# Module 2

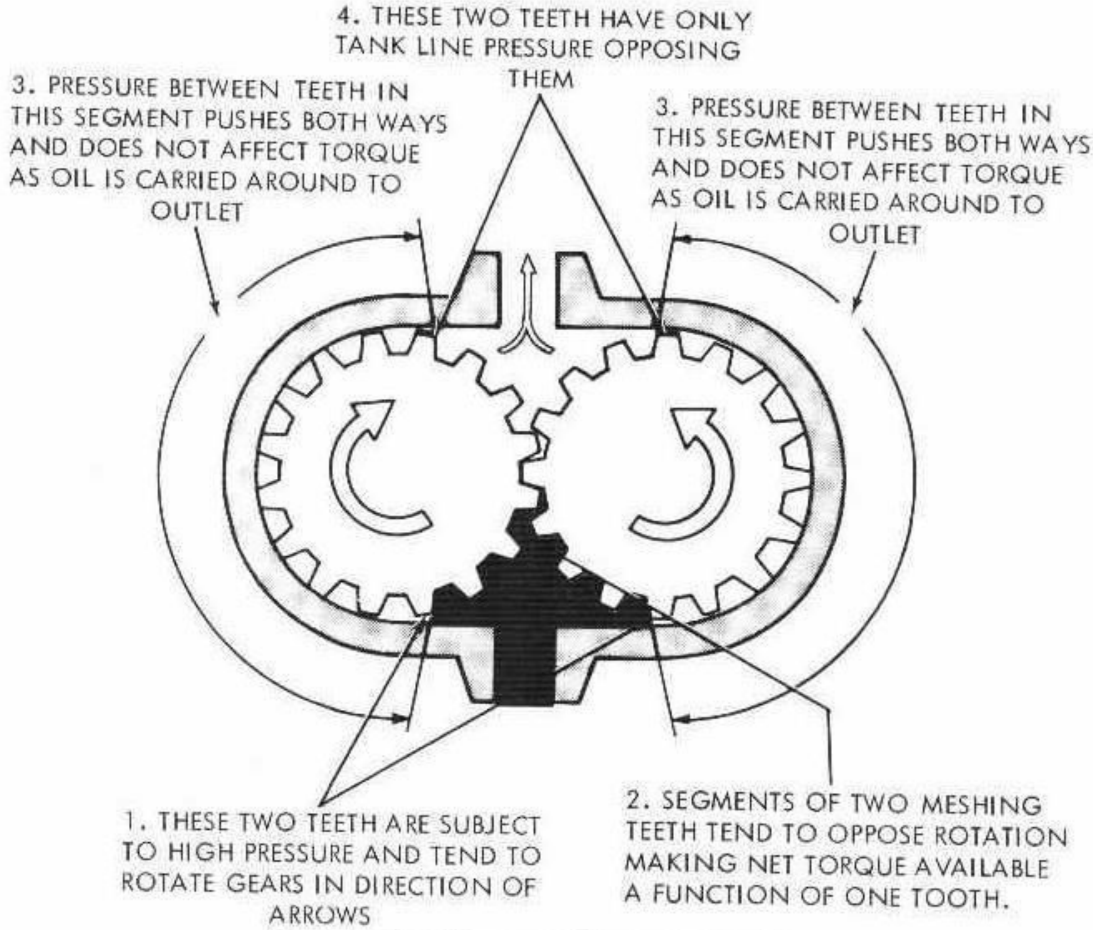
**System Drives and devices:** Hydraulic and pneumatic motors and their features, Electrical motors AC/DC and their features

**Actuators:** Electrical Actuators; Solenoids, Relays, Diodes, Thyristors, Triacs, Hydraulic and Pneumatic actuators, Design of Hydraulic and Pneumatic circuits, Piezoelectric actuators, Shape memory alloys.

# Hydraulic motors

Hydraulic motors are actuators that can rotate continuously and as such have the same basic configuration as pumps. However, instead of pushing on the fluid as pumps do, motors are pushed upon by the fluid. In this way, hydraulic motors develop torque and produce continuous rotary motion. Since the casing of a hydraulic motor is pressurized from an outside source, most hydraulic motors have casing drains to protect shaft seals. There are three basic types of hydraulic motors: gear, vane, and piston. Let's first examine the operation and configuration of the gear motor.

A gear motor develops torque due to hydraulic pressure acting on the sur-
faces of the gear teeth, as illustrated in Fig.




Torque development by a gear motor.

The direction of rotation of the
motor can be reversed by reversing the direction of flow. As is the case for gear pumps, the volumetric displacement of a gear motor is fixed. The gear motor
shown in Fig.
is not balanced with respect to pressure loads. The high

motor can be reversed by reversing the direction of flow. As is the case for gear pumps, the volumetric displacement of a gear motor is fixed. The gear motor shown in Fig. 7-22 is not balanced with respect to pressure loads. The high pressure at the inlet, coupled with the low pressure at the outlet, produces a large side load on the shaft and bearings. Gear motors are normally limited to 2000-psi operating pressures and 2400-rpm operating speeds. They are available with a maximum flow capacity of 150 gpm.

The main advantages of a gear motor are its simple design and subsequent low cost. Figure 7-23 shows a cutaway view of an actual gear motor. Also shown is the hydraulic symbol used in hydraulic circuits for representing fixed displacement motors.

Hydraulic motors can also be of the internal gear design. This type can operate at higher pressures and speeds and also has greater displacements than the external gear motor.

As in the case of pumps, screw-type hydraulic motors exist using three meshing screws (a power rotor and two idler rotors). Such a motor is illustrated in Fig. 7-24. The rolling screw set results in extremely quiet operation. Torque is developed by differential pressure acting on the thread area of the screw set. Motor torque is proportional to differential pressure across the screw set. This particular motor can operate at pressures up to 3000 psi and can possess volumetric displacements up to 13.9 in.$^3$.

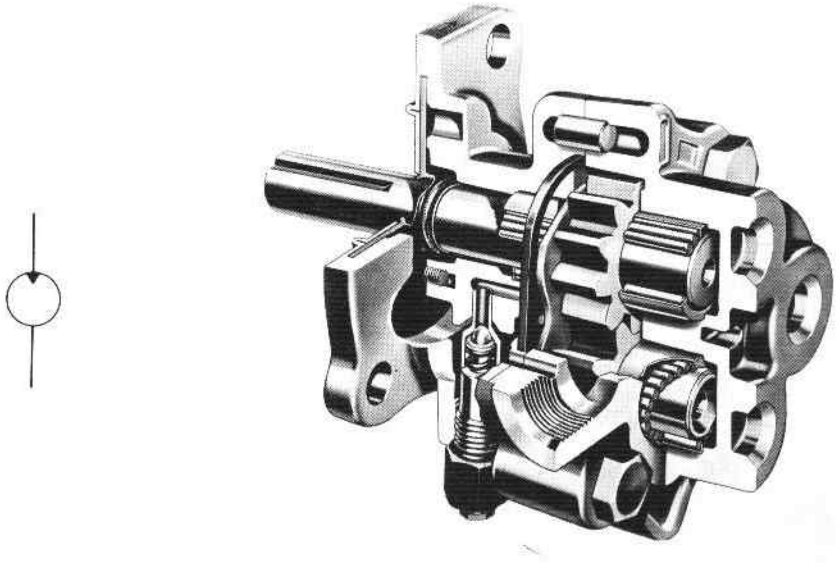


**Figure 7-23.** External gear motor. (*Courtesy of Webster Electric Company, Inc., subsidiary of STA-RITE Industries, Inc., Racine, Wisconsin.*)

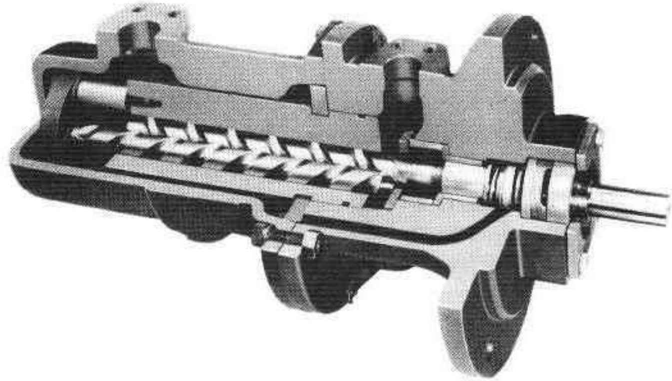


**Figure 7-24.** Screw motor. (*Courtesy of DeLaval, IMO Pump Division, Trenton, New Jersey.*)

## 7.6 VANE MOTORS

Vane motors develop torque by the hydraulic pressure acting on the exposed surfaces of the vanes, which slide in and out of the rotor connected to the drive shaft (see Fig. 7-25, view A). As the rotor revolves, the vanes follow the surface of the cam ring because springs (not shown in Fig. 7-25) are used to force the vanes radially outward. No centrifugal force exists until the rotor starts to revolve. Therefore, the vanes must have some means other than centrifugal force to hold them against the cam ring. Some designs use springs, whereas other types use pressure-loaded vanes. The sliding action of the vanes forms sealed chambers, which carry the fluid from the inlet to the outlet.

Vane motors are universally of the balanced design illustrated in view B of Fig. 7-25. In this design, pressure buildup at either port is directed to two interconnected cavities located 180° apart. The side loads that are created are therefore canceled out. Since vane motors are hydraulically balanced, they are fixed displacement units.

Figure 7-26 shows a design where pivoted rocker arms are attached to the rotor and serve as springs to force the vanes outward against the elliptical cam ring. This type of motor is available to operate at pressures up to 2500 psi and at speeds up to 4000 rpm. The maximum flow delivery is 250 gpm.

## 7.7 PISTON MOTORS

Piston motors can be either fixed or variable displacement units. They generate torque by pressure acting on the ends of pistons reciprocating inside a cylinder block. Figure 7-27 illustrates the in-line design in which the motor driveshaft and

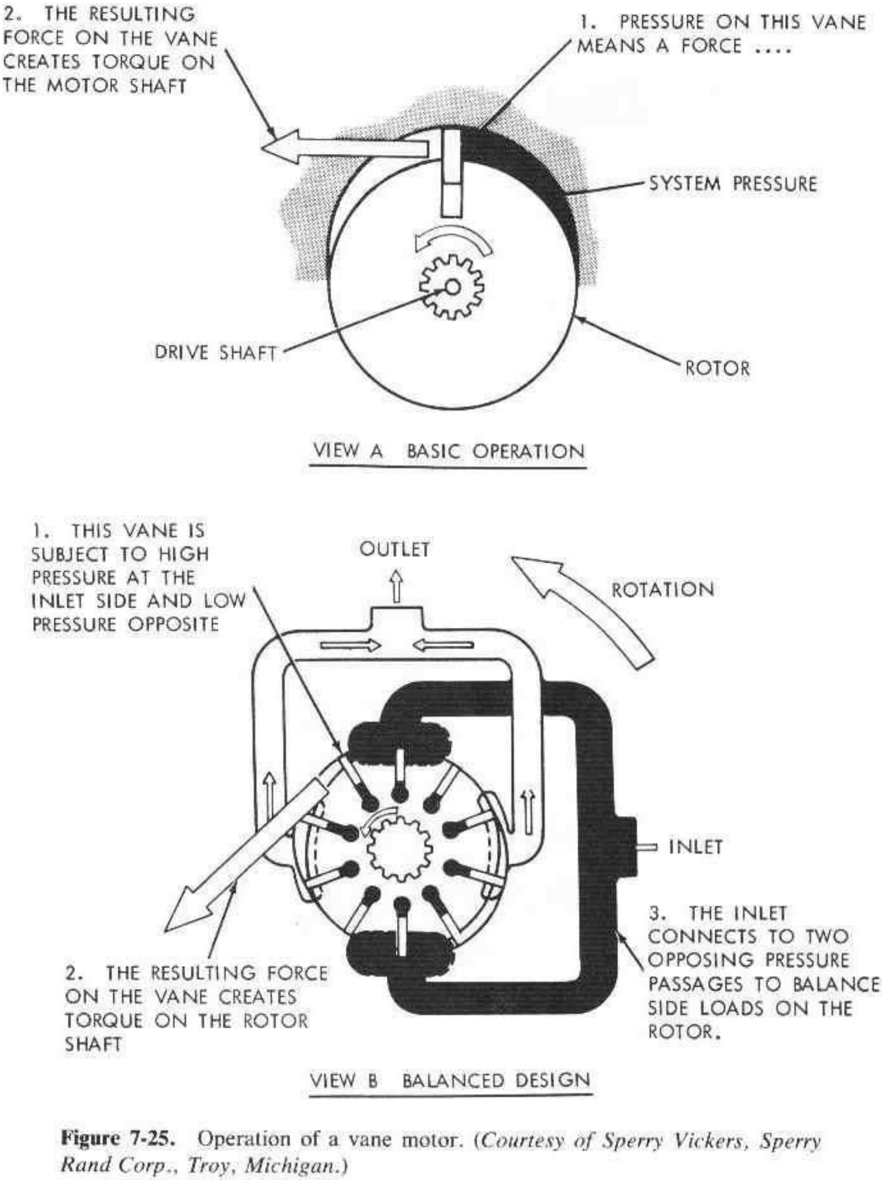



**Figure 7-25.** Operation of a vane motor. (*Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.*)

cylinder block are centered on the same axis. Pressure acting on the ends of the pistons generates a force against an angled swash plate. This causes the cylinder block to rotate with a torque that is proportional to the area of the pistons. The torque is also a function of the swash plate angle. The in-line piston motor is designed either as a fixed or variable displacement unit (see Fig. 7-28). As illustrated in Fig. 7-29, the swash plate angle determines the volumetric displacement.

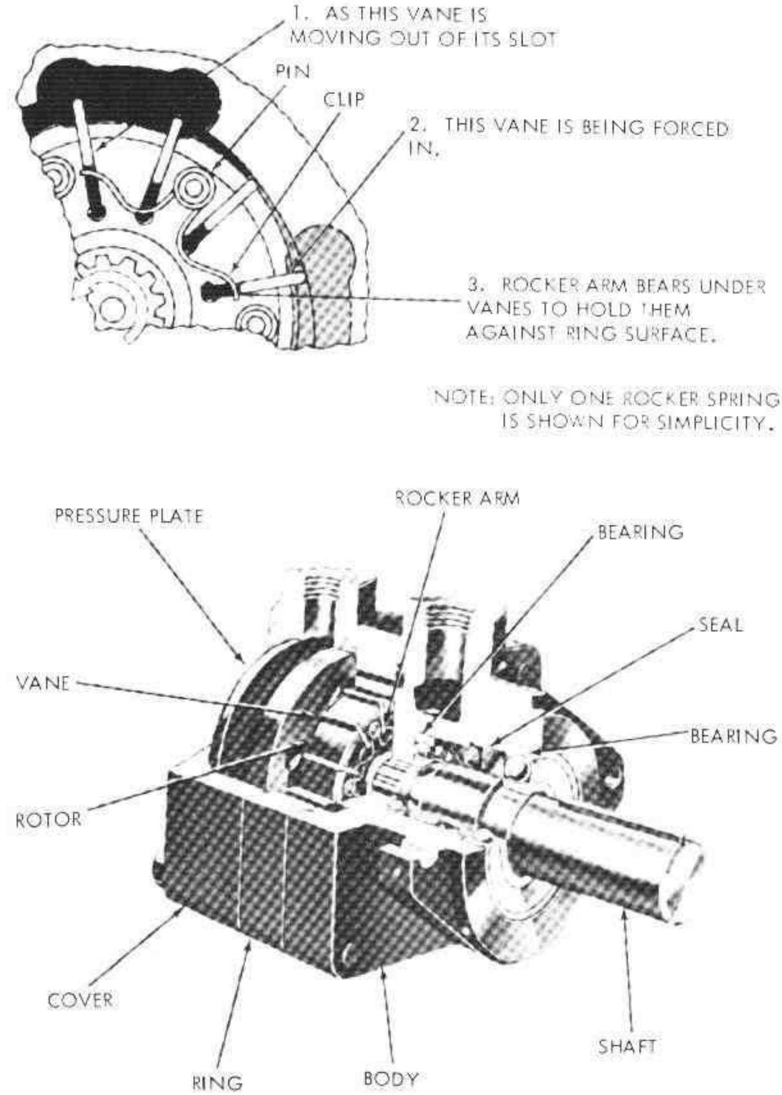



**Figure 7-26.** Vane motors with spring-loaded vanes. *(Courtesy of Sperry Vickers, Sperry Rand Corp, Troy, Michigan.)*

In variable displacement units, the swash plate is mounted in a swinging yoke. The angle of the swash plate can be altered by various means, such as a lever, handwheel, or servo control. If the swash plate angle is increased, the torque capacity is increased, but the drive shaft speed is decreased. Mechanical stops are usually incorporated so that the torque and speed capacities stay within prescribed limits.

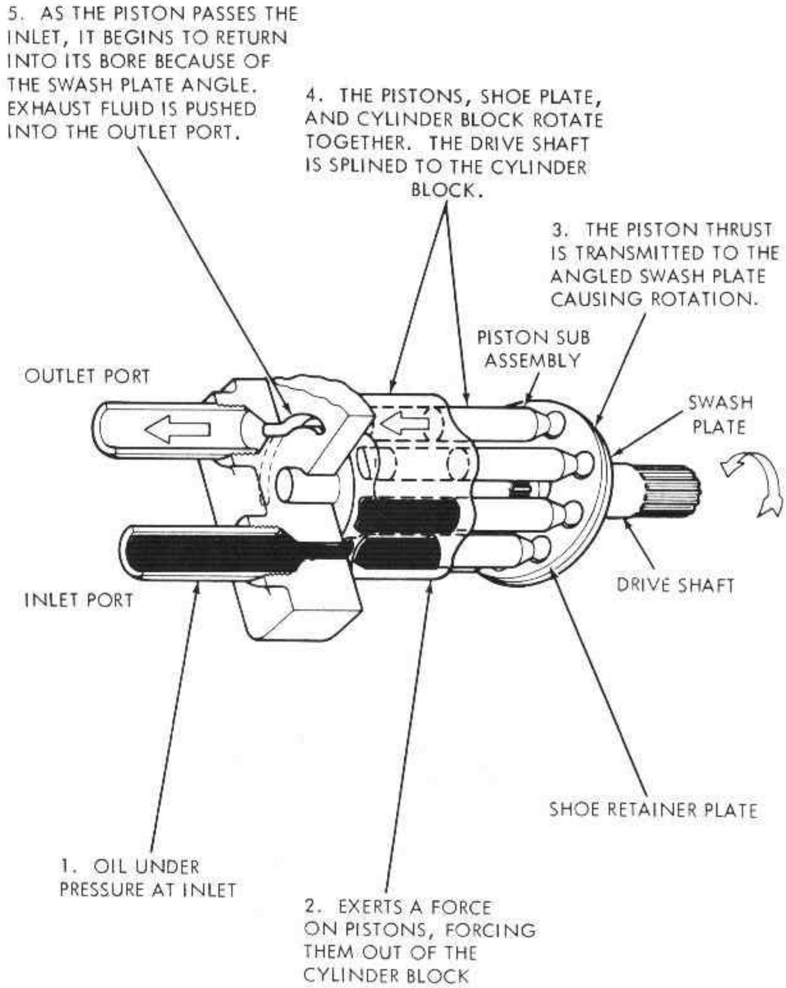



**Figure 7-27.** In-line piston motor operation. (*Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.*)

A bent-axis piston motor is illustrated in Fig. 7-30. This type of motor also develops torque due to pressure acting on reciprocating pistons. This design, however, has the cylinder block and driveshaft mounted at an angle to each other so that the force is exerted on the driveshaft flange.

