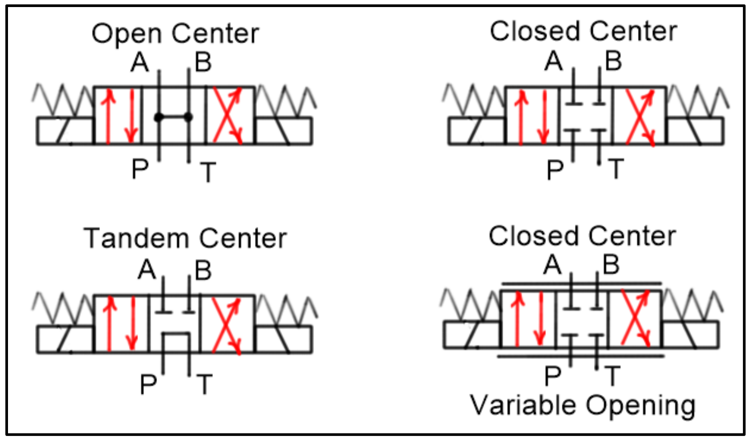


The figure to the right shows a ***performance curve*** for a typical pressure compensated variable volume pump. The flow rate is zero at the compensator setting, but it will begin to significantly drop flow rate (by decreasing its volume) at pressures below this value. Hence, the pump lowers the hydraulic power to zero as the pressure approaches the compensator setting.

Pressure Relief Valves

Pressure relief valves are used to control the ***maximum pressure*** at some point within a system and should always be present for safety purposes. In the system shown above ***on the left***, the directional control valve has a ***closed center position*** meaning that when the valve spool is centered, no flow can pass through the valve. In this case, the use of a pressure relief valve is essential, because without it, the pressure in the line feeding the control valve would continue to rise when the valve is closed. This would result in one of two possibilities: 1) the pressure line would fail, or 2) the electric motor would be overloaded and stop.

Directional Control Valves



Four-way directional control valves are very commonly used in hydraulic actuation systems. As the name implies, there are ***four ways (ports) for fluid to enter or leave the valve***. These ports are referred to as the pressure (P) port, the tank (T) port and the working ports A and B. The supply line connects to the P port, and the return line to the T port.

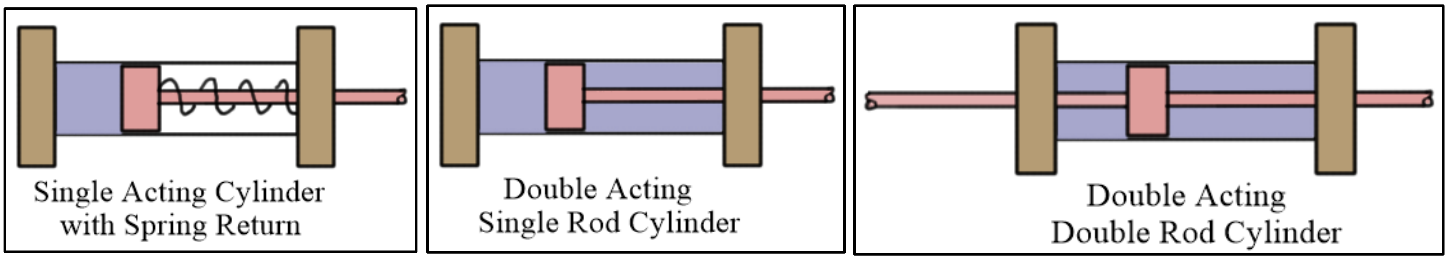
The figure above depicts some ***common four-way valve configurations***. The two on the left and the one on the upper right are each ***four-way, three-position, solenoid valves***, each having a different center configuration. A ***solenoid*** is used to move the valve spool into either the left or right position, and a ***spring*** is used to center the spool when no voltage is applied to the solenoid. When the spool is in the ***left position***, pressurized fluid is sent to the A port and the B port is connected to the tank. When the spool is in the ***right position***, pressurized fluid is sent to the B port and the A port is connected to the tank.

Open center valves allow fluid to flow freely from the P, A, and B ports to the tank when the valve spool is centered. If a cylinder is connected to an open center valve, it will be ***free*** to ***move*** when the valve spool is centered. ***Closed center valves*** stop all fluid flow when the valve spool is centered. A cylinder connected to this type of valve will be unable to move when the valve spool is centered. ***Tandem center valves*** block the flow to the A and B ports, holding a connected cylinder in place, but allow the pump flow to return to the tank when the spool is centered.

The valve on the bottom right is a ***proportional directional valve***. The solenoid in this valve may be used to move the valve spool to a ***continuously variable position*** between the left and right extremes. This allows the circuit to not only control the ***direction*** of the ***flow***, but also the ***flow rate***. This type of valve combines the attributes of ***directional control*** and ***flow control*** valves.

Hydraulic Cylinders

Hydraulic cylinders are used to convert fluid power into ***translational (or linear) mechanical power***. Cylinders fall into three general categories – ***single-acting***; ***double-acting, single-rod***; and ***double-acting, double-rod***.



Each type of cylinder has a ***piston*** and a ***rod***. In a ***single-acting*** cylinder, pressurized fluid is used to push on one side of the piston only (usually to extend), while in a ***double-acting*** cylinder, pressurized fluid is used to both extend and retract the cylinder. In a ***single-rod*** cylinder, the ***area*** on the ***rod end*** of the piston ***is smaller*** than the area on the ***cap end***. In a ***double-rod*** cylinder, the ***area*** on ***both ends*** of the piston ***are the same***. Hence, for a given pressure, a single-rod cylinder will apply a ***larger force*** in extension than it does in retraction, where as a double-rod cylinder will apply the ***same force*** in both directions.

Assuming the hydraulic fluid is ***incompressible***, the ***speed*** of the rod can be related to the flow rates into and out of the cylinder.

$$\boxed{Q_i = v A_i} \quad \text{and} \quad \boxed{Q_o = v A_o}$$

Here, Q_i and Q_o are the ***volumetric flow rates into*** and ***out of*** the cylinder, A_i and A_o are the ***piston areas*** on the ***in-flow*** and ***out-flow*** sides of the piston, and v is the ***speed*** of the piston and rod.

Hydraulic Motors

Hydraulic motors are much like pumps except they are driven by pressurized fluid instead of an engine or electric motor. They ***convert hydraulic power*** into ***rotational mechanical power***. The most common types are gear motors, vane motors and piston motors. (Gear motors are the most common.) The ***speed*** and ***direction of rotation*** of the motor is determined by the ***rate*** and ***direction*** of ***flow*** through the motor.