Hydraulic Systems

- designed to move large loads and heavy equipment (e.g., construction equipment and large industrial machines).
- use a fluid (light-grade oil) to transfer energy from a pump to an actuator.
- Typical pressure are in the 1000 psi (6.89 MPa) to 3000 psi (20.7 MPa) range.
- A simplified system consists of the following components:
  - a tank of hydraulic fluid, a pump, a control valve, a distribution system composed of hoses or pipes, and a cylinder,.
- A complete simple hydraulic system includes:
  - tank, filter, pump, accumulator, pressure-control valve, directional control valve, distribution system composed of hoses or pipes and cylinder.

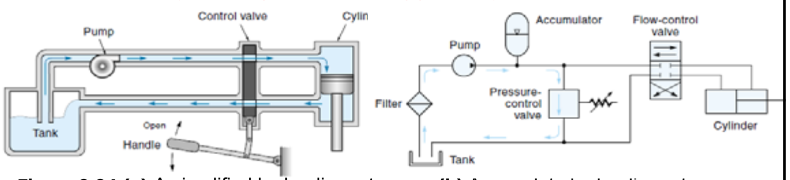


Figure 3.24 (a) A simplified hydraulic system **(b)** A complete hydraulic system

Hydraulic Systems

- The pump pushes the fluid through a tube to the control valve.
- The control valve directs the fluid to the cylinder, causing the piston to move down in response to the fluid pressure.
- The pump is the actual source of mechanical power, and it is physically separate from the cylinder actuator.
  - only the cylinder needs to be mounted at the place where the motion is needed; the pump can be elsewhere.
  - This allows a relatively small component such as a hydraulic cylinder to provide far more power than a similarly sized electric actuator, which must have the motor attached.
- When the piston in the cylinder is not moving, the fluid from the pump, after filling the accumulator, returns to the tank through the pressure-control valve.
- The filter removes small contaminants, which can get into the fluid. These contaminants can cause abrasive wear on the system components and reduce their lifetime considerably.

Hydraulic Systems: Hydraulic Pumps

- In an active hydraulic system, a pump is used to create the hydrostatic pressure.

Gear Pump

- consists of two meshed gears in a housing.
- As the gears rotate, fluid is trapped in the little spaces between the teeth and the housing (both top and bottom) and is conveyed from the inlet to the outlet.
- The mesh between the gears in the center is tight enough so that no fluid moves through either way at that point.
- This type of pump is also known as a **positive-displacement pump** because a constant volume of fluid is pumped for every revolution of the gears.

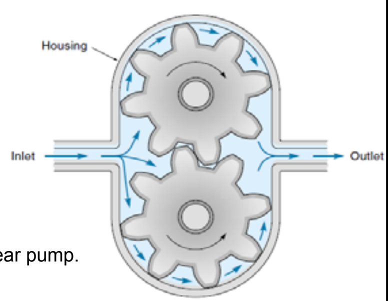


Figure 3.25
A hydraulic gear pump.

Hydraulic Pumps: Vane Pump

- consists of an offset rotor in a housing with retractable vanes.
- The spring-loaded vanes push out and seal against the housing wall.
- Because there is more fluid between the vanes in the top half of the housing than in the bottom, there is a net transfer of fluid from the inlet to the outlet.
- In some designs, the position of the rotor axis is adjustable.
- The more offset the rotor axis, the more fluid is pumped.
- Such a pump is called a **variable-displacement pump.**

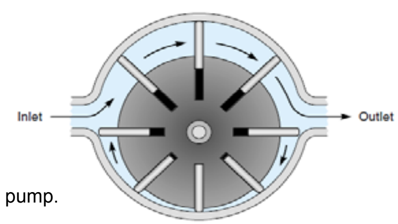


Figure 3.26
A hydraulic vane pump.

Hydraulic Actuators:

- May be linear or rotary types.
- The most common type of linear hydraulic actuator is the **hydraulic cylinder.**
- A typical cylinder shown in Figure is known as a **double-acting cylinder** because it can provide force in either direction.
- It consists of a piston and a cylinder body. The piston has a rod that extends out one end of the cylinder.
- Fluid can enter and leave the cylinder on either side of the piston through ports.
- Under normal operating conditions, both ends of the cylinder are filled with fluid. If additional fluid enters port A, the piston will move toward the right, but the fluid must be able to escape through port B.

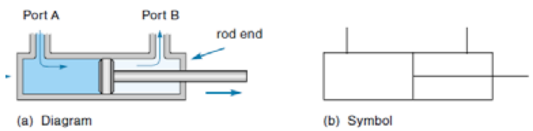


Figure 3.27
A double-acting hydraulic cylinder.