Speed and torque depend on the angle between the cylinder block and driveshaft. The larger the angle, the greater the displacement and torque but the smaller the speed. This angle varies from a minimum of $7\frac{1}{2}°$ to a maximum of 30°. Figure 7-31 shows a fixed displacement, bent-axis motor, whereas Fig. 7-32 illustrates the variable displacement design in which the displacement is varied by a handwheel.

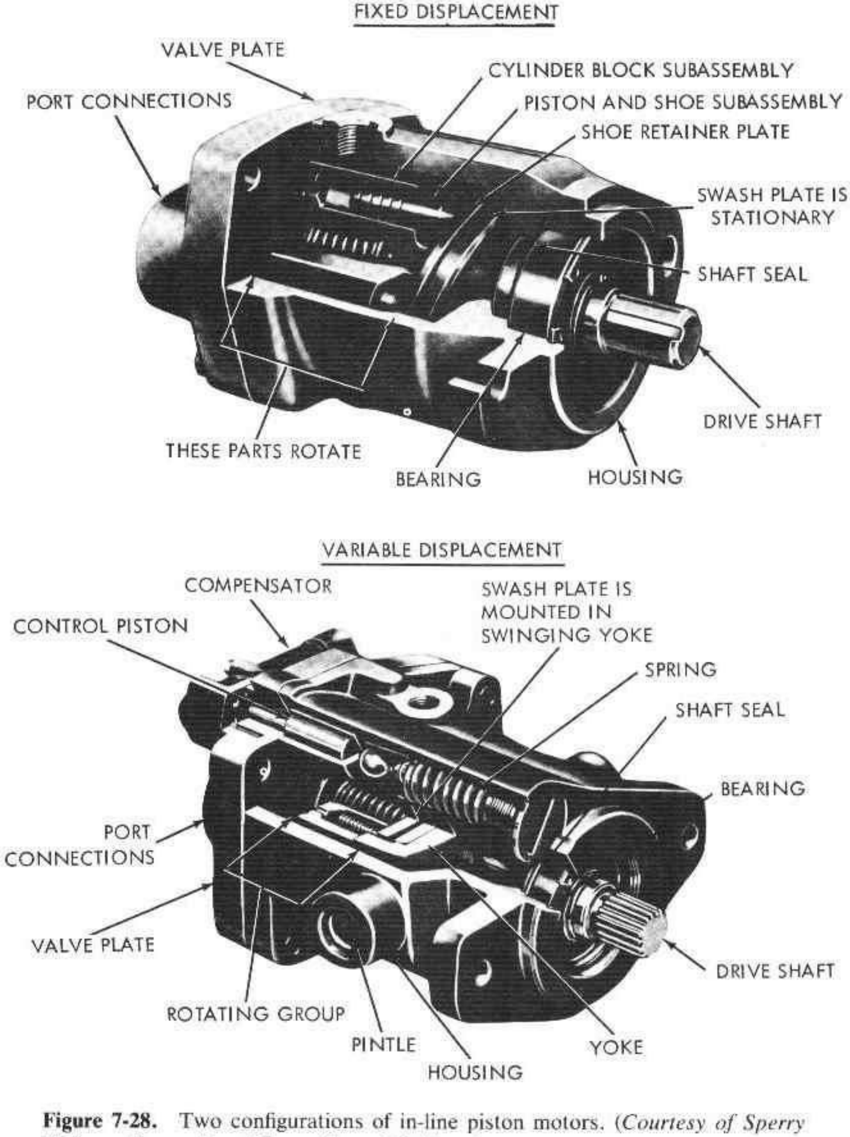



**Figure 7-28.** Two configurations of in-line piston motors. (*Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.*)

Piston motors are the most efficient of the three basic types and are capable of operating at the highest speeds and pressures. Operating speeds of 12,000 rpm and pressures of 5000 psi can be obtained with piston motors. Large piston motors are capable of delivering flows up to 450 gpm.

A direct drive wheel hub motor is illustrated in Fig. 7-33. This type of motor imparts torque directly to drive wheels of vehicles such as tractors without any

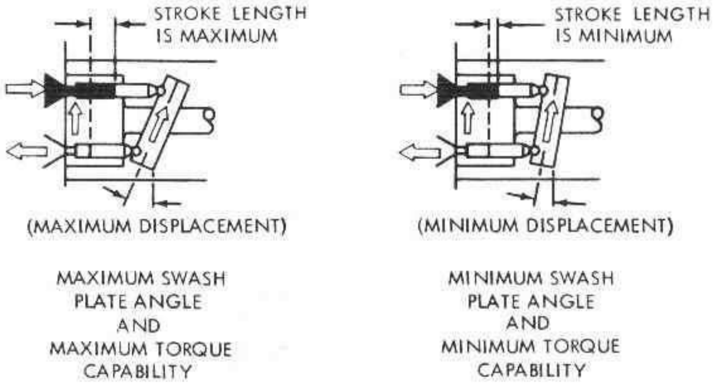



**Figure 7-29.** Motor displacement varies with swash plate angle. *(Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.)*

intermediate reduction gears. Designed to be mounted directly into a standard 15- or 20-in. wheel rim, these simplified power packages eliminate axles, gear boxes, torque converters, conventional hydrostatic transmissions, and reduction gears.

These wheel motors are of multistroke radial piston design, working against a cam ring. The special design of the cam permits full rated torque from start-up through maximum rpm. In most applications, the inherent dynamic braking is sufficient. A secondary, static braking system is available, which provides fail-safe "holding" where such is required.

Other significant features of this wheel motor are instantaneous reversing through simply changing the direction of the oil flow; two-speed ranges, with full or half displacement; high external loading; operations at 5000 psi; low noise level; free wheeling; and ultrasmooth performance.

The theoretical torque capacity of a hydraulic motor can be determined by the following equation, which is identical to that used for hydraulic actuators:

$$T\ (\text{in.}\cdot\text{lb}) = \frac{V_D\left(\frac{\text{in.}^3}{\text{rev}}\right) \times P\ (\text{psi})}{6.28} \tag{7-15}$$

Using metric units we have

$$T\ (\text{N}\cdot\text{m}) = \frac{V_D\left(\frac{\text{m}^3}{\text{rev}}\right) \times P\ (\text{Pa})}{6.28} \tag{7-15M}$$

Thus, the torque capacity is proportional not only to the pressure but also to the volumetric displacement.

# Pneumatic motor

A pneumatic motor (air motor) or compressed air engine is a type of motor which does mechanical work by expanding compressed air. Pneumatic motors generally convert the compressed air energy to mechanical work through either linear or rotary motion. Linear motion can come from either a diaphragm or piston actuator, while rotary motion is supplied by either a vane type air motor, piston air motor, air turbine or gear type motor.

Pneumatic motors have existed in many forms over the past two centuries, ranging in size from hand-held motors to engines of up to several hundred horsepower. Some types rely on pistons and cylinders; others on slotted rotors with vanes (vane motors) and others use turbines. Many compressed air engines improve their performance by heating the incoming air or the engine itself. Pneumatic motors have found widespread success in the hand-held tool industry, but are also used stationary in a wide range of industrial applications. Continual attempts are being made to expand their use to the transportation industry. However, pneumatic motors must overcome inefficiencies before being seen as a viable option in the transportation industry.

**Classification**

**Linear**

In order to achieve linear motion from compressed air, a system of pistons is most commonly used. The compressed air is fed into an air-tight chamber that houses the shaft of the piston. Also inside this chamber a spring is coiled around the shaft of the piston in order to hold the chamber completely open when air is not being pumped into the chamber. As air is fed into the chamber the force on the piston shaft begins to overcome the force being exerted on the spring. As more air is fed into the chamber, the pressure increases and the piston begins to move down the chamber. When it reaches its maximum length the air pressure is released from the chamber and the spring completes the cycle by closing off the chamber to return to its original position.

Piston motors are the most commonly used in hydraulic systems. Essentially, piston motors are the same as hydraulic motors except they are used to convert hydraulic energy into mechanical energy.

Piston motors are often used in series of two, three, four, five, or six cylinders that are enclosed in a housing. This allows for more power to be delivered by the pistons because several motors are in sync with each other at certain times of their cycle.

**Rotary vane motors**

A type of pneumatic motor, known as a rotary vane motor, uses air to produce rotational motion to a shaft. The rotating element is a slotted rotor which is mounted on a drive shaft. Each slot of the rotor is fitted with a freely sliding rectangular vane. The vanes are extended to the housing walls using springs, cam action, or air pressure, depending on the motor design. Air is pumped through the motor input which pushes on the vanes creating the rotational motion of the central shaft. Rotation speeds can vary between 100 and 25,000 rpm depending on several factors which include the amount of air pressure at the motor inlet and the diameter of the housing.

One application for vane-type air motors is to start large industrial diesel or natural gas engines. Stored energy in the form of compressed air, nitrogen or natural gas enters the sealed motor chamber and exerts pressure against the vanes of a rotor. This causes the rotor to turn at high speed. Because the engine flywheel requires a great deal of torque to start the engine, reduction gears are used. Reduction gears create high torque levels with the lower amounts of energy input. These reduction gears allow for sufficient torque to be generated by the engine flywheel while it is engaged by the pinion gear of the air motor or air starter.

**TYPES OF AIR MOTORS**

- VANE MOTORS
- PISTON TYPE
- TURBINE MOTORS
- GEROTOR

**Rotary vane motors** normally are used in applications requiring low- to medium-power outputs.

• Simple and compact vane motors most often drive portable power tools, but certainly are used in a host of mixing, driving, turning, and pulling applications as well.

• The vanes are biased to seal against the housing interior wall by springs, cam action, or air pressure, depending on design.

• The centrifugal force that develops when the rotor turns aids this sealing action.

• Torque develops from pressure acting on one side of the vanes.

• Torque at the output shaft is proportional to the exposed vane area, the pressure, and the moment arm (radius from the rotor centerline to the center of the exposed vane) through which the pressure acts.

## VANE MOTORS

• In the slot, there are generally 3 to 10 vanes.

• To enable the vanes to come out of the slots they are designed with compression spring or pressure air.

• For motors equipped with an even number of vanes, a connecting pin links diametrically opposite vanes so that as the bore surface pushes one vane in, the pin pushes the other vane.

• But leakage probability will be there when the vane tip wears out.

• Vane motors run at 100 to 25,000 rpm.

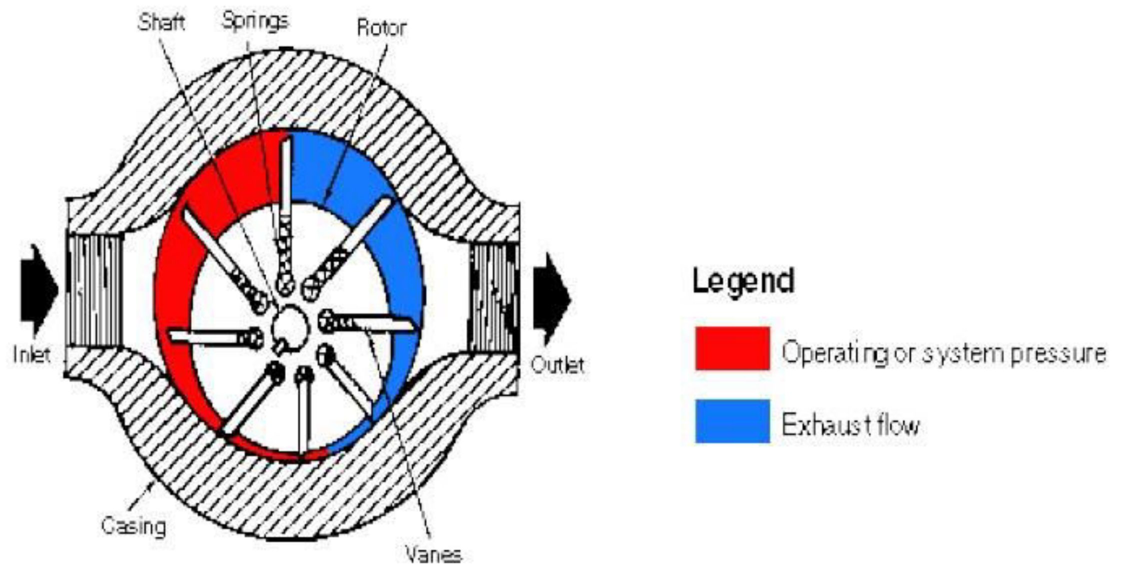



*Figure 4-11. Vane-type motor*

**PISTON TYPE**

• Piston air motors are used in applications requiring high power, high starting torque, and accurate speed control at low speeds.

• They have either two, three, four, five, or six cylinders arranged either axially or radially within a housing.

• Output torque is developed by pressure acting on pistons that reciprocate within the cylinders.

• Power developed by a piston motor depends on the inlet pressure, the number of pistons, and piston area, stroke, and speed.

Radial- and axial-piston motors have one significant limitation: they are internally lubricated, so oil and grease supplies must be checked periodically and replenished.

**Radial-piston motors :**

•Feature robust, oil-lubricated construction and are well-suited to continuous operation.

•They have the highest starting torque of any air motor and are particularly beneficial for applications involving high starting loads.

•Overlapping power impulses provide smooth torque in both forward and reverse directions.

• Sizes range to about 35 hp for speeds to 4,500 rpm.

## Axial-piston motors

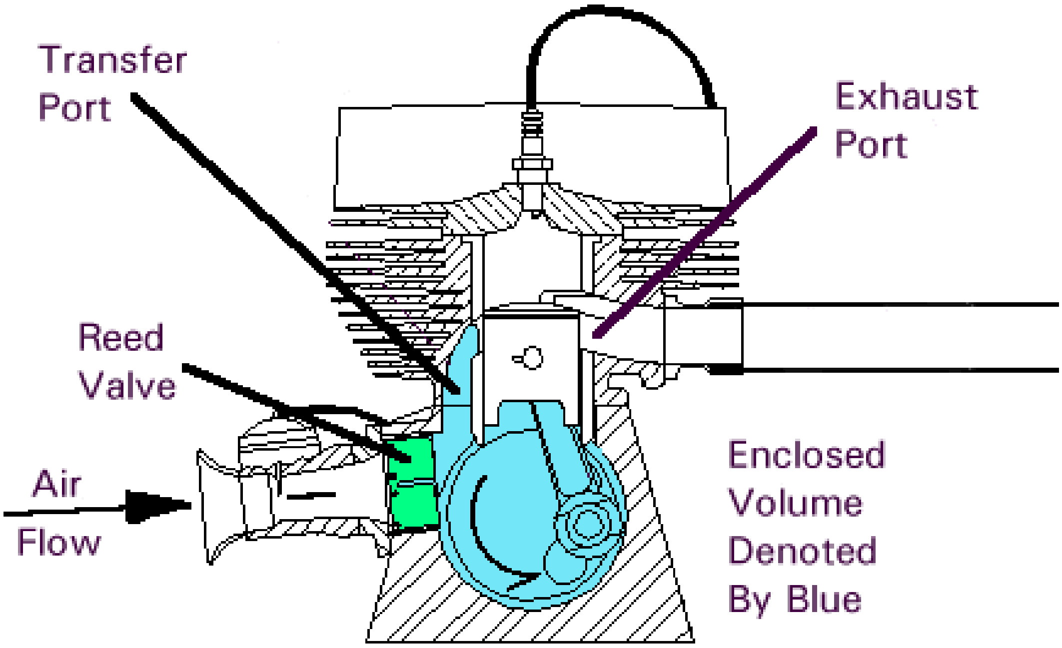
• Are more compact than radial-piston motors, making them ideal for mounting in close quarters.

• Their design is more complex and costly than vane motors, and they are grease lubricated.

• However, axial-piston motors run smoother and deliver maximum power at much lower speeds than vane motors can.

• axial-piston motors also tolerate higher ambient temperatures.

Maximum size is about 3-1/2 hp.




## TURBINE MOTORS

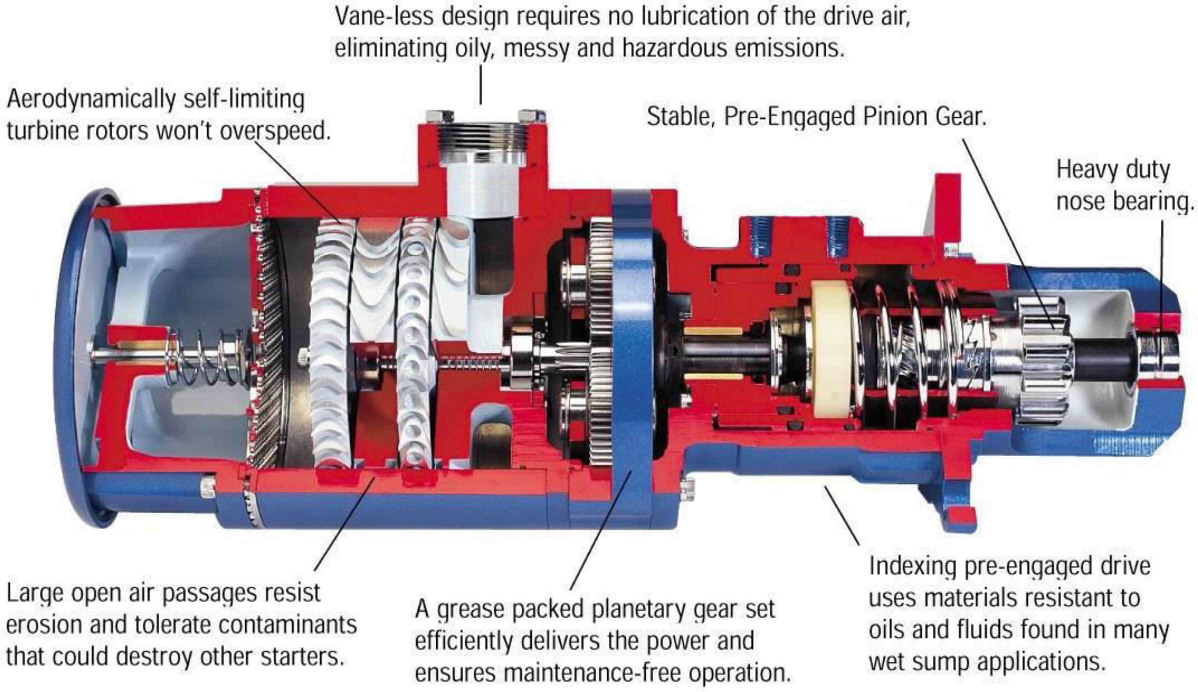
• It converts low velocity high pressure air to high velocity low pressure air by passing it through metering nozzles.

• Major advantage of this is that there is no rubbing or sliding contact between the rotating parts and the body cavity.

• This reduces wear and lubricated air is not required to seal and lubricant problem.

• Application is advisable only in low ambient temperature because of lubricant problem.

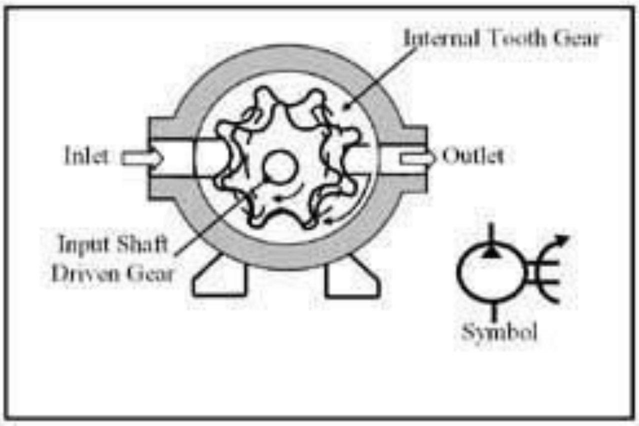
• These are high speed low torque motor for same volume of air than piston vane type.