Hydraulic Actuators:

- A typical rotary hydraulic actuator is the **gear motor**.
- The gear motor is almost identical to the gear pump.
- For the motor, fluid is pumped in the left side of the case, putting that area under pressure (indicated by *p*).
- Within the pressurized area, all surfaces receive a force, but only those three surfaces indicated with arrows will affect rotation (the other surfaces are balanced out or unmoveable).
- The pressure on the teeth next to the case (top and bottom arrows) will cause the gears to rotate as shown.
- The pressure on the meshing teeth in the center would cause the gears to turn in the opposite direction, but this torque is overpowered because two teeth (top and bottom) are pushing the other way.

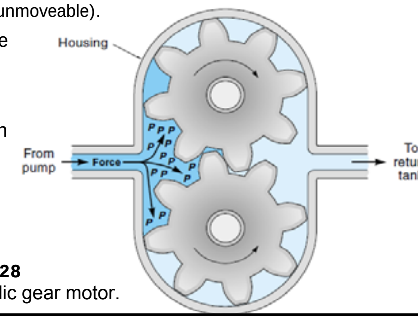


Figure 3.28
A hydraulic gear motor.

Pressure-control valve

- a spring-loaded valve that is capable of maintaining a constant pressure in a system, regardless of the flow rate.
- This is important because most pumps (such as the gear pump) are constant-displacement types—a constant volume of fluid is pumped for each revolution of the pump shaft.
- If the pump were connected directly to the cylinder, it would have to start and stop each time the piston moved to a new position. Such on-off cycling reduces the lifetime of machinery and is therefore undesirable.
- When a pressure-control valve is put into the system, the pump can remain on the whole time—when the fluid pressure exceeds the preset limit, the valve opens, and the surplus fluid is simply returned to the tank.

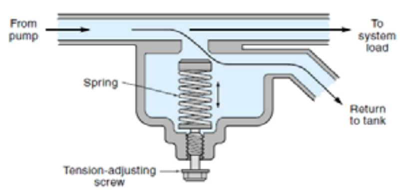
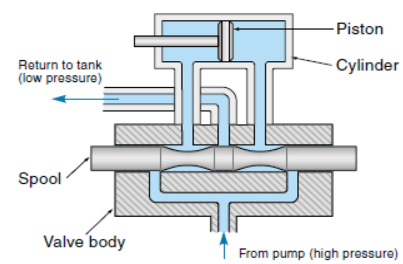


Figure 3.29
A pressure-control valve (partially open position).

Flow-control valve

- The flow-control valve is used to regulate the flow rate of hydraulic fluid.
- The most important type of flow valve is the **directional control valve,** which regulates the movement of the piston in the cylinder.
- A sophisticated device, capable of admitting pressurized fluid to either end of the cylinder while providing a return path for fluid being squeezed out of the other end of the cylinder.



(a) Spool centered

Figure 3.30
A directional control valve for a double acting cylinder.

Flow-control valve

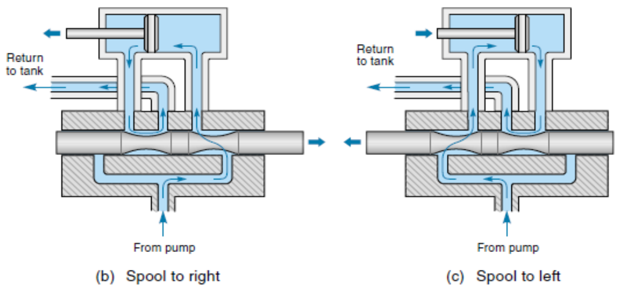


Figure 3.30 A directional control valve for a double acting cylinder.

Accumulators

- An **accumulator** is a special kind of spring-loaded storage tank for hydraulic fluid.
- The accumulator serves two functions.
  - First, it acts as a low-pass filter to remove pressure pulsations from the pump;
  - second, it stores extra fluid for those high-demand times when the actuator requires fluid at a faster rate than the pump can supply.

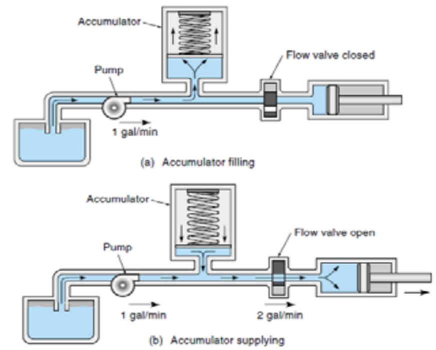


Figure 3.31
An accumulator in a system.
(For simplicity, pressure regulator and return line are not shown).

Pneumatic Systems

- use air pressure to create mechanical motion.
- The basic system includes
  - an intake filter that traps dirt before it enters the system,
  - an air compressor that provides a source of compressed air,
  - a dryer that removes the moisture in the air,
  - a pressure tank that is a reservoir of compressed air,
  - a pressure regulator that maintains air pressure,
  - a valve that controls the air flow, and
  - a pneumatic cylinder that creates the mechanical motion.

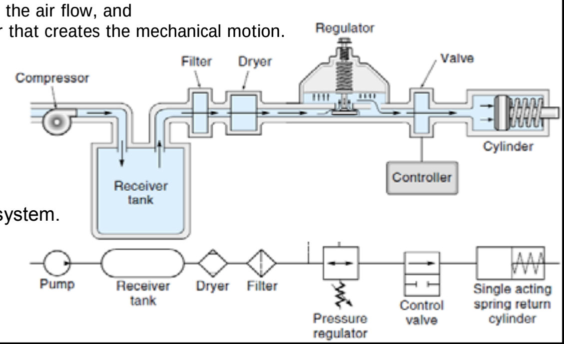


Figure 3.32
A simplified pneumatic system.

Pneumatic Systems

Dryer

- Water vapor in the compressed air must be removed, or it will eventually damage the pneumatic components.
- Removing the moisture in the air is done by the **dryer.**

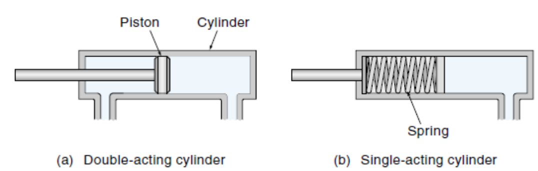
Types of dryers:

(i) Aftercooler: - chills the air, causing the moisture to condense into drops, which can then be drained off.

(ii) Desiccant dryer

- circulates the air through a moisture-absorbing chemical called a desiccant.
- When the desiccant becomes saturated (often indicated by a change in color), it must be changed.

Pneumatic cylinders



Pneumatic Systems:

Figure 3.33
Pneumatic cylinders.

Pneumatic Systems: Problem

A spring-loaded single-acting cylinder has a diameter of 5 cm and a stroke of 5 cm. The return spring has a spring constant of 53 kg/m. The available air pressure is 206 kPa.

What force can this cylinder supply to a load at the end of its stroke?

First we calculate the piston surface area

$$A = \pi r^2 = 3.14 \times 2.5 \text{ cm}^2 = 7.85 \times 10^{-4} \text{ m}^2$$

Now, find the force exerted by piston,

$$F_{piston} = PA = 206 \times 10^3 \text{ Pa} \times 7.85 \times 10^{-4} \text{ m}^2 = 161.71 \text{ N}$$

Some of this force is used to compress the spring and is *not* available to the external load.

The force needed to compress the spring 5 cm is calculated as follows:

$$F_{spring} = \text{spring constant} \times \text{length} = 53 \text{ kg/m} \times 5 \times 10^{-2} \text{m} = 2.65 \text{ N}$$

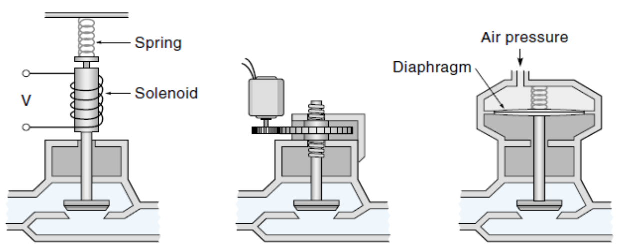
Therefore, the total available force from the cylinder is

$$F = F_{piston} - F_{spring} = (161.71 - 2.65) \text{ N} = 159.06 \text{ N}$$

Actuators: Flow-control Valves

- One common type of actuator used in process control systems is the **flow-control valve,** which regulates the flow of fluids.
- The control valve has a built-in valve-operating mechanism, allowing it to be controlled remotely by a signal from the controller. Usually, this signal is either electric or pneumatic.

Figure 3.34
Flow-control valves.



(a) On–off type: solenoid-actuated
(b) Variable flow: electric-actuated
(c) Variable flow: pneumatic-actuated

Actuators: Flow-control Valves

(a) Solenoid-actuated, on-off valve

- when the solenoid is energized, the valve is pulled open, and the fluid flows.
- when the solenoid is deenergized, a spring returns the valve to the closed position.
- On-off valves are used in batch processes (e.g., a washing machine where the tank is filled to a specified level as quickly as possible, agitated for a while, then emptied).

(b) Electrically operated valve

- an electric motor drives a leadscrew-type valve stem, so it can be put in any position
- used in the processes that require the ability to vary the flow of a fluid in a pipe on a continuous basis.

(c) Pneumatically operated valves

- use air pressure as the control signal.
- when the air pressure is increased, the diaphragm will move down (against a spring) and close the valve.
- this type of valve could be used in an on-off or a variable-flow application.