## GEROTOR

• These gerotor type motor are mostly used for low rpm pressure applications such as 20-30 rpm.

• Hence they may not be suitable for high torque application.



## ADVANTAGES OF AIR MOTORS

- Variable speed.
- Easy to use.
- Low weight.
- Inexpensive.
- Stall w/o damage - perfect for conditions where motor works in stall conditions.
- Runs cool - especially in overload conditions.
- Explosion proof.
- Instantaneously reverses - except when specifically noted.

## APPLICATIONS OF AIR MOTORS

- Construction Engineering.
- Hand –tools.
- Mining Engineering.
- Wood working fields.
- Mechanical applications like hammering, riveting and drilling.
- Indoor manufacturing plants.
- Mobile / portable equipment at sea or on land.
- Non-electrical for hazardous locations.
- Emergency back-up to electric motors for critical operations.
- Outdoor / remote / underwater equipment.

# Electrical motors

Electrical motor: It is a machine which convert electrical energy into mechanical energy.

**AC Motor:** motor that runs on alternating current (AC) electricity.
**DC Motor:** motor that runs on direct current (DC) electricity.

## AC Motor

 AC motor is an electric motor driven by an alternating current.
 Commonly consists of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field.
 Two main types of AC motors- depending on the type of rotor used.
- the asynchronous motor
- the synchronous motor

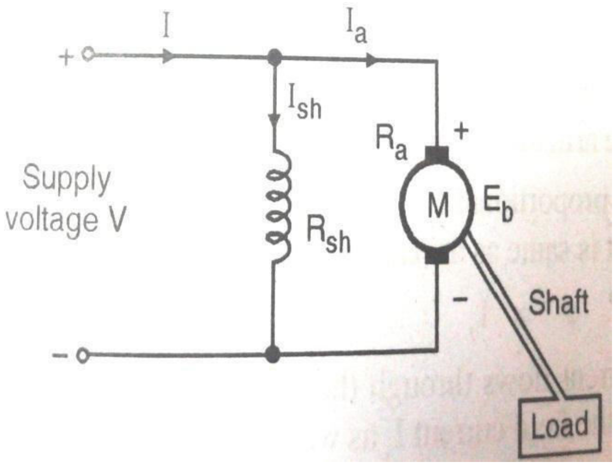
## DC Motor

 DC motor is an electric motor that runs on direct current (DC) electricity.
 Two types of DC motor - brush and brushless DC Motor.
 Brushed DC electric motor generates torque directly from DC power supplied to the motor by using internal commutation, stationary magnets (permanent or electromagnets), and rotating electrical magnets.
 Brushless DC motors use a rotating permanent magnet or soft magnetic core in the rotor, and stationary electrical magnets on the motor housing.

**Types of DC Motor:**
Classification of the d.c. motor depends on the way of connecting the armature and field winding of a d.c. motor:
1.DC Shunt Motor
2.DC Series Motor
3.DC Compound Motor

- Short shunt compound
  - Cumulative compound motor
  - Differential compound motor
- long shunt compound
  - Cumulative compound motor
  - Differential compound motor

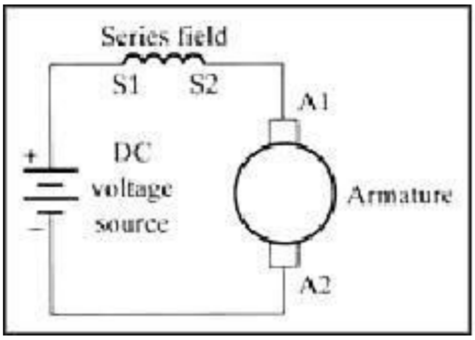
**DC Shunt Motor:**
•In dc shunt motor the armature and field winding are connected in parallel across the supply voltage
•The resistance of the shunt winding $R_{sh}$ is always higher than the armature winding $R_a$
•Since V and $R_{sh}$ both remains constant the $I_{sh}$ remains essentially constant, as field current is responsible for generation of flux. thus $\emptyset \propto I_{sh}$
•So, shunt motor is also called as constant flux motor.




**Applications of DC shunt Motor:**
These motors are constant speed motors, hence used in applications requiring constant speed. Like:
1) Lathe machine 2) Drilling machine 3) Grinders 4) Blowers 5) Compressors

**DC Series Motor:**
•In this type of DC motor the armature and field windings are connected in series.
• the resistance of the series field winding Rs is much smaller than the armature resistance Ra

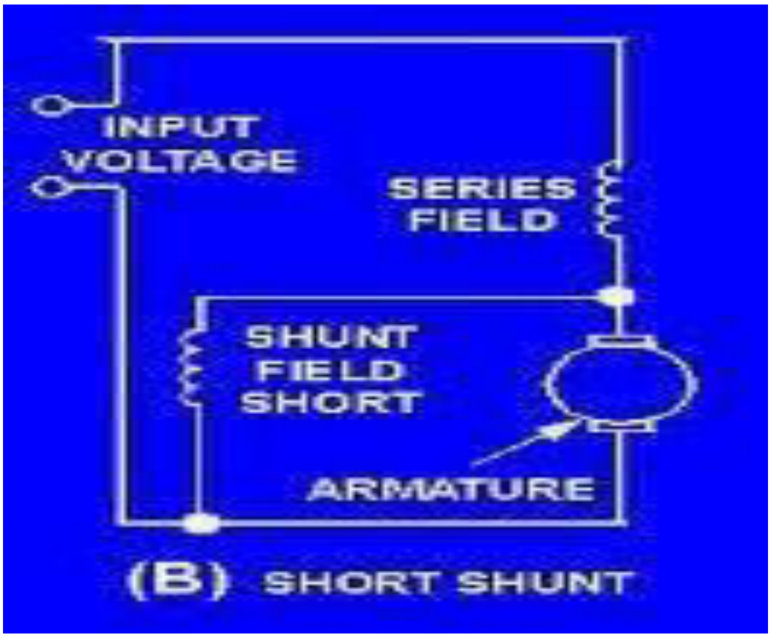
•The flux produced is proportional to the field current but in this $If=Ia$ thus $\emptyset \propto Ia$
•Thus flux can never become constant in dc series motor as load changes If and Ia also gets changed
•Thus dc series motor is not a constant flux motor.




**Applications of DC series Motor-**
These motors are useful in applications where starting torque required is high and quick acceleration. Like:
1) Traction 2) Hoists and Lifts 3) Crane 4) Rolling mills 5) Conveyors

## DC Compound Motor:
•The DC compound motor is a combination of the series motor and the shunt motor. It has a series field winding that is connected in series with the armature and a shunt field that is in parallel with the armature. The combination of series and shunt winding allows the motor to have the torque characteristics of the series motor and the regulated speed characteristics of the shunt motor. Several versions of the compound motor are:
•Short shunt Compound Motors
•Long shunt Compound Motors

## Short shunt compound motor:
•When shunt field winding is connected in parallel with armature like dc shunt motor and this assembly is connected in series with the series field winding then this type of motor is called as short shunt compound motor.
•Depending on the polarity of the connection short shunt motor is classified as:
1.Cumulative compound motor.
2.Differential compound motor.



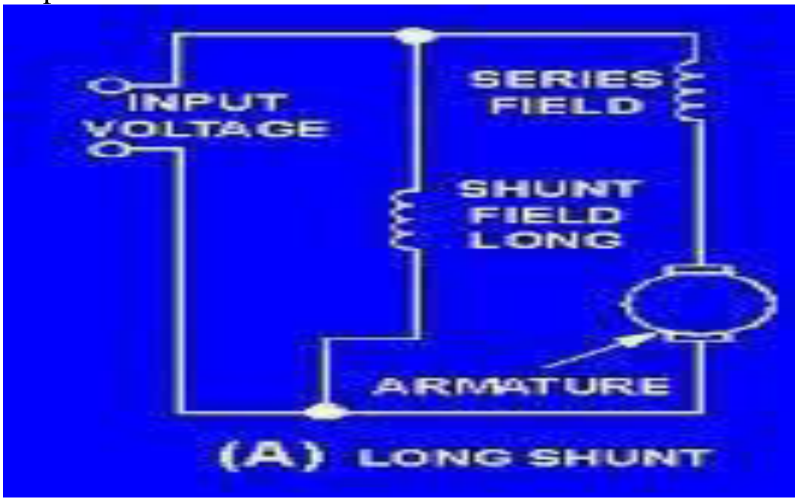

**Long shunt compound motor:**

•when the shunt field is connected in parallel with both the series field and the armature then this type of motor is called as long shunt compound motor.

•Depending on the polarity of connection of shunt field winding, series field winding and armature, long shunt motor is classified as:

1.Cumulative Compound Motor.

2.Differential Compound Motor.




**Applications of DC Compound Motor:**

Cumulative Compound Motor:

•These motors have high starting torque.

•They can be operated even at no loads as they run at a moderately high speed at no load.

•Hence cumulative compound motors are used for the following applications.

1.Elevators

2.Rolling mills

3.Punches
4.Shears
5.planers

## Applications of DC Compound Motor:

Differential Compound Motor:
•The speed of these motors increases with increases in the load which leads to an unstable operation.
•Therefore, we cannot use this motor for any practical applications.

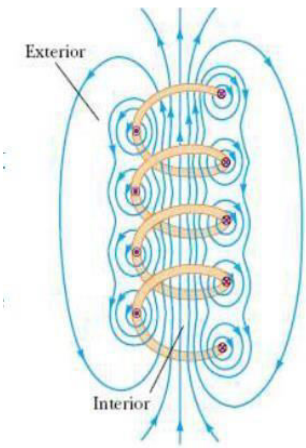
# Actuators

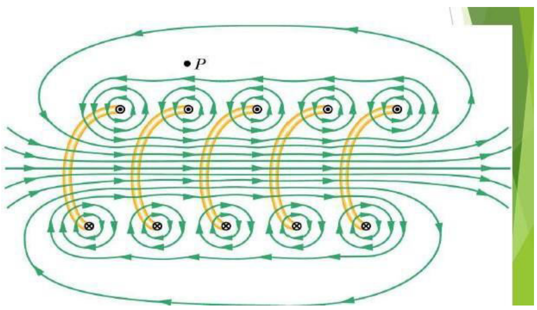
An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. In simple terms, it is a "mover". An **actuator** requires a control signal and a source of energy.

## Solenoids

Solenoid is an electromechanical device.
Electrical energy is used to magnetically cause mechanical movement

- A solenoid is a long wire wound as a helix to produce a reasonably uniform magnetic field B in the interior of the solenoid coils when the solenoid carries a steady current I.
- When the coils (turns) are closely spaced, each turn can be approximated as a circular loop and the net magnetic field B is the vector sum of the fields resulting from all of the turns.
- Inside the solenoid, the field lines are nearly parallel, uniformly distributed, and close together, indicating that the magnetic field is uniform.
- The magnetic field lines between the turns tends to cancel each other.
- The magnetic field outside the solenoid is nonuniform and weak.
- The field at exterior points, such as P, are weak because current elements on the upper portions tends to cancel the current elements on the lower portions.



## Types of Solenoids

1.AC Solenoid
2.DC Solenoid

**AC Solenoid**

•This type of solenoid are noise damping and would likely cause premature overheating and failure.
•This solenoid requires great care to insure precise alignment of plunger pole face to stator pole face.

**DC Solenoid**

•This solenoid have capability of being modified in such a fashion to prevent the pole faces from making contact at end of stroke.
•So in DC solenoid a slight gap between the pole pieces at the end of stroke have drastic effect on improving overall life of solenoid.

**Applications of Solenoid**

The solenoids are used in variety of fields
1. Locking applications
2. Automotive applications
3. Medical applications
4. Railway applications
5. Industrial applications

**Locking Applications**

Solenoids are frequently used in locking mechanisms, it include door locking, in hotels, offices and secure areas, vending machines, remote access systems, turnstiles, car park and access barriers. The list is extensive. Latching can be mechanical or magnetic, and the main function can suit the application to include single acting solenoids, bistable solenoids, two-directional solenoids or holding solenoids in many cases with or without springs.

**Automotive Applications**
Other applications for solenoids include petrol cap locking, in-car entertainment release mechanisms, anti-vibration engine mountings, air conditioning control and security systems. Automotive applications are not just for cars. We supply solenoids for integration into joystick controls for agricultural machinery, for lorry systems and many other automotive applications. There are just far too many to be listed here.

**Railway Applications**
Applications within the railway industry are particularly diverse, including functions on locomotives, rolling stock, tracks, signals and power distribution as well as conventional uses in maintenance and building. Safety interlock on passenger car doors use a solenoid operated mechanism that is controlled remotely by the train manager.
The Solenoid Company has developed a special solenoid for the operation of fire extinguishers in locomotives. This application calls for a very high force for the relevant size, to operate the jets of a fire suppressant system.

**Industrial Applications**
The use for solenoids in industry is extensive.
Anywhere that electrical power is required to achieve a movement becomes an application for a solenoid. Some general examples of use are locking, cutting, clamping, punching, positioning, diverting, holding or rotating.
The range of standard or modified standard solenoids from The Solenoid Company will satisfy most of these applications.

## Relays

Relays are switching that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit. when a relay contact is normally open (NO), there is an open contact when the relay is not energized. When a relay contact is Normally Closed (NC), there is a closed contact when the relay is not energized. In either case, applying electrical current to the contacts will change their state.

Relays consist of an electromagnet and also a set of contacts. A relay is used when a circuit is to be controlled at a low power signal. Relays are often grouped together or with other components like fuses.

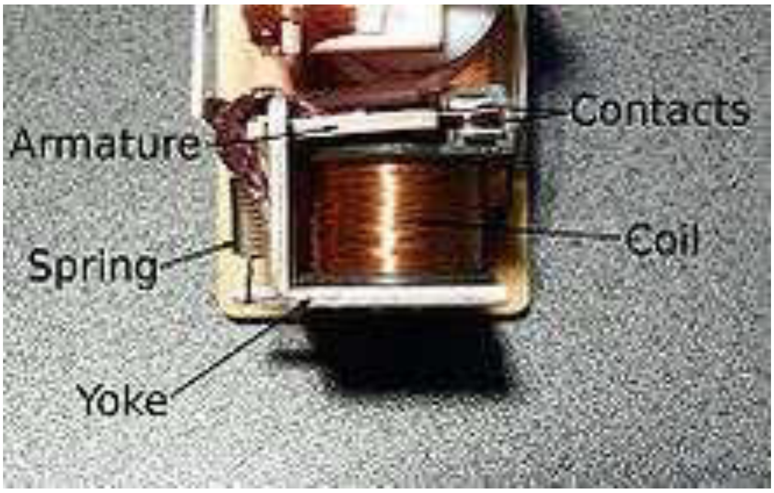
Relays have two circuit: a control circuit and a load circuit.

### History about Relays

The relay was invented in 1835 by American scientist Joseph Henry in order to improve his version of the electrical telegraph.

**Basic design or operation**

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts. The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is deenergized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay is closed, and the other set is open.




## Types of Relays

Basically, Relays are of two types either electromechanical or solid-state relays. Both accomplish the same result but the physical structure and functionality makes them different.

1. Electromechanical Relays (EMR) : In electromechanical relays contacts are open or closed by a magnetic force. Basic parts and functions of electromechanical relays include:

- Frame
- Coil
- Armature
- Contacts

2. Solid State Relays(SSR): In solid state Relays there are no contacts and switching is totally electronics. It consist of

- an input circuit
- a control circuit

**Applications**

- Amplifying a digital signal, switching a large amount of power with a small operating power.
- Detecting and isolating faults on transmission and distribution lines by opening and closing circuit breakers.
- Isolating the controlling circuit from the controlled circuit when the two are at different potentials.
- In logic functions.

- Time delay functions.

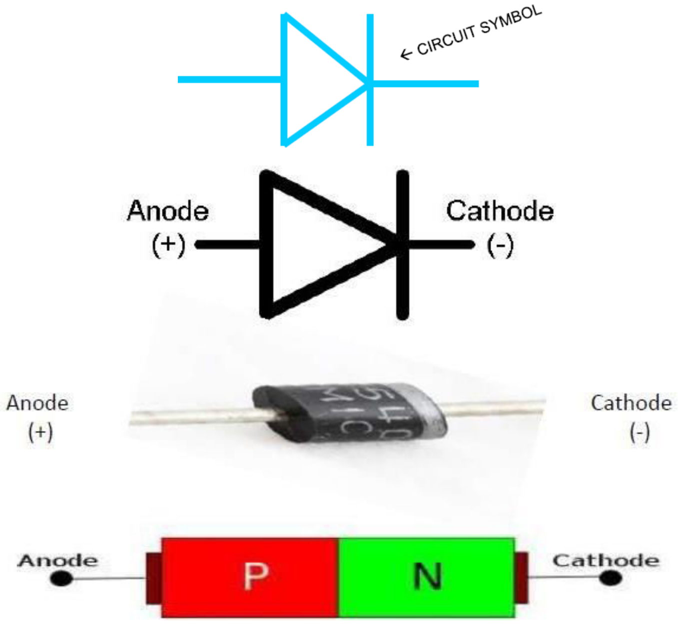
**Advantages of Relays**

- Used as a kind of safety switch to allow a circuit with a small current through to switch on a circuit that will have a larger current flow through it.
- Minimize the amount of damage to the system during a fault.
- Small control signal controls a larger load current or voltage.
- Decreased electrical noise when switching.
- Totally silent operation.

## Diodes

What's a diode?

- Di+Ode
- A semiconductor device with two terminals allowing the flow of current in one direction only.



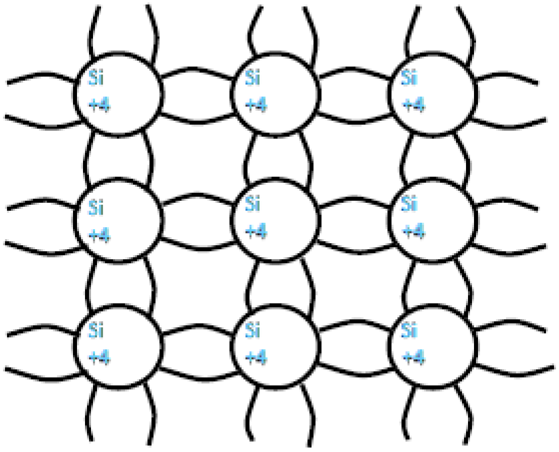

What are diodes made out of?

- Silicon
- Germanium
- GaAs

Silicon (Si) and Germanium (Ge) are the two most common single elements that are used to make Diodes.

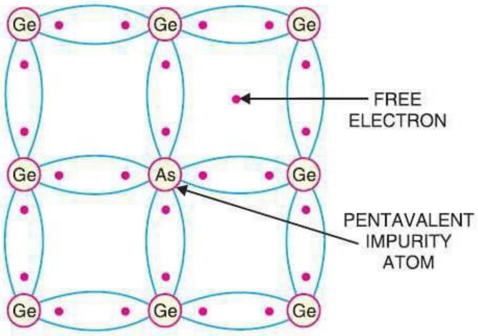
•Silicon and Germanium are both group 4 elements, meaning they have 4 valence electrons. Their structure allows them to grow in a shape called the diamond lattice.

•Gallium is a group 3 element while Arsenide is a group 5 element. When put together as a compound, Ga As creates a zincblend lattice structure.

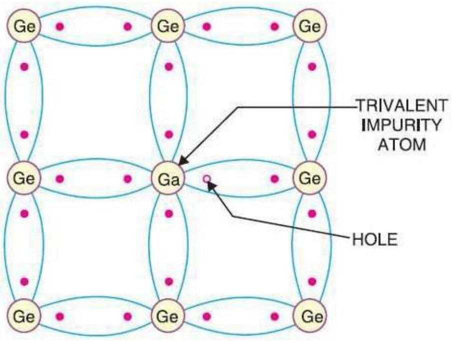


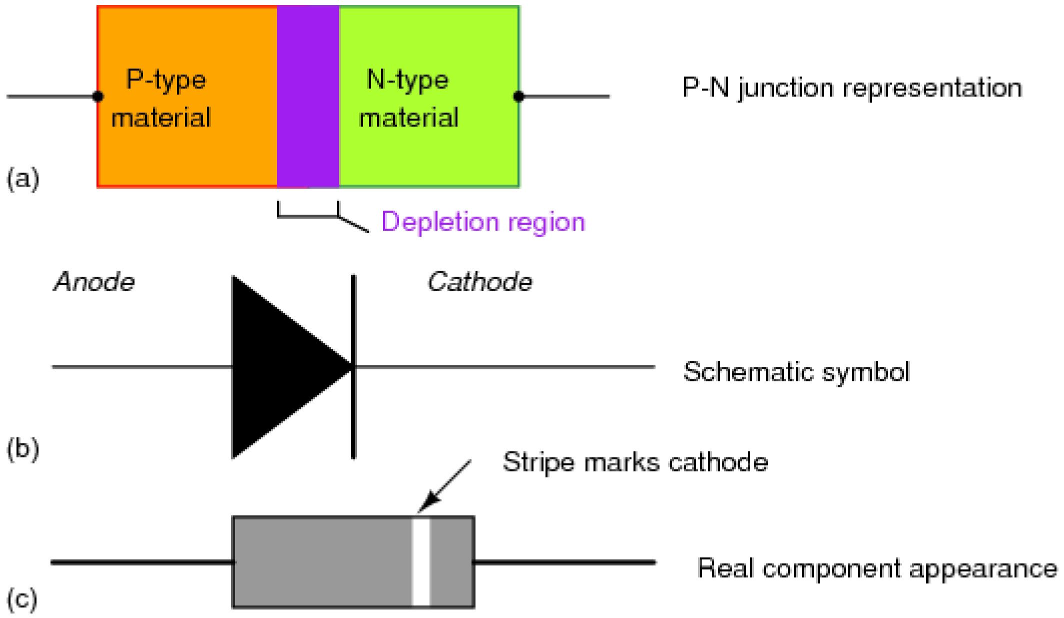

Diode Is made from join P and N junctions

**N-Type**: When a small amount of pentavalent impurity is added to a pure semiconductor,it's known as a N-type semiconductor.




**P-type**: when a small amount of trivalent impurity is added to a pure semiconductor,it's called P-type semiconductor.



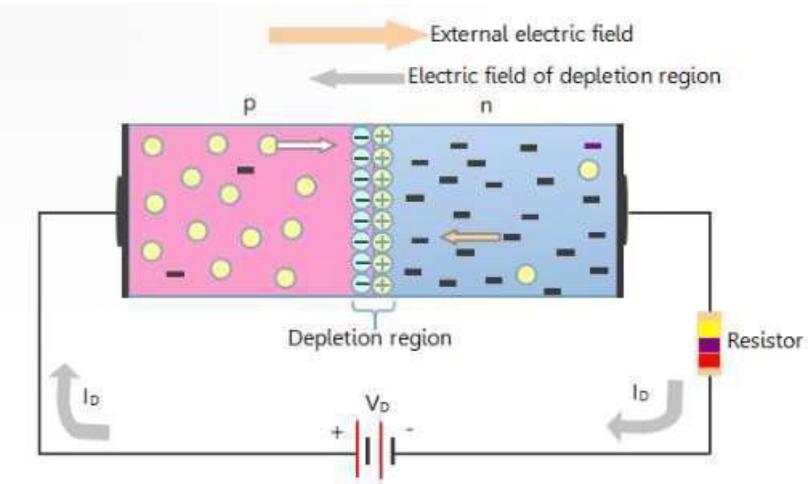



**IDEAL DIODE**

An **ideal diode** is a **diode** that acts like a perfect conductor when voltage is applied forward biased and like a perfect insulator when voltage is applied reverse biased. So when positive voltage is applied across the anode to the cathode, the **diode** conducts forward current instantly.

**FORWARD BIAS**

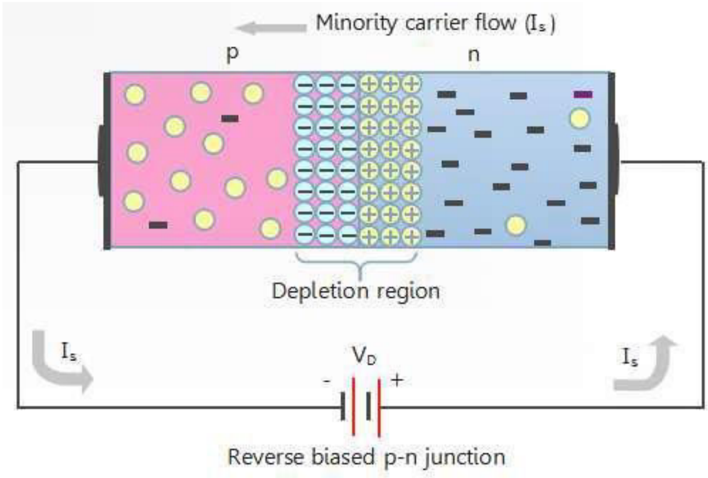
When voltage is applied across a diode in such a way that the diode allows current and the potential barrier reduced, the diode is said to be forward-biased.




Forward biased p-n junction

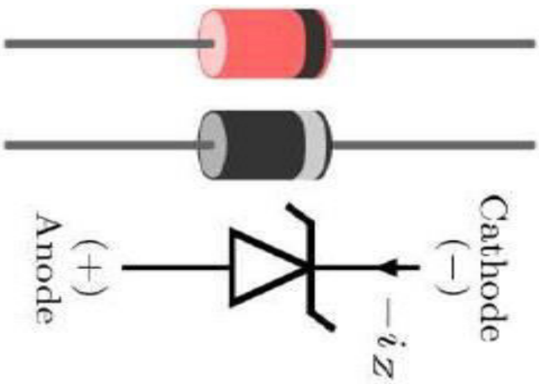
**REVERSE BIAS**

When voltage is applied across a diode in such a way that the diode prohibits current and potential barrier increase, the diode is said to be reverse-biased.




**<u>TYPES OF DIODES</u>**

**ZENER DIODE**




A Zener Diode allows current to flow from its anode to its cathode like a normal semiconductor diode, but it also permits current to flow in the reverse direction when its "Zener voltage" is reached. Zener diodes have a highly doped p-n junction. Normal diodes will also break down with a reverse voltage but the voltage and sharpness of the knee are not as well defined as for a Zener diode. Also normal diodes are not designed to operate in the breakdown region, but Zener diodes can reliably operate in this region.

**LIGHT EMITTING DIODE(LED)**

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated.[4]When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

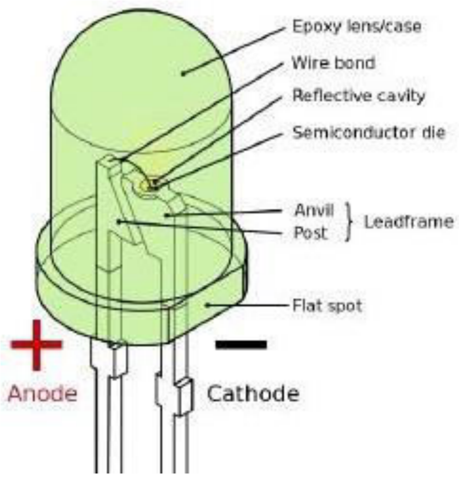
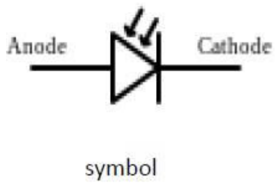
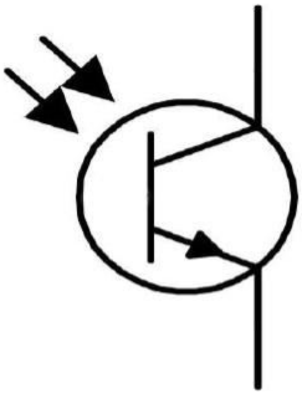



**PHOTO DIODE**

While LEDs emit light, Photodiodes are sensitive to received light. They are constructed so their pn junction can be exposed to the outside through a clear window or lens.



**APPLICATION OF DIODE**

1. Diode Rectifier

 Type of diode that converts alternating current into unidirectional current (DC)

 Typically seen in power supplies

2. Clippers

 Electronic circuits that have the ability to clip – off a portion of the input signal without distorting the remaining part of the alternating waveform

 Other names are **limiters**, **amplitude selectors** and **slicers**

3. Clampers

 Circuits that shift the waveform of the input signal either all above or below the reference voltage

 Add or restore a DC level to an electrical signal

 Also known as **DC restorer**

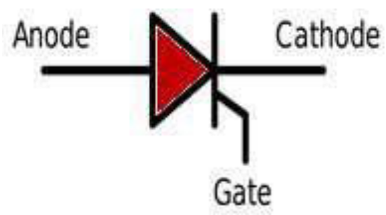
4. Voltage Multiplier
 Circuit which produces a greater DC output voltage than AC input voltage to the rectifiers
 Uses clamping action to increase peak rectified voltages without the necessity of increasing the input's transformers voltage rating
 Used in high – voltage, low current applications such as TV receivers

# Thyristors

Thyristor is a small device which can control large amounts of voltage and power. Thyristors are used as current reversal to turn off the device.
Actually, it takes direct current so it is very difficult to apply to the device.

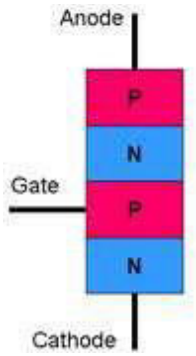
What is a Thyristor?
 A thyristor is a four layer solid-state semiconductor device with P and N type material.
 Whenever a gate receives a triggering current.
 It starts' conducting until the voltage across the thyistor device is under forward bias.
 So it acts as a bistable switch under this condition.
 To control the large amount of current of the two leads.

**Thyristor Circuit Symbol**
It has three terminals Anode, cathode and gate.




**Different States in a Thyristor**
There are three states in a thyristor
 Reverse blocking mode– In this mode of operation, the diode will block the voltage which is applied.
 Forward blocking mode– In this mode, the voltage applied in a direction makes a diode to conduct. But conduction will not happen here because the thyristor has not triggered.
 Forward conducting mode– The thyristor has triggered and current will flow through the device until the forward current reaches below the threshold value which is known as "Holding current".

**Thyristor Layer Diagram**



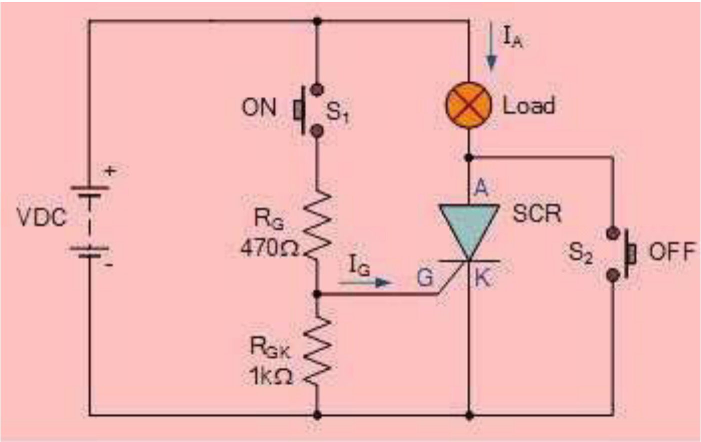

**Thyristor Layer Diagram**

 Thyristor consists of three **p-n junctions** namely J1, J2, and J3.
 If the anode is at a positive potential with respect to the cathode and the gate terminal is not triggered with any voltage.
 Then J1 and J3 will be under forward bias condition.
 While J2 junction will be under reverse bias condition.
 So J2 junction will be in the off state (no conduction will take place).
 If the increase in voltage across anode and cathode beyond the VBO (Breakdown voltage).
 Then avalanche breakdown occurs for J2.
 Then thyristor will be in ON state (starts conducting).
 If a VG (Positive potential) is applied to the gate terminal.
 Then a breakdown occurs at the junction J2 which will be of low value VAK.
 The thyristor can switch to ON state, by selecting a proper value VG.
 Under avalanche breakdown condition.
 The thyristor will conduct continuously without taking consideration of gate voltage, until and unless,
o The potential VAK is removed or
o Holding current is greater than the current flowing through the device.
 Here VG– Voltage pulse which is the output voltage of the UJT relaxation oscillator.

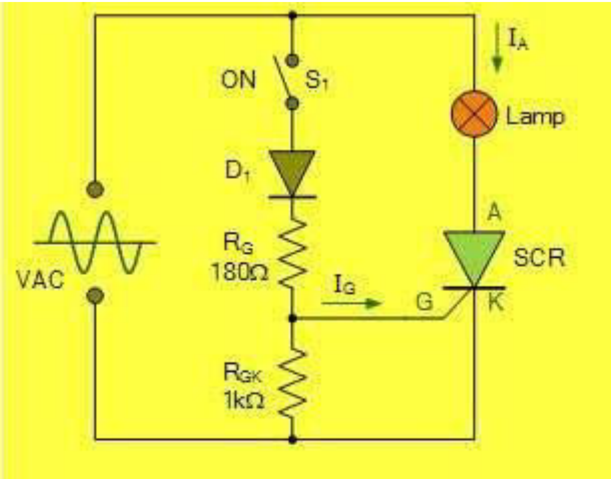
**The two types of thyristor switching circuits are**
**1. DC Thyristor Circuit.**
**2. AC Thyristor circuit.**

**DC Thyristor Circuit**

 When connected to the DC supply, to control the larger DC loads and current we usethyristor.
 The main advantage of thyristor in a DC circuit as a switch gives a high gain in current.
 A small gate current can control large amounts of anode current.
 So the thyristor is known as a current operated device.




**AC Thyristor Circuit**




 When connected to the AC supply,
 Thyristor acts differently because it is not same as DC connected circuit.
 During one half of a cycle,
 Thyristor used as an AC circuit causing it to turn off automatically due to its reverse biased condition.

**Types of Thyristors**

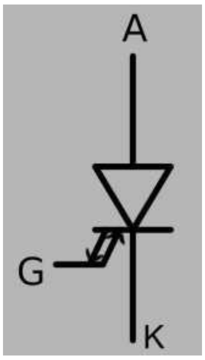
 Based on turn on and turn off capabilities the thyristors are classified into the following types:

o Silicon controlled thyristor or SCRs
o Gate turn off thyristors or GTOs
o Emitter turn off thyristors or ETOs
o Reverse conducting thyristors or RCTs
o Bidirectional Triode Thyristors or TRIACs
o MOS turn off thyristors or MTOs

 Based on turn on and turn off capabilities the thyristors are classified into the following types:
o Bidirectional phase controlled thyristors or BCTs
o Fast switching thyristors or SCRs
o Light activated silicon controlled rectifiers or LASCRs
o FET controlled thyristors or FET-CTHs
o Integrated gate commutated Thyristors or IGCTs

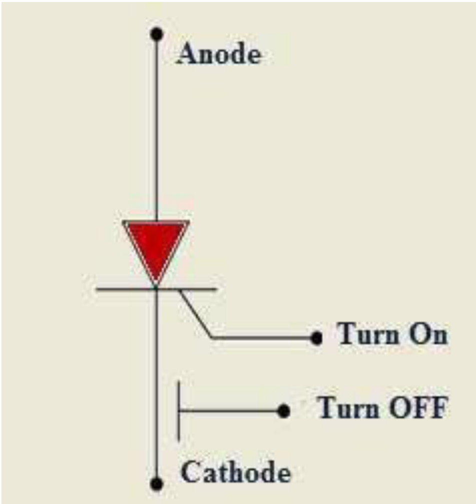
**Silicon Controlled Rectifier (SCR)**
 A silicon controlled rectifier is also known as thyristor rectifier.
 It is a four layered current controlling solid state device.
 SCRs can conduct current in only one direction (unidirectional devices).
 SCRs can be triggered normally by the current which is applied to the gate terminal.

**Gate Turn Off Thyristors (GTOs)**
 One of the special types of high power semiconductor devices is GTO (gate turn-off thyristor).
 The gate terminal controls the switches to be turned ON and OFF.




**Applications**
 Variable speed motor drives
 High power inverters and traction

**Emitter Turn OFF Thyristor**
 The Emitter turn OFF thyristor is one type of the thyristor.
 It will turn ON and turn OFF by using MOSFET.
 It includes both the advantages of the MOSFET and GTO.
 It consists of two gates- one gate is used to turn ON
 Another gate with a series MOSFET is used to turn OFF.



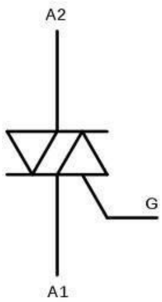

**Applications**

 ETO device is used for the fault current limiter and solid-state circuit breaker.

 Because of its high capability current interruption, fast switching speed, compact structure and low conduction loss.

## Triacs

Triode for Alternating Current (TRIAC)




Symbol

 Triac can conduct current in either direction and formally called bidirectional triode thyristor

 Closely related to SCR

Differences between Triac and SCR

Triac is bidirectional devices (can conduct current in either direction) while SCR is unidirectional devices (can conduct current only in one way) force commutation by reversed biasing cannot be employed.

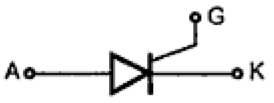
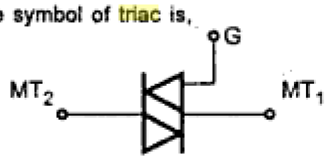
TRIACs can be triggered by either a positive or a negative current applied to its gate electrode while SCR can only triggered when a positive current apply to the gate terminal

In order to create a triggering current, a positive or negative voltage has to be applied to the gate with respect to the A1 terminal (otherwise known as MT1).

Parameter of TRIAC

| Variable name | Parameter | Typical value | Unit |
|---|---|---|---|
| $V_{gt}$ | Gate threshold Voltage | 1.5 [4][5] | V |
| $I_{gt}$ | Gate threshold Current | 10 - 50 [5] | mA |
| $V_{drm}$ | Repetitive peak off-state Voltages | 600 - 800 [4] | V |
| $I_t$ | RMS on-state current Non-repetitive peak | 4 - 40 [5] | A |
| $V_t$ | on-state forward voltage | 1.5 [5] | V |

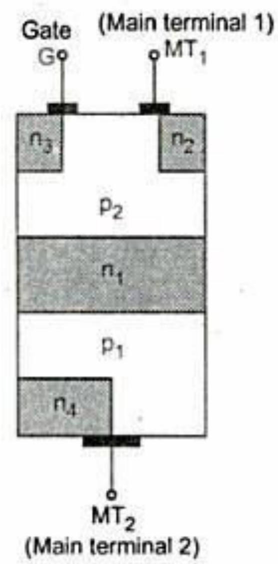
Comparison between SCR (Silicon controller rectifier) and TRIAC

| | SCR | Triac |
|---|---|---|
| 1. | The SCR is unidirectional device. | The triac conducts in both the directions hence bilateral device. |
| 2. | The terminals are called anode-cathode due to unilateral property. | The terminals are called $MT_1$ and $MT_2$ with gate. |
| 3. | The gate current can be only in direction to turn on SCR. | For both the directions of gate current, triac conducts. |
| 4. | The symbol of SCR is,   | The symbol of triac is,   |
| 5. | The characteristics are lying in first quadrant only, hence are nonsymmetrical. | The characteristics are lying in first and third quadrant and are symmetrical. |
| 6. | Only one mode of operation is possible. | The operation in four different mode is possible. |
| 7. | The reliability is more. | The reliability is less. |
| 8. | Available in large ratings. | Not available in large ratings. |
| 9. | Unijunction transistor (UJT) is used for triggering. | The diac is used for triggering. |
| 10. | The applications are phase control, protection of power supplies etc. | The applications are phase control, light dimmer, motor control etc. |

## Characteristic

- It can be seen that it is an extension IV characteristic of SCR
- The characteristic are symmetrical about the first and the third quadrants
- It shows the gate can be used to control the main current flow in either direction
- TRIAC will be continuously ON until the current through A1 to A2 are below the holding current.

**Turning the TRIAC ON**




**(a) Construction**

**With gate open,** either $MT_1$ is positive with respect to $MT_2$ or $MT_2$ is positive with respect to $MT_1$.

**Forward blocking region :** When gate is open and $MT_2$ is positive with respect to $MT_1$ but the voltage is less than forward breakover voltage then triac does not conduct. This region is called **forward blocking region.** If this voltage is increased beyond breakover voltage, the triac conducts in the forward direction similar to SCR.

**Reverse blocking region :** When gate is open and $MT_2$ is negative with respect to $MT_1$ but the voltage is less than breakover voltage then triac does not conduct. This region is called **reverse blocking region.** But note that if this voltage is increased beyond the breakover voltage, triac conducts in reverse direction while SCR does not conduct in reverse direction at all.

In forward or reverse blocking, now if gate is made positive or negative with respect to $MT_1$ then also the triac conducts. This is the gate control of triac and easy way of switching triac ON.

**Applications of TRIAC:**

TRIACs are used in numerous applications such as light dimmers, speed controls for electric fans and other electric motors and in the modern computerized control circuits of numerous household small and major appliances. They can be used both into AC and DC circuits however the original design was to replace the utilization of two SCRs in AC circuits. There are two families of TRIACs, which are mainly used for application purpose, they are BT136, BT139.

# Hydraulic and Pneumatic actuators

## Actuators :

•Actuators are those components of a fluid power system, which produces mechanical work output.
•They develop force and displacement, which is required to perform any specific task. The task may be of any kind, to move, to press, to lift, to clamp.
•Actuators are common for both hydraulic and pneumatic system.
•Hydraulic actuators are made stronger to with stand pressure of oil and develop huge amount of force.
•Speed of actuator depends on rate of working fluid. Rate of flow of working fluid can be controlled using Flow Control Valve (FCV).
•Force developed by cylinder is the product of pressure of working fluid and the piston area.
•Force of actuator is controlled by controlling the pressure of working fluid using Pressure Control Valve (PCV).
•Direction of motion of actuator is controlled by controlling the direction of flow of fluid, by using Direction Control Valve (DCV).

**Actuators:**

•Actuators are of two types:
–Linear actuator
–Rotary actuator

**Actuators :**

•Linear actuator
–Rotating cylinder
–Non-rotating cylinder
•Single acting cylinder
•Double acting cylinder
–Special type cylinder
•Diaphragm cylinder
•Tandem cylinder
•Double rod end cylinder
•Telescopic cylinder
•Cylinder with cushioning

Hydraulics
- Economic
- Reliable
- Resistant to overloads
- Able to support heavy loads

**Hydraulic actuators**
- Low working speed
- Hydraulic group noisy in operation

❑ **APPLICATIONS:**
✓ Hydraulic jack.
✓ Hydraulic brake.
✓ Hydraulic ram.
✓ Used as sensor.
✓ Close loop velocity controlling.
✓ Highly precise positioning for heavy loads.

Pneumatic actuators (cylinders)
- Economic
- Reliable
- High operation speed
- Resistant to overloads
- Operation at constant force

- No speed control
- Poor position speed
- Noisy operation

Comparison between Hydraulic and Pneumatic system

# 9 Hydraulic Circuit Design and Analysis

## Learning Objectives

Upon completing this chapter, you should be able to

1. Describe the operation of a complete hydraulic circuit drawn with symbols for all components.
2. Troubleshoot hydraulic circuits to determine causes of malfunction.
3. Determine the operating speeds and load-carrying capacities of regenerative cylinders.
4. Discuss the operation of air-over-oil circuits.
5. Describe the purpose, construction, and operation of various accumulators.
6. Explain the operation of accumulator circuits.
7. Understand the operation of a mechanical-hydraulic servo system.
8. Analyze a hydraulic circuit to evaluate the safety of operation.
9. Design a hydraulic circuit to perform a desired function.
10. Perform an analysis of hydraulic circuit operation, including the effects of frictional losses.

## 9.1 INTRODUCTION

The material presented in previous chapters dealt with basic fundamentals and system components. In this chapter we discuss basic hydraulic circuits. A hydraulic circuit is a group of components such as pumps, actuators, control valves, and conductors so arranged that they will perform a useful task. When analyzing or designing a hydraulic circuit, the following three important considerations must be taken into account:

1. Safety of operation
2. Performance of desired function
3. Efficiency of operation

It is very important for the fluid power technician or designer to have a working knowledge of components and how they operate in a circuit. Hydraulic circuits are developed through the use of graphical symbols for all components. Before hydraulic circuits can be understood, it is necessary to know these fluid power symbols. Figure 9-1 gives a table of symbols that conform to the American National Standards Institute (ANSI) specifications. Many of these symbols are presented in previous chapters, and ANSI symbols are used throughout this book. Although complete memorization of basic symbols is not necessary, Fig. 9-1 should be studied so that the symbols become familiar. The discussions that follow will cover circuits that represent basic hydraulic technology.

## 9.2 CONTROL OF A SINGLE-ACTING HYDRAULIC CYLINDER

Figure 9-2 shows how a two-position, three-way, manually actuated, spring offset directional control valve (DCV) can be used to control the operation of a single-acting cylinder. In the spring offset mode, full pump flow goes to the tank via the pressure relief valve. The spring in the rod end of the cylinder retracts the piston as oil from the blank end drains back to the tank. When the valve is manually actuated into its left envelope flow path configuration, pump flow extends the cylinder. At full extension, pump flow goes through the relief valve. Deactivation of the DCV allows the cylinder to retract as the DCV shifts into its spring offset mode.

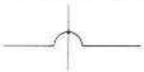
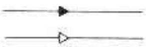
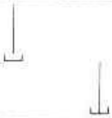
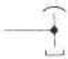
## 9.3 CONTROL OF A DOUBLE-ACTING HYDRAULIC CYLINDER

Figure 9-3 gives a circuit used to control a double-acting hydraulic cylinder.

The operation is described as follows:

1. When the four-way valve is in its spring-centered position (tandem design), the cylinder is hydraulically locked. Also the pump is unloaded back to the tank at essentially atmospheric pressure.

THE SYMBOLS SHOWN CONFORM TO THE AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI) SPECIFICIATIONS. BASIC SYMBOLS CAN BE COMBINED IN ANY COMBINATION. NO ATTEMPT IS MADE TO SHOW ALL COMBINATIONS.

| LINES AND LINE FUNCTIONS | |
|---|---|
| LINE, WORKING |  |
| LINE, PILOT (L>20W) |  |
| LINE, DRAIN (L<5W) |  |
| CONNECTOR |  |
| LINE, FLEXIBLE |  |
| LINE, JOINING |  |
| LINE, PASSING |  |
| DIRECTION OF FLOW, HYDRAULIC PNEUMATIC |  |
| LINE TO RESERVOIR ABOVE FLUID LEVEL BELOW FLUID LEVEL |  |
| LINE TO VENTED MANIFOLD |  |
| PLUG OR PLUGGED CONNECTION |  |
| RESTRICTION, FIXED |  |
| RESTRICTION, VARIABLE |  |

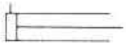
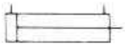
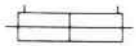
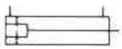
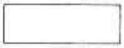
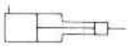
| PUMPS | |
|---|---|
| PUMP, SINGLE FIXED DISPLACEMENT |  |
| PUMP, SINGLE VARIABLE DISPLACEMENT |  |
| MOTORS AND CYLINDERS | |
| MOTOR, ROTARY, FIXED DISPLACEMENT |  |
| MOTOR, ROTARY VARIABLE DISPLACEMENT |  |
| MOTOR, OSCILLATING |  |
| CYLINDER, SINGLE ACTING |  |
| CYLINDER, DOUBLE ACTING |  |
| CYLINDER, DIFFERENTIAL ROD |  |
| CYLINDER, DOUBLE END ROD |  |
| CYLINDER, CUSHIONS BOTH ENDS |  |

**Figure 9-1.** ANSI symbols of hydraulic components.

| MISCELLANEOUS UNITS | |
|---|---|
| DIRECTION OF ROTATION (ARROW IN FRONT OF SHAFT) |  |
| COMPONENT ENCLOSURE |  |
| RESERVOIR, VENTED |  |
| RESERVOIR, PRESSURIZED |  |
| PRESSURE GAGE |  |
| TEMPERATURE GAGE |  |
| FLOW METER (FLOW RATE) |  |
| ELECTRIC MOTOR |  |
| ACCUMULATOR, SPRING LOADED |  |
| ACCUMULATOR, GAS CHARGED |  |
| FILTER OR STRAINER |  |
| HEATER |  |
| COOLER |  |
| TEMPERATURE CONTROLLER |  |
| INTENSIFIER |  |
| PRESSURE SWITCH |  |
| BASIC VALVE SYMBOLS | |
| CHECK VALVE |  |
| MANUAL SHUT OFF VALVE |  |
| BASIC VALVE ENVELOPE |  |
| VALVE, SINGLE FLOW PATH, NORMALLY CLOSED |  |

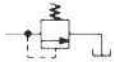
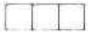
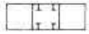
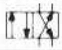
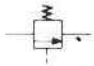
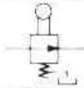
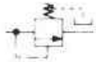
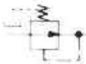
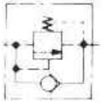
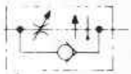
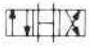
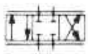
| BASIC VALVE SYMBOLS (CONT.) | |
|---|---|
| VALVE, SINGLE FLOW PATH, NORMALLY OPEN |  |
| VALVE, MAXIMUM PRESSURE (RELIEF) |  |
| BASIC VALVE SYMBOL, MULTIPLE FLOW PATHS |  |
| FLOW PATHS BLOCKED IN CENTER POSITION |  |
| MULTIPLE FLOW PATHS (ARROW SHOWS FLOW DIRECTION) |  |
| VALVE EXAMPLES | |
| UNLOADING VALVE, INTERNAL DRAIN, REMOTELY OPERATED |  |
| DECELERATION VALVE, NORMALLY OPEN |  |
| SEQUENCE VALVE, DIRECTLY OPERATED, EXTERNALLY DRAINED |  |
| PRESSURE REDUCING VALVE |  |
| COUNTER BALANCE VALVE WITH INTEGRAL CHECK |  |
| TEMPERATURE AND PRESSURE COMPENSATED FLOW CONTROL WITH INTEGRAL CHECK |  |
| DIRECTIONAL VALVE, TWO POSITION, THREE CONNECTION |  |
| DIRECTIONAL VALVE, THREE POSITION, FOUR CONNECTION |  |
| VALVE, INFINITE POSITIONING (INDICATED BY HORIZONTAL BARS) |  |

**Figure 9-1.** Con't.

| METHODS OF OPERATION | | METHODS OF OPERATION | |
|---|---|---|---|
| PRESSURE COMPENSATOR |  | LEVER |  |
| DETENT |  | PILOT PRESSURE |  |
| MANUAL |  | SOLENOID |  |
| MECHANICAL |  | SOLENOID CONTROLLED, PILOT PRESSURE OPERATED |  |
| PEDAL OR TREADLE |  | SPRING |  |
| PUSH BUTTON |  | SERVO |  |

**Figure 9-1.** Con't.

**2.** When the four-way valve is actuated into the flow path configuration of the left envelope, the cylinder is extended against its load force $F_{load}$ as oil flows from port $P$ through port $A$. Also, oil in the rod end of the cylinder is free to flow back to the tank via the four-way valve from port $B$ through port $T$. Note that the cylinder could not extend if this oil were not allowed to leave the rod end of the cylinder.

**3.** When the four-way valve is deactivated, the spring-centered envelope prevails, and the cylinder is once again hydraulically locked.

**4.** When the four-way valve is actuated into the right envelope configuration, the cylinder retracts as oil flows from port $P$ through port $B$. Oil in the blank end is returned to the tank via the flow path from port $A$ to port $T$.

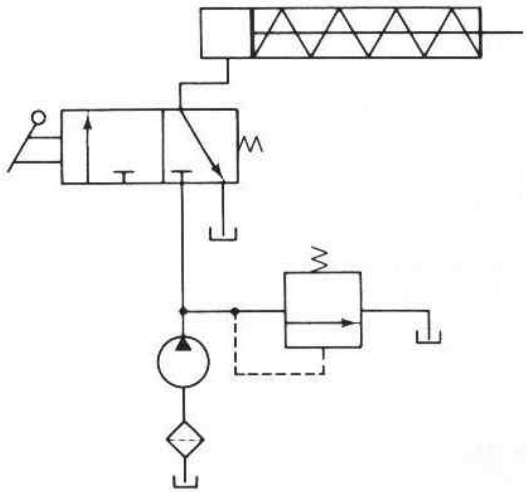


**Figure 9-2.** Control of single-acting hydraulic cylinder.

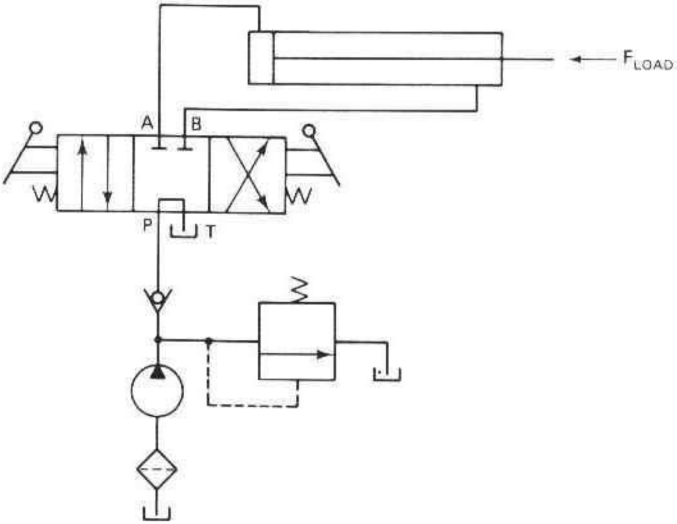



**Figure 9-3.** Control of a double-acting hydraulic cylinder.

**5.** At the ends of the stroke, there is no system demand for oil. Thus, the pump flow goes through the relief valve at its pressure-level setting unless the four-way valve is deactivated. In any event, the system is protected from any cylinder overloads.

**6.** The check valve prevents the load (if it becomes excessive) from retracting the cylinder while it is being extended using the left envelope flow path configuration.

## 9.4 REGENERATIVE CIRCUIT

Figure 9-4 shows a regenerative circuit that is used to speed up the extending speed of a double-acting hydraulic cylinder. Notice that the pipelines to both ends of the hydraulic cylinder are connected in parallel and that one of the ports of the four-way valve is blocked. The operation of the cylinder during the retraction stroke is the same as that of a regular double-acting cylinder. Fluid flows through the DCV via the right envelope during retraction. In this mode, fluid from the pump bypasses the DCV and enters the rod end of the cylinder. Fluid in the blank end drains back to the tank through the DCV as the cylinder retracts.

When the DCV is shifted into its left envelope configuration, the cylinder extends. The speed of extension is greater than that for a regular double-acting cylinder because flow from the rod end ($Q_R$) regenerates with the pump flow ($Q_P$) to provide a total flow rate ($Q_T$), which is greater than the pump flow rate to the blank end of the cylinder.

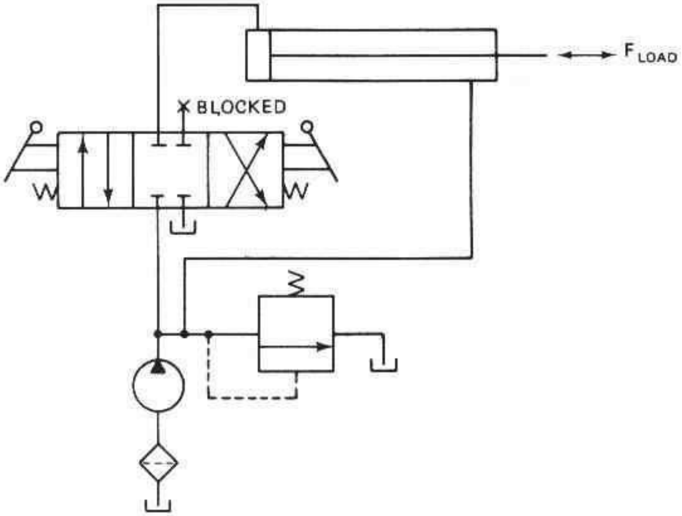



**Figure 9-4.** Regenerative circuit.

The equation for the extending speed can be obtained as follows (refer to Fig. 9-4): The total flow rate entering the blank end of the cylinder equals the pump flow rate plus the regenerative flow rate coming from the rod end of the cylinder:

$$Q_T = Q_P + Q_R$$

Solving for the pump flow, we have

$$Q_P = Q_T - Q_R$$

We know that the total flow rate equals the piston area multiplied by the extending speed of the piston ($v_{P_{ext}}$). Similarly, the regenerative flow rate equals the difference of the piston and rod areas ($A_P - A_r$) multiplied by the extending speed of the piston. Substituting these two relationships into the preceding equation yields

$$Q_P = A_P v_{P_{ext}} - (A_P - A_r)v_{P_{ext}}$$

Solving for the extending speed of the piston, we have

$$v_{P_{ext}} = \frac{Q_P}{A_r} \tag{9-1}$$

From Eq. (9-1), we see that the extending speed equals the pump flow divided by the area of the rod. Thus, a small rod area (which produces a large regenerative flow) provides a large extending speed. In fact the extending speed can be greater than the retracting speed if the rod area is made small enough. Let's find the ratio of extending and retracting speeds to determine under what conditions the extending and retracting speeds are equal. We know that the retracting speed ($v_{P_{ret}}$) equals the pump flow divided by the difference of the piston and rod areas:

$$v_{P_{ret}} = \frac{Q_P}{A_P - A_r} \tag{9-2}$$

Dividing Eq. (9-1) by Eq. (9-2), we have

$$\frac{v_{P_{ext}}}{v_{P_{ret}}} = \frac{Q_P/A_r}{Q_P/(A_P - A_r)} = \frac{A_P - A_r}{A_r}$$

Upon further simplification we obtain the desired equation:

$$\frac{v_{P_{ext}}}{v_{P_{ret}}} = \frac{A_P}{A_r} - 1 \tag{9-3}$$

From Eq. (9-3), we see that when the piston area equals two times the rod area, the extension and retraction speeds are equal. In general, the greater the ratio of piston area to rod area, the greater the ratio of extending speed to retracting speed.

It should be kept in mind that the load-carrying capacity of a regenerative cylinder during extension is less than that obtained from a regular double-acting cylinder. The load-carrying capacity ($F_{load}$) for a regenerative cylinder equals the pressure times the piston rod area rather than the pressure times piston area. This is due to the same system pressure acting on both sides of the piston during the extending stroke of the regenerative cylinder. This is in accordance with Pascal's law.

$$F_{load} = PA_r \tag{9-4}$$

Thus, we are not obtaining more power from the regenerative cylinder because the extending speed is increased at the expense of load-carrying capacity.

**Example 9-1**

A double-acting cylinder is hooked up in the regenerative circuit of Fig. 9-4. The relief valve setting is 1000 psi. The piston area is 25 in.$^2$, and the rod area is 7 in.$^2$. If the pump flow is 20 gpm, find the cylinder speed and load-carrying capacity for the

**a.** Extending stroke
**b.** Retracting stroke

***Solution***

**a.** $$v_{P_{ext}} = \frac{Q_P}{A_r} = \frac{(20 \text{ gpm})(231 \text{ in.}^3/1 \text{ gal})(1 \text{ min}/60 \text{ s})}{7 \text{ in.}^2} = 11.0 \text{ in./s}$$

$$F_{load_{ext}} = PA_r = 1000 \text{ lb/in.}^2 \times 7 \text{ in.}^2 = 7000 \text{ lb}$$

**b.** $$v_{P_{ret}} = \frac{Q_P}{A_P - A_r} = \frac{20 \times \frac{231}{60}}{25 - 7} = 4.28 \text{ in./s}$$

$$F_{load_{ret}} = P(A_P - A_r) = 1000 \text{ lb/in.}^2 \times (25 - 7) \text{ in.}^2 = 18{,}000 \text{ lb}$$

Figure 9-5 shows an application using a four-way valve having a spring-centered design with a closed tank port and a pressure port open to outlet ports *A* and *B*.

The application is for a drilling machine, where the following operations take place:

1. The spring-centered position gives rapid spindle advance (extension).
2. The left envelope mode gives slow feed (extension) when the drill starts to cut into the workpiece.
3. The right envelope mode retracts the piston.

Why does the spring-centered position give rapid extension of the cylinder (drill spindle)? The reason is simple. Oil from the rod end regenerates with the pump flow going to the blank end. This effectively increases pump flow to the

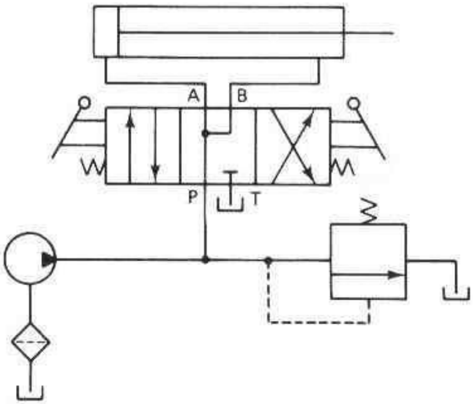



**Figure 9-5.** Drilling machine application.

blank end of the cylinder during the spring-centered mode of operation. Once again we have a regenerative cylinder. It should be noted that the cylinder used in a regenerative circuit is actually a regular double-acting cylinder. What makes it a regenerative cylinder is the way it is hooked up in the circuit. The blank and rod ends are connected in parallel during the extending stroke of a regenerative cylinder. The retraction mode is the same as a regular double-acting cylinder.

## 9.5 PUMP-UNLOADING CIRCUIT

In Fig. 9-6 we see a circuit using an unloading valve to unload a pump. The unloading valve opens when the cylinder reaches the end of its extension stroke because the check valve keeps high-pressure oil in the pilot line of the unloading valve. When the DCV is shifted to retract the cylinder, the motion of the piston reduces the pressure in the pilot line of the unloading valve. This resets the unloading valve until the cylinder is fully retracted, at which point the unloading valve unloads the pump. Thus, the unloading valve unloads the pump at the ends of the extending and retraction strokes as well as in the spring-centered position of the DCV.

## 9.6 DOUBLE-PUMP HYDRAULIC SYSTEM

Figure 9-7 shows a circuit that uses a high-pressure, low-flow pump in conjunction with a low-pressure, high-flow pump. A typical application is a punch press in which the hydraulic ram must extend rapidly over a large distance with very low pressure but high flow requirements. However, during the short motion portion

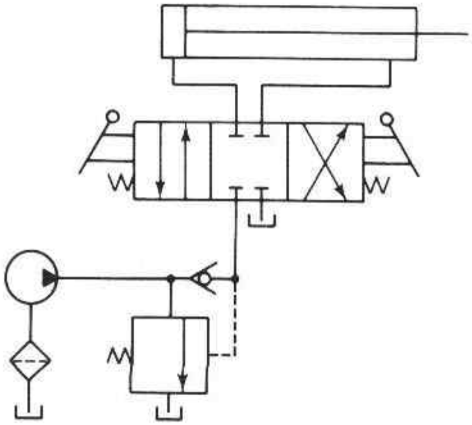


**Figure 9-6.** Pump-unloading circuit.

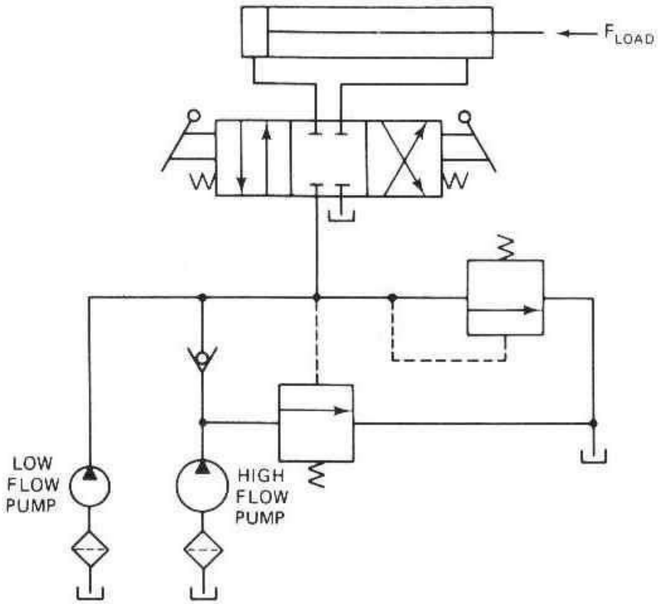



**Figure 9-7.** Double-pump hydraulic system.

when the punching operation occurs, the pressure requirements are high due to the punching load. Since the cylinder travel is small during the punching operation, the flow-rate requirements are also low.

The circuit shown eliminates the necessity of having a very expensive high-pressure, high-flow pump. When the punching operation begins, the increased pressure opens the unloading valve to unload the low-pressure pump. The purpose of the relief valve is to protect the high-pressure pump from overpressure at the end of the cylinder stroke. The check valve protects the low-pressure pump from high pressure, which occurs during the punching operation, at the ends of the cylinder stroke, and when the DCV is in its spring-centered mode.

## 9.7 PRESSURE INTENSIFIER CIRCUIT

One way to eliminate the high-pressure, low-flow pump in the punch press application of Fig. 9-7 is to use a pressure intensifier. This is done in the circuit of Fig. 9-8, which also includes a pilot check valve and sequence valve. Very high pressures can be supplied by a pressure intensifier operating on a low-pressure pump. The intensifier should be installed near the cylinder to keep the high-pressure lines as short as possible. An automatic-type pressure intensifier similar to that illus-

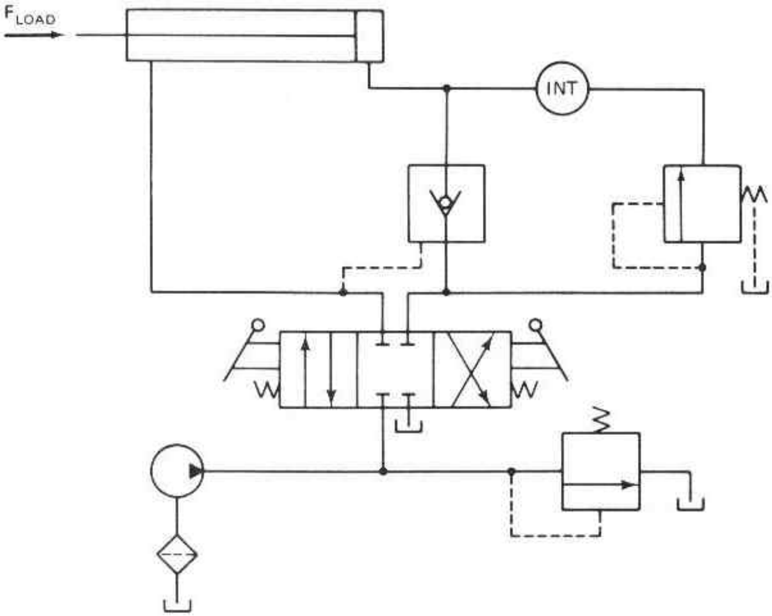



**Figure 9-8.** Pressure intensifier circuit.

trated in Fig. 9-9 is utilized. When the pressure in the cylinder reaches the sequence valve pressure setting, the intensifier starts to operate. The high-pressure output of the intensifier closes the pilot check valve and pressurizes the blank end of the cylinder to perform the punching operation. A pilot check valve is used instead of a regular check valve to permit retraction of the cylinder.

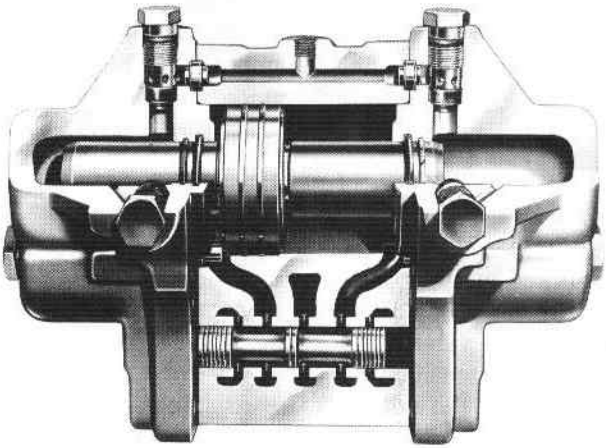


**Figure 9-9.** Automatic pressure intensifier. (*Courtesy of Rexnord Inc., Hydraulic Components Division, Racine, Wisconsin.*)

## 9.8 COUNTERBALANCE VALVE APPLICATION

Figure 9-10 illustrates the use of a counterbalance or back-pressure valve to keep a vertically mounted cylinder in the upward position while the pump is idling. The counterbalance valve is set to open at slightly above the pressure required to hold the piston up. This permits the cylinder to be forced downward when pressure is applied on the top. The open-center directional control valve unloads the pump. The DCV is a solenoid-actuated, spring-centered valve with an open-center flow path configuration.

## 9.9 HYDRAULIC CYLINDER SEQUENCING CIRCUIT

As stated earlier, a sequence valve causes operations in a hydraulic circuit to behave sequentially. Figure 9-11 is an example where two sequence valves are used to control the sequence of operations of two double-acting cylinders. When the DCV is shifted into its left envelope mode, the left cylinder extends completely, and then the right cylinder extends. If the DCV is then shifted into its right envelope mode, the right cylinder retracts fully, and then the left cylinder retracts. This sequence of cylinder operation is controlled by the sequence valves. The spring-centered position of the DCV locks both cylinders in place.

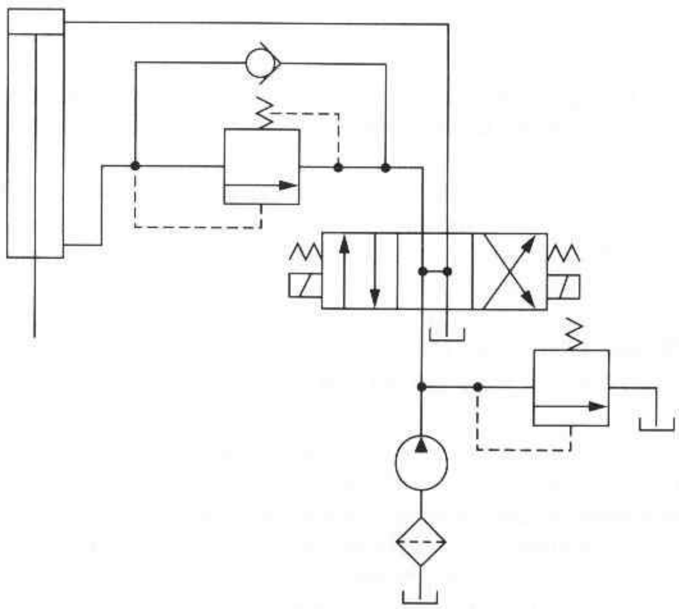


**Figure 9-10.** Counterbalance valve application.

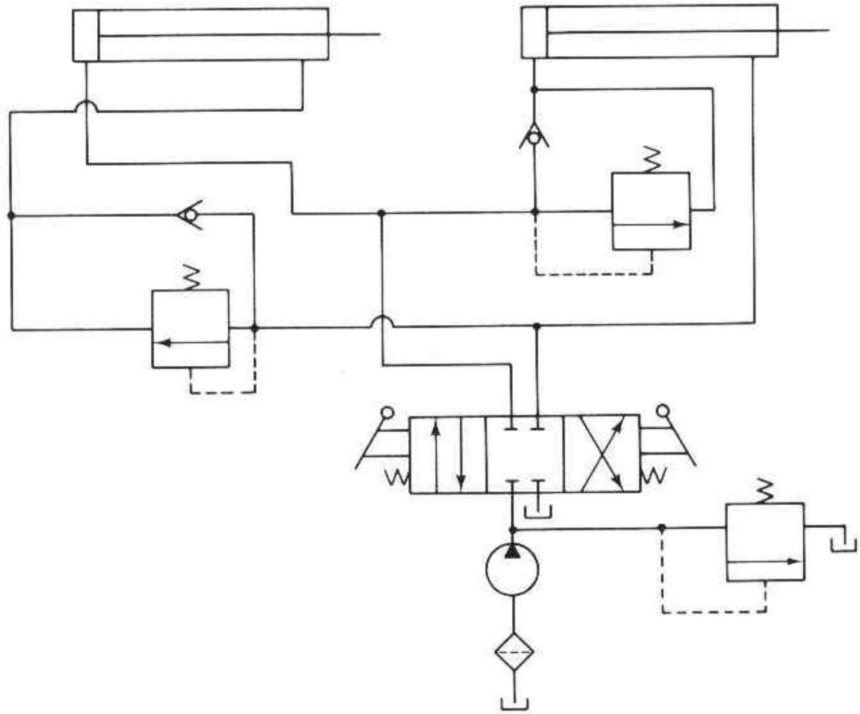


**Figure 9-11.** Hydraulic cylinder sequence circuit.

One application of this circuit is a production operation. For example, the left cylinder could extend and clamp a workpiece via a power vise jaw. Then the right cylinder extends to drive a spindle to drill a hole in the workpiece. The right cylinder then retracts the drill spindle, and then the left cylinder retracts to release the workpiece for removal. Obviously these machining operations must occur in the proper sequence as established by the sequence valves in the circuit.

## 9.10 AUTOMATIC CYLINDER RECIPROCATING SYSTEM

Figure 9-12 is a circuit that produces continuous reciprocation of a hydraulic cylinder. This is accomplished by using two sequence valves, each of which senses a stroke completion by the corresponding buildup of pressure. Each check valve and corresponding pilot line prevents shifting of the four-way valve until the particular stroke of the cylinder has been completed. The check valves are needed to allow pilot oil to leave either end of the DCV while pilot pressure is applied to the opposite end. This permits the spool of the DCV to shift as required.

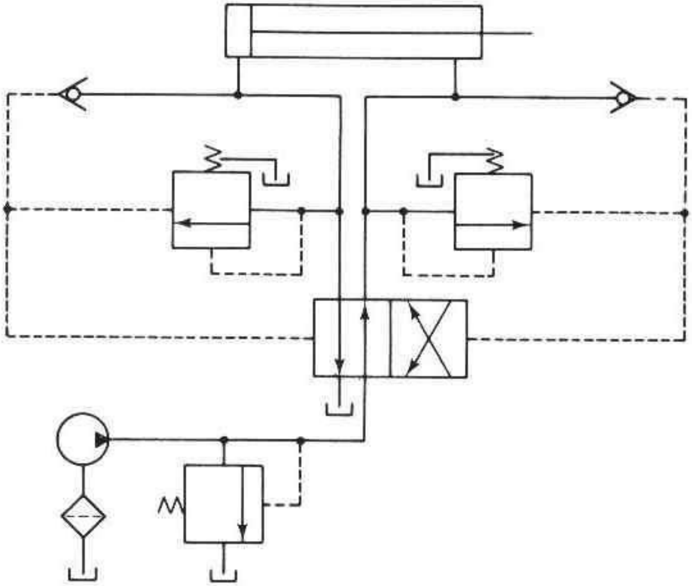


**Figure 9-12.** Automatic cylinder reciprocating system.

## 9.11 LOCKED CYLINDER USING PILOT CHECK VALVES

In many cylinder applications, it is necessary to lock the cylinder so that its piston cannot be moved due to an external force acting on the piston rod. One method for locking a cylinder in this fashion is by using pilot check valves, as shown in Fig. 9-13. The cylinder can be extended and retracted as normally done by the action of the directional control valve. If regular check valves were used, the cylinder could not be extended or retracted by the action of the DCV. An external force, acting on the piston rod, will not move the piston in either direction because reverse flow through either pilot check valve is not permitted under these conditions.

## 9.12 CYLINDER SYNCHRONIZING CIRCUIT

Figure 9-14 is a very interesting circuit, which seems to show how two identical cylinders can be synchronized by piping them in parallel. However, even if the two cylinders are identical, it would be necessary for the loads on the cylinders to be identical in order for them to extend in exact synchronization. If the loads are not exactly identical (as is always the case), the cylinder with the smaller load

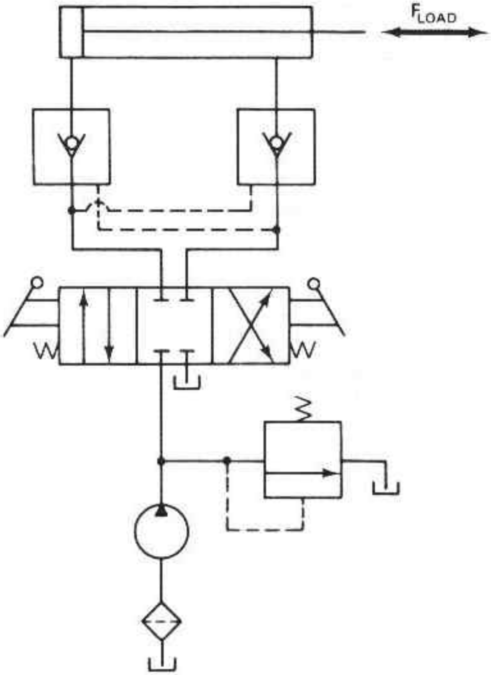



**Figure 9-13.** Locked cylinder using pilot check valves.

would extend first because it would move at a lower pressure level. After this cylinder has fully completed its stroke, the system pressure will increase to the higher level required to extend the cylinder with the greater load. It should be pointed out that no two cylinders are really identical. For example, differences in packing friction will vary from cylinder to cylinder. This alone would prevent cylinder synchronization for the circuit of Fig. 9-14.

The circuit of Fig. 9-15 shows a simple way to synchronize two cylinders. Fluid from the pump is delivered to the blank end of cylinder 1, and fluid from the

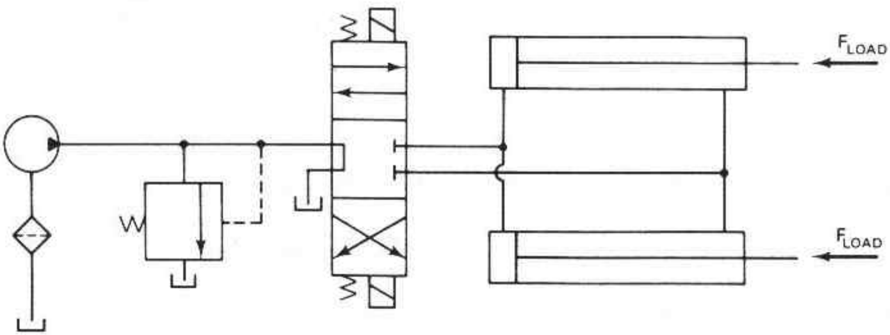



**Figure 9-14.** Cylinders hooked in parallel will not operate in synchronization.

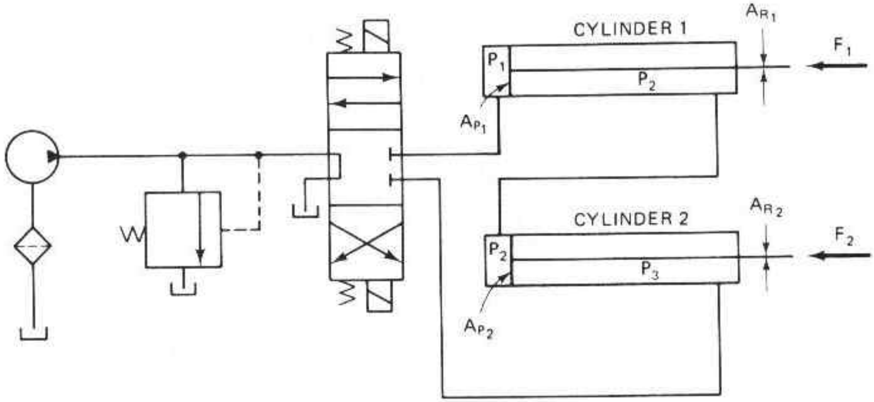



**Figure 9-15.** Cylinders hooked in series will operate in synchronization.

rod end of cylinder 1 is delivered to the blank end of cylinder 2. Fluid returns to the tank from the rod end of cylinder 2 via the DCV. Thus, the cylinders are hooked in series. For the two cylinders to be synchronized, the piston area of cylinder 2 must equal the difference between the areas of the piston and rod for cylinder 1. It should also be noted that the pump must be capable of delivering a pressure equal to that required for the piston of cylinder 1 by itself to overcome the loads acting on both cylinders. This can be shown as follows, noting that the pressures are equal at the blank end of cylinder 2 and the rod end of cylinder 1 per Pascal's law (refer to Fig. 9-15 for area, load, and pressure identifications):

$$P_1 A_{P_1} - P_2(A_{P_1} - A_{R_1}) = F_1$$

and

$$P_2 A_{P_2} - P_3(A_{P_2} - A_{R_2}) = F_2$$

Adding both equations and noting that $A_{P_2} = A_{P_1} - A_{R_1}$ and that $P_3 = 0$ (due to the drain line to the tank), we obtain the desired result:

$$P_1 A_{P_1} = F_1 + F_2 \tag{9-5}$$

## 9.13 FAIL-SAFE CIRCUITS

Fail-safe circuits are those designed to prevent injury to the operator or damage to equipment. In general they prevent the system from accidentally falling on an operator, and they also prevent overloading of the system. Figure 9-16 shows a fail-safe circuit that prevents the cylinder from accidentally falling in the event a

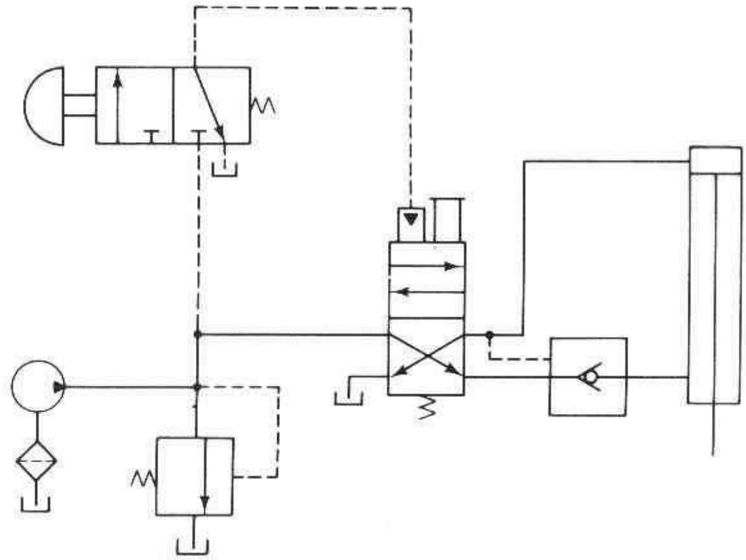


**Figure 9-16.** Fail-safe circuit.

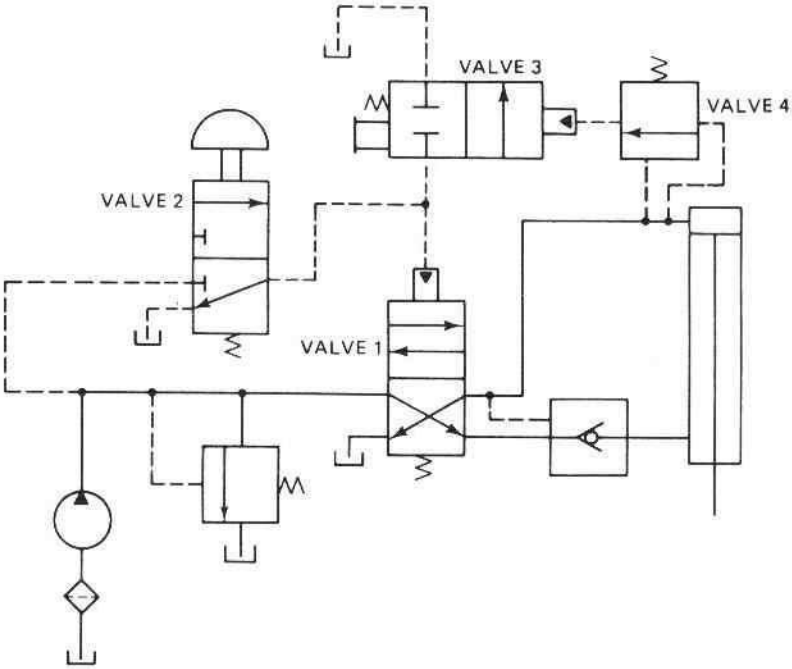



**Figure 9-17.** Fail-safe circuit with overload protection.

hydraulic line ruptures or a person inadvertently operates the manual override on the pilot-actuated directional control valve when the pump is not operating. To lower the cylinder, pilot pressure from the blank end of the piston must pilot-open the check valve at the rod end to allow oil to return through the DCV to the tank. This happens when the push-button valve is actuated to permit pilot pressure actuation of the DCV or when the DCV is directly manually actuated while the pump is operating. The pilot-operated DCV allows free flow in the opposite direction to retract the cylinder when this DCV returns to its spring offset mode.

Figure 9-17 shows a fail-safe circuit that provides overload protection for system components. Directional control valve 1 is controlled by push-button three-way valve 2. When overload valve 3 is in its spring offset mode, it drains the pilot line of valve 1. If the cylinder experiences excessive resistance during the extension stroke, sequence valve 4 pilot-actuates overload valve 3. This drains the pilot line of valve 1, causing it to return to its spring offset mode. If a person then operates push-button valve 2, nothing will happen unless overload valve 3 is manually shifted into its blocked port configuration. Thus, the system components

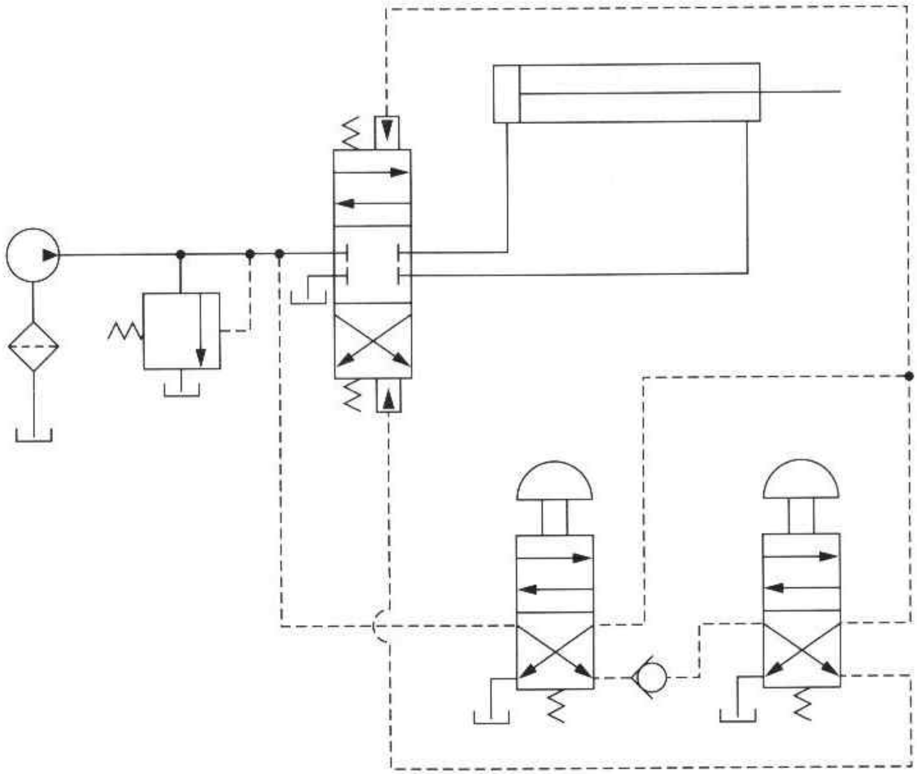


**Figure 9-18.** Two-hand safety circuit.

are protected against excessive pressure due to an excessive cylinder load during its extension stroke.

The safety circuit of Fig. 9-18 is designed to protect an operator from injury. For the circuit to function (extend and retract the cylinder), the operator must depress both manually actuated valves via the push buttons. Furthermore, the operator cannot circumvent this safety feature by tying down one of the buttons, because it is necessary to release both buttons to retract the cylinder. When the two buttons are depressed, the main three-position directional control valve is pilot-actuated to extend the cylinder. When both push buttons are released, the cylinder retracts.

## 9.14 SPEED CONTROL OF A HYDRAULIC MOTOR

Figure 9-19 shows a circuit where speed control of a hydraulic motor is accomplished using a pressure-compensated flow control valve.

The operation is as follows:

**1.** In the spring-centered position of the tandem four-way valve, the motor is hydraulically locked.

**2.** When the four-way valve is actuated into the left envelope, the motor rotates in one direction. Its speed can be varied by adjusting the setting of the throttle of the flow control valve. In this way the speed can be infinitely varied as the excess oil goes through the pressure relief valve.

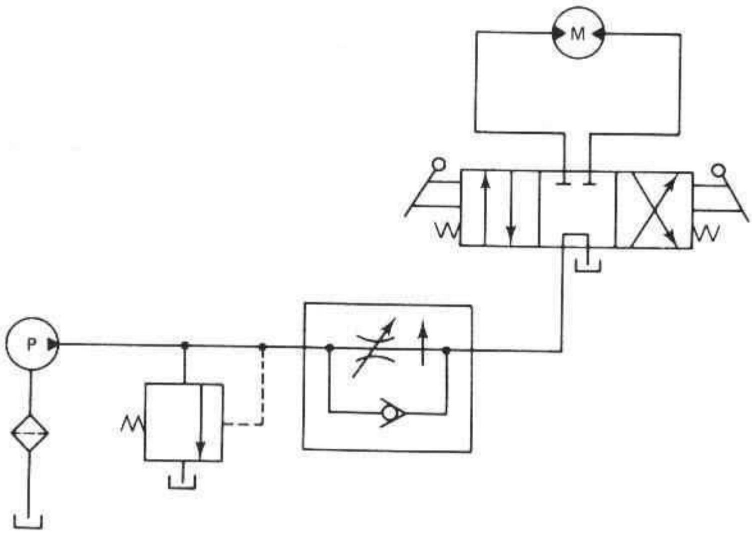



**Figure 9-19.** Speed control of hydraulic motor using flow control valve.

**3.** When the four-way valve is deactivated, the motor stops suddenly and becomes locked.

**4.** When the right envelope of the four-way valve is in operation, the motor turns in the opposite direction. The pressure relief valve provides overload protection if, for example, the motor experiences an excessive torque load.

## 9.15 HYDRAULIC MOTOR BRAKING SYSTEM

When using a hydraulic motor in a fluid power system, consideration should be given to the type of loading that the motor will experience. A hydraulic motor may be driving a machine having a large inertia. This would create a flywheel effect on the motor, and stopping the flow of fluid to the motor would cause it to act as a pump. In a situation such as this, the circuit should be designed to provide fluid to the motor while it is pumping to prevent it from pulling in air. In addition, provisions should be made for the discharge fluid from the motor to be returned to the tank either unrestricted or through a relief valve. This would stop the motor rapidly but without damage to the system. Figure 9-20 is a motor circuit that possesses these desirable features for either direction of motor rotation.

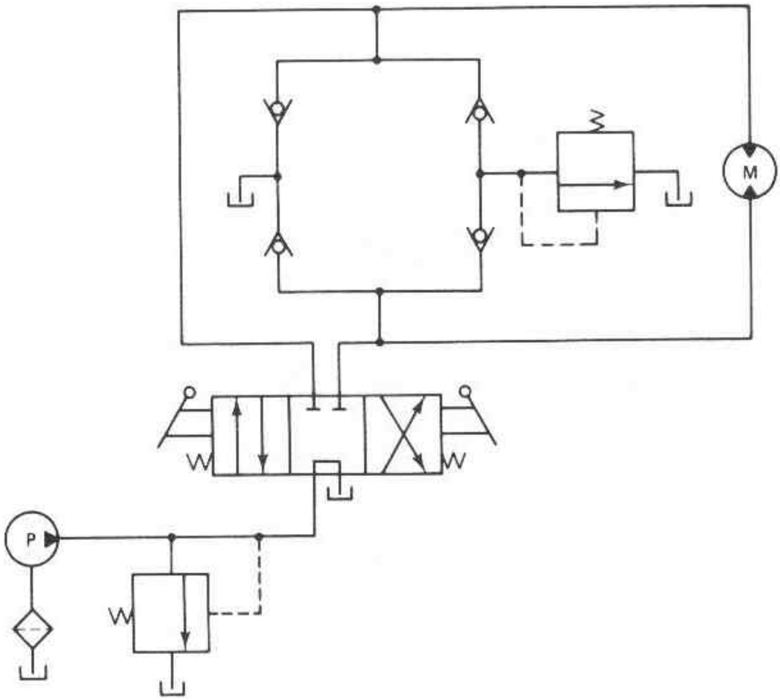



**Figure 9-20.** Hydraulic motor braking system.

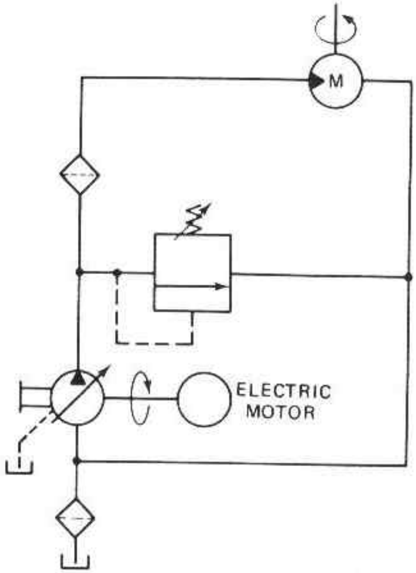



**Figure 9-21.** Closed-circuit one-direction hydrostatic transmission.

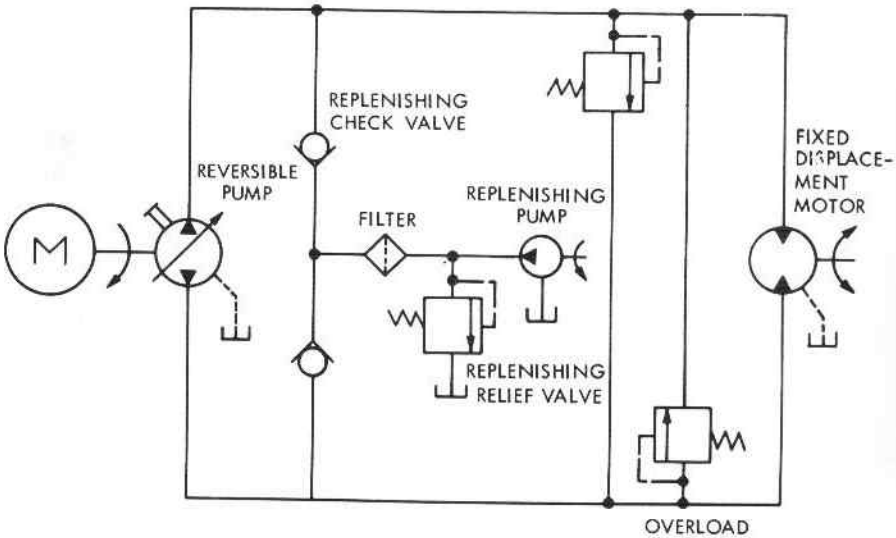
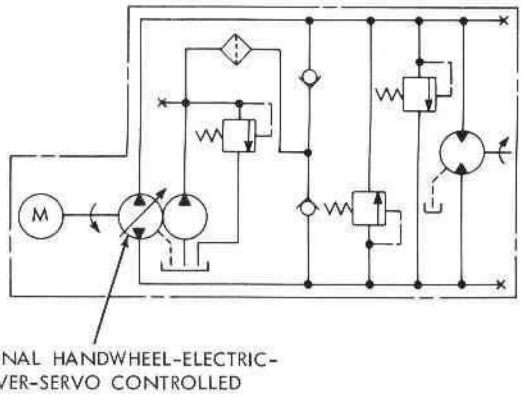



**Figure 9-22.** Closed-circuit reversible-direction hydrostatic transmission. (*Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.*)

## 9.16 HYDROSTATIC TRANSMISSION SYSTEM

Figures 9-19 and 9-20 are actually hydrostatic transmissions. They are called open-circuit drives because the pump draws its fluid from a reservoir. Its output is then directed to a hydraulic motor and discharged from the motor back into the reservoir. In a closed-circuit drive, exhaust oil from the motor is returned directly to the pump inlet. Figure 9-21 gives a circuit of a closed-circuit drive that allows for only one direction of motor rotation. The motor speed is varied by changing



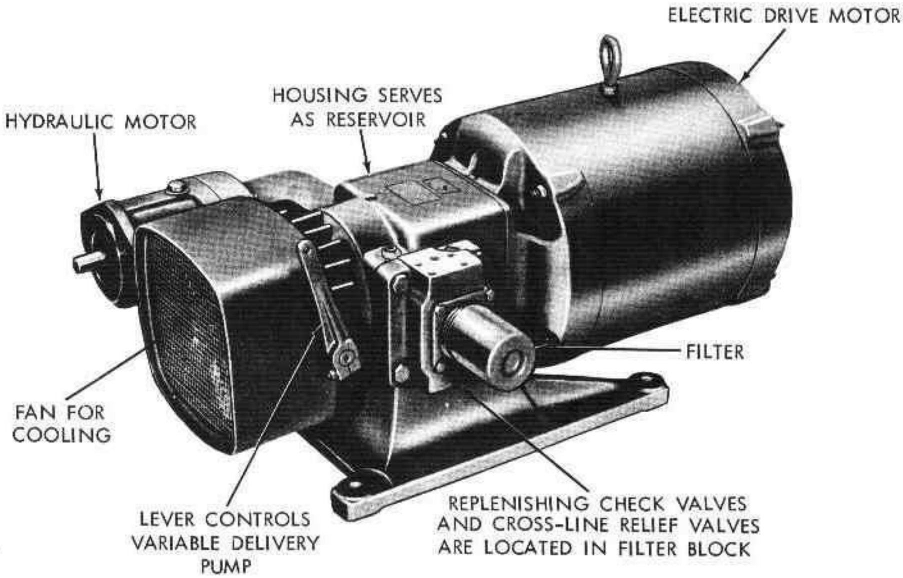




**Figure 9-23.** Packaged unit hydrostatic drive-reversible direction. (*Courtesy of Sperry Vickers, Sperry Rand Corp., Troy, Michigan.*)

the pump displacement. The torque capacity of the motor can be adjusted by the pressure setting of the relief valve. Makeup oil to replenish leakage from the closed loop flows into the low-pressure side of the circuit through a line from the reservoir.

Many hydrostatic transmissions are reversible closed-circuit drives that use a variable displacement reversible pump. This allows the motor to be driven in either direction and at infinitely variable speeds depending on the position of the pump displacement control. Figure 9-22 shows a circuit of such a system using a fixed displacement hydraulic motor. Internal leakage losses are made up by a replenishing pump, which keeps a positive pressure on the low-pressure side of the system. There are two check and two relief valves to accommodate the two directions of flow and motor rotation.

Closed-circuit drives are available as completely integrated units with all the controls and valving enclosed in a single, compact housing. Figure 9-23 shows such a system, which is driven by an electric motor. Notice the lever controls for varying the pump displacement. This unit is not only rugged and compact but also is easy to install.

## 9.17 AIR-OVER-OIL CIRCUIT

Sometimes circuits using both air and oil are utilized to obtain the advantages of each medium. Figure 9-24 shows a counterbalance system, which is an air-over-oil circuit. Compressed air flows through a filter, regulator, lubricator unit (FRL) and

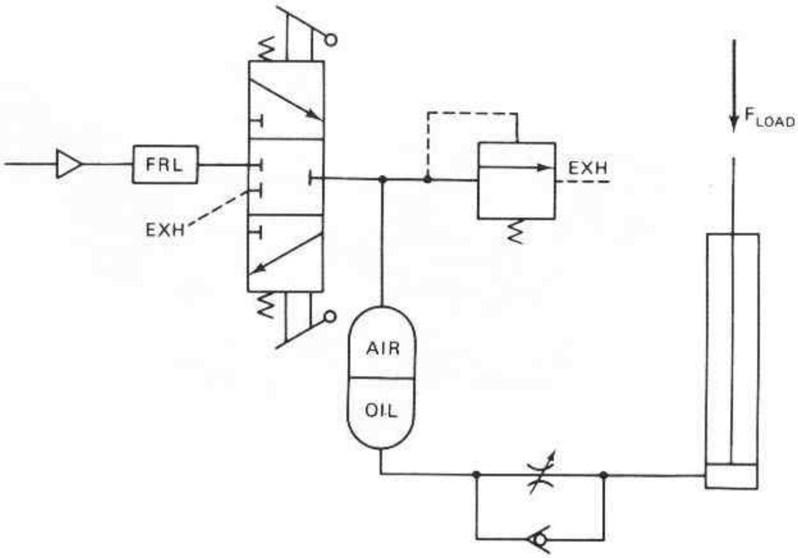



**Figure 9-24.** Air-over-oil circuit.

into a surge tank via a directional control valve (upper flow path configuration). Thus, the surge tank is pressurized by compressed air. This pushes oil out the bottom of the surge tank and to the hydraulic cylinder through a check valve and orifice hooked in parallel. This extends the cylinder to lift a load. When the directional control valve is shifted into its lower flow path mode, the cylinder retracts at a controlled rate. This happens because the variable orifice provides a controlled return flow of oil as air leaves the surge tank and exhausts into the atmosphere via the directional control valve. The load can be stopped at any intermediate position by the spring-centered position of the directional control valve. This system eliminates the need for a costly hydraulic pump and tank unit.

## 9.18 AIR-OVER-OIL INTENSIFIER SYSTEM

In Fig. 9-25 we see an air-over-oil circuit, which drives a cylinder over a large distance at low pressure and then over a small distance at high pressure. Shop air can be used to extend and retract the cylinder during the low-pressure portion of

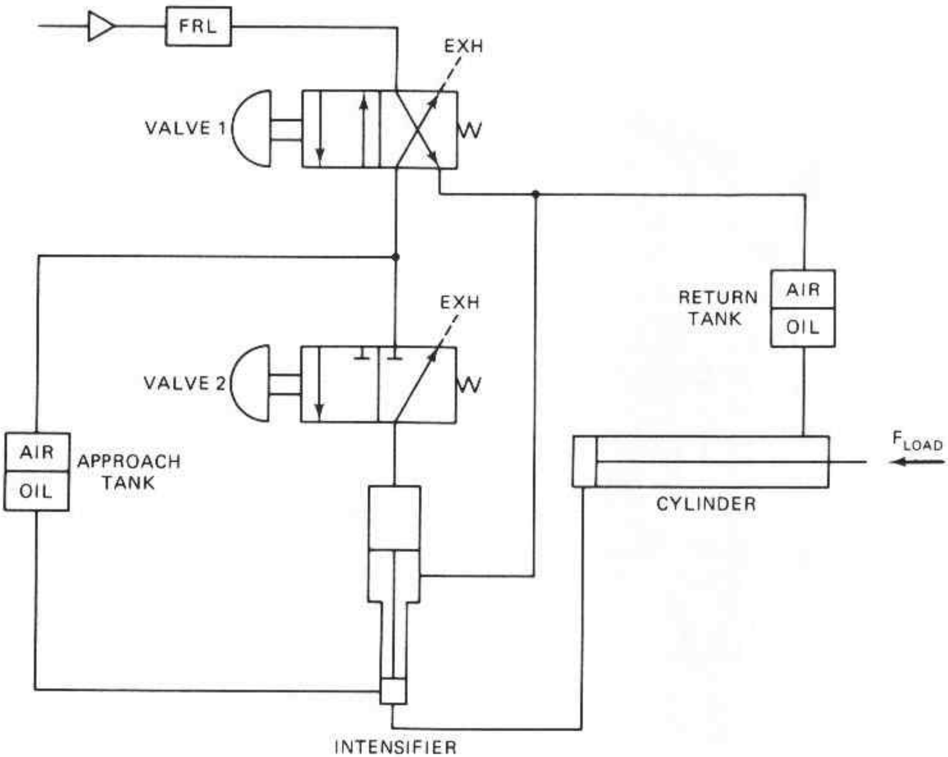
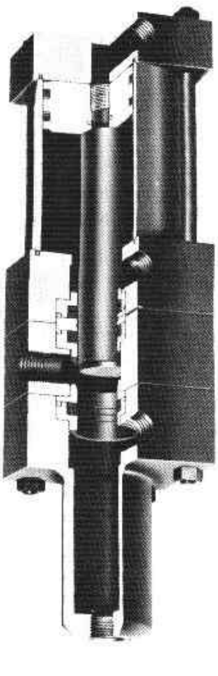
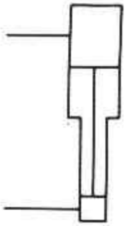



**Figure 9-25.** Air-over-oil intensifier circuit.

the cycle. The system operates as follows: Valve 1 extends and retracts the cylinder using shop air at approximately 80 psi. Valve 2 applies air pressure to the top end of the hydraulic intensifier. This produces high hydraulic pressure at the bottom end of the intensifier. Actuation of valve 1 directs air to the approach tank. This forces oil at 80 psi through the bottom of the intensifier to the blank end of the cylinder. When the cylinder experiences its load (such as the punching operation in a punch press), valve 2 is actuated, which sends shop air to the top end of the intensifier. The high-pressure oil cannot return to the approach tank because this port is blocked off by the downward motion of the intensifier piston. Thus, the cylinder receives high-pressure oil at the blank end to overcome the load. When valve 2 is released, the shop air is blocked, and the top end of the intensifier is vented to the atmosphere. This terminates the high-pressure portion of the cycle. When valve 1 is released, the air in the approach tank is vented, and shop air is directed to the return tank. This delivers oil at shop pressure to the rod end of the cylinder, causing it to retract. Oil enters the bottom end of the intensifier and flows back to the approach tank. This completes the entire cycle. Figure 9-26 shows an air-oil intensifier and its graphical symbol. This type of intensifier is capable of producing output hydraulic pressures up to 3000 psi.





ANSI SYMBOL

**Figure 9-26.** Cutaway view of an air-oil pressure intensifier. (*Courtesy of the S-P Manufacturing Corp., Cleveland, Ohio.*)

# 11 Pneumatics: Circuits and Applications

## *Learning Objectives*

Upon completing this chapter, you should be able to

1. Explain the important considerations that must be taken into account when analyzing or designing a pneumatic circuit.
2. Determine pressure losses in pipelines of pneumatic circuits.
3. Evaluate the economic costs of energy losses due to friction in pneumatic systems.
4. Determine the economic cost of air leakage in pneumatic systems.
5. Troubleshoot pneumatic circuits for determining causes of system malfunction.
6. Read pneumatic circuit diagrams and describe the corresponding system operation.
7. Discuss the operation of pneumatic vacuum systems.
8. Calculate the weight-lifting capacity of pneumatic vacuum systems.
9. Determine the time required for a vacuum pump to establish the desired vacuum pressure in vacuum lift systems.
10. Perform an analysis of gas-loaded accumulator systems.

## 11.1 INTRODUCTION

The material presented in Chapter 10 discussed the basic fundamentals of pneumatics in regard to air preparation and component operation. This chapter discusses pneumatic circuits and applications. A pneumatic circuit consists of a variety of components, such as compressors, receivers, filters, pressure regulators, lubricators, mufflers, air dryers, actuators, control valves, and conductors, arranged so that a useful task can be performed.

In a pneumatic circuit the force delivered by a cylinder and the torque delivered by a motor are determined by the pressure levels established by pressure regulators placed at the desired locations in the circuit. Similarly, the linear speed of a pneumatic cylinder and the rotational speed of an air motor are determined by flow control valves placed at desired locations in the circuit. The direction of flow in various flow paths is established by the proper location of directional control valves. After the pressurized air is spent driving actuators, it is then exhausted back into the atmosphere.

Figure 11-1 shows a riveting assembly machine, which performs continuous, high-speed, repetitive production of riveted components. The control system contains many pneumatic components such as regulators, filters, lubricators, solenoid valves, and cylinders. These machines were designed to operate under tough production-line conditions with a minimum of downtime for maintenance and adjustment.

## 11.2 PNEUMATIC CIRCUIT DESIGN CONSIDERATIONS

When analyzing or designing a pneumatic circuit, the following four important considerations must be taken into account:

1. Safety of operation
2. Performance of desired function
3. Efficiency of operation
4. Costs

Safety of operation means that an operator must be protected by the use of build-in emergency stop features as well as safety interlock provisions that prevent unsafe, improper operation. Although compressed air is often quiet, it can cause sudden movements of machine components. These movements could injure a technician who, while troubleshooting a circuit, inadvertently opens a flow control valve that controls the movement of actuator.

Performance of the desired function must be accomplished on a repeatable basis. Thus, the system must be relatively insensitive to adverse conditions such as high ambient temperatures, humidity, and dust. Shutting down a pneumatic system due to failure or misoperation can result in the stoppage of a production

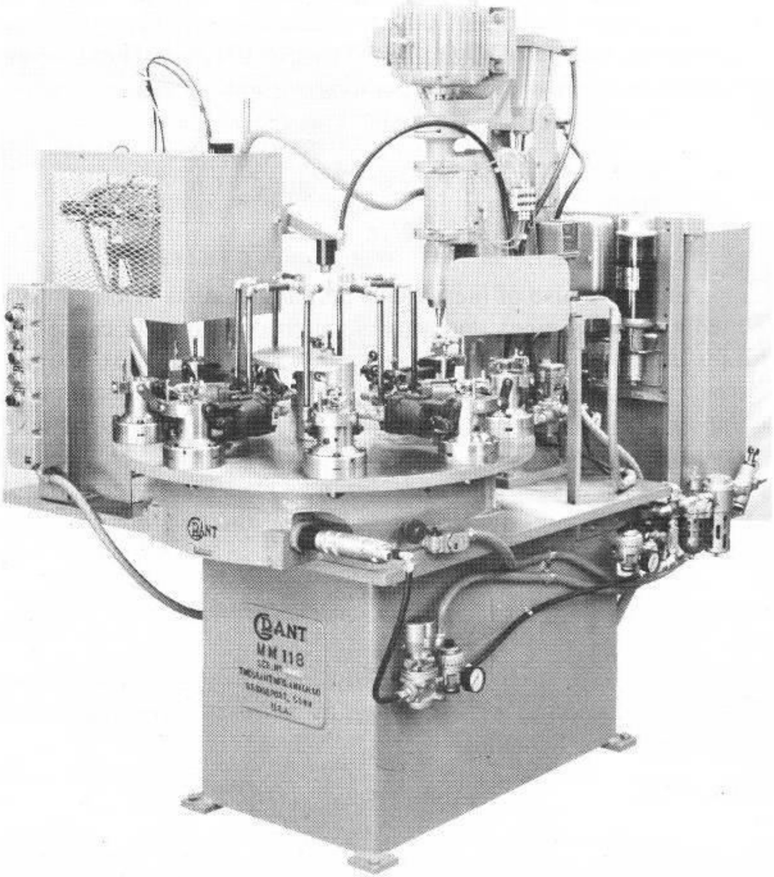


**Figure 11-1.** Pneumatically controlled riveting assembly machine. (*Courtesy of C. A. Norgren Co., Littleton, Colorado*).

line. Stoppage can result in very large costs, especially if the downtime is long due to difficulty in repairing the pneumatic system involved.

Efficiency of operation and costs are related design parameters. A low-efficiency compressor requires more electrical power to operate, which increases the system operating costs. Although atmospheric air is "free," compressed air is not. Yet if a pneumatic system leaks air into the atmosphere without making significant noise, it is often ignored, because the air is clean. On the other hand, a hydraulic leak would be fixed immediately, because it is messy and represents a safety hazard to personnel walking in the vicinity of the leak.

Pneumatic circuit air losses through various leakage areas with a combined area of a 0.25-in.-diameter hole would equal about 70 scfm for an operating pressure of 100 psig. Examples of such leakage areas include the imperfect sealing

## 11.5 BASIC PNEUMATIC CIRCUITS

In this section we present a number of basic pneumatic circuits utilizing pneumatic components that have been previously discussed. Pneumatic circuits are similar to their hydraulic counterparts. One difference is that no return lines are used in pneumatic circuits because the exhausted air is released directly into the atmosphere. This is depicted by a short dashed line leading from the exhaust port of each valve. Also, no input device (such as a pump in a hydraulic circuit) is shown, because most pneumatic circuits use a centralized compressor as their source of energy. The input to the circuit is located at some conveniently located manifold, which leads directly into the filter-regulator-lubricator (FRL) unit.

Figure 11-4 shows a simple pneumatic circuit, which consists of a three-way valve controlling a single-acting cylinder. The return stroke is accomplished by a compression spring located at the rod end of the cylinder. When the push-button valve is actuated, the cylinder extends. It retracts when the valve is deactivated. Needle valves *V*1 and *V*2 permit speed control of the cylinder extension and retraction strokes, respectively.

In Fig. 11-5 we see the directional control of a double-acting cylinder using a four-way valve. Notice that control of a double-acting cylinder requires a DCV with four different functioning ports (each of the two exhaust ports perform the same function). Thus a four-way valve has four different functioning ports. In contrast, the control of a single-acting, spring-return cylinder requires a DCV with only three ports. Hence a three-way valve has only three ports, as shown in Fig. 11-4.

Actuation of the push-button valve extends the cylinder. The spring offset mode causes the cylinder to retract under air power.

In Fig. 11-6 we see a circuit in which a double-acting cylinder can be remotely operated through the use of an air pilot-actuated DCV. Push-button valves *V*1 and *V*2 are used to direct air flow (at low pressure such as 10 psi) to actuate the air-piloted DCV, which directs air at high pressure such as 100 psi to the cylinder. Thus, operating personnel can use low-pressure push-button valves to remotely

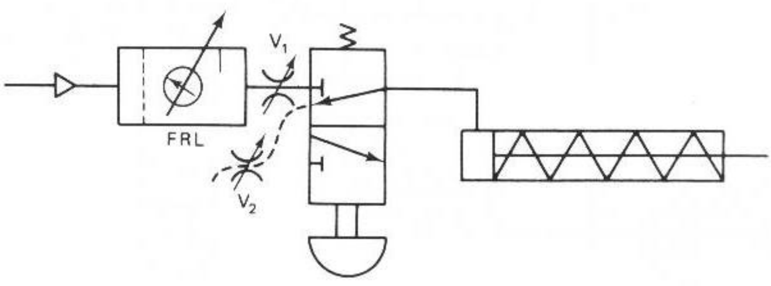



**Figure 11-4.** Operation of a single-acting cylinder.

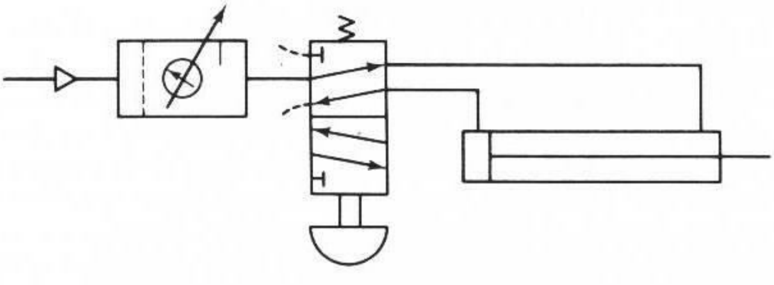


**Figure 11-5.** Operation of a double-acting cylinder.

control the operation of a cylinder that requires high-pressure air for performing its intended function. When *V*1 is actuated and *V*2 is in its spring offset mode, the cylinder extends. Deactivating *V*1 and then actuating *V*2 retracts the cylinder.

Figure 11-7 shows a circuit that employs a limit valve to provide a timed cylinder extend and retract cycle. When push-button valve *V*3 is momentarily actuated, valve *V*2 shifts to extend the cylinder. When the piston rod cam actuates limit valve *V*4, it shifts *V*2 into its opposite mode to retract the cylinder. Flow control valve *V*1 controls the flow rate and thus the cylinder speed.

A two-step speed control system is shown in Fig. 11-8. The operation is as follows, assuming that flow control valve *V*3 is adjusted to allow a greater flow