Relays: Electromechanical Relays

- The **electromechanical relay** (EMR) is a device that uses an electromagnet to provide the force to close (or open) switch contacts, in other words, an electrically powered switch.
- When the electromagnet, called the coil, is energized, it pulls down on the spring-loaded armature.
- Relay contacts are of two kinds: (i) normally open contacts (NO), which are open in the unenergized state, and (ii) normally closed contacts (NC), which are closed in the unenergized state.
- By convention, the Relay symbol always depicts the relay in the unenergized state, so we can easily determine which are the NC and NO contacts from the schematic.

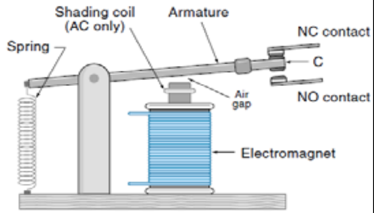
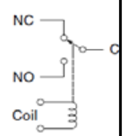


Figure 3.35
An electromagnetic relay.



Relay symbol

Relays: Electromechanical Relays

- Relays are available in a variety of sizes, contact configurations, and power-handling capabilities.
- Figure 3.36 shows a selection of different relays.

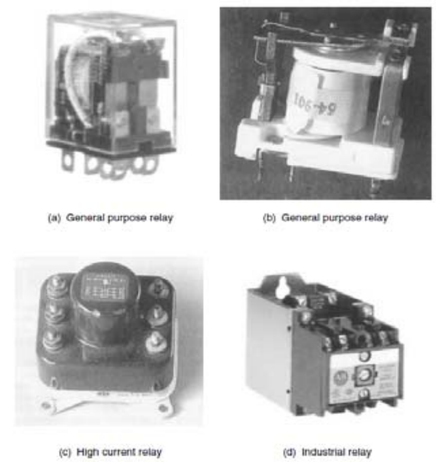


Figure 3.36
A selection of relays.

Relays: Electromechanical Relays

- Relays have a finite life, because
  - First, because the relay is a mechanical device, the moving parts eventually wear out, and
  - second, the electrical contacts can become pitted because of arcing.
- The contact wear is very dependent on the electric current that is being switched.
  - For example, a certain relay is rated for 9 million operations at 1.5 amps but only 2 million operations at 3 amps.
  - Two million operations sounds like a lot, but if this relay were in a 24-hour factory being used in a repetitive operation every 10 seconds, it would have to be replaced every 8 months.
- Contact life also depends on the type of load being controlled.
  - For example, inductive loads such as motors cause much more arcing and pitting than resistive loads such as lights and heating elements.

Electromechanical Relays: reed relay

- The **reed relay** is unique because the small reedlike contacts are encapsulated in a small sealed glass tube that is evacuated or filled with an inert gas like dry nitrogen.
- The contacts are activated by an external magnetic field.
- Contacts are either dry or mercury-wetted.
- Mercury-wetted contacts have a thin coating of mercury that fills in surface irregularities, making a larger conduction area, and reduces pitting.
- Generally, reed relays have a long life.

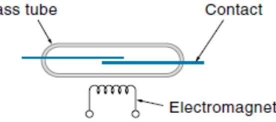
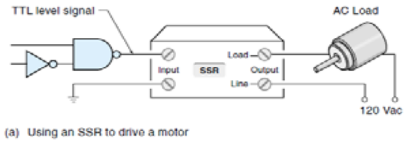
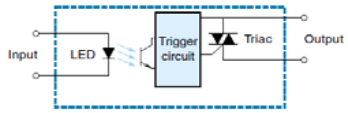


Figure 3.37
A reed relay.

Solid-State Relays

- purely solid-state device that has replaced the EMR.
- Physically, the SSR is packaged in a box (about the same size as an EMR), with four electrical terminals, as shown in Figure 3.38(a).
  - The two input terminals are analogous to the coil of an EMR, and
  - the two output terminals are analogous to the contacts of the EMR (usually SPST, normally open).





(b) SSR circuit

Figure 3.38
A solid-state relay.

Solid-State Relays

Working principle

- The input voltage drives an LED, and the light from the LED turns on a photo transistor, which in turn turns on the triac (a solid-state switching device).
- The LED electrically isolates the input and output sections of the SSR.
  - This is important for two reasons:
  - First, it allows the control electronics to have a separate ground from the power lines;
  - second, it prevents high-voltage spikes in the power circuit from working their way back upstream to the more delicate control electronics.

Advantage

- Having no moving parts means that (theoretically) they will never wear out and makes them practically immune to shock and vibration.
- Because of the built-in electronics, they can be driven with a low-voltage source (such as TTL) regardless of the output-current capability.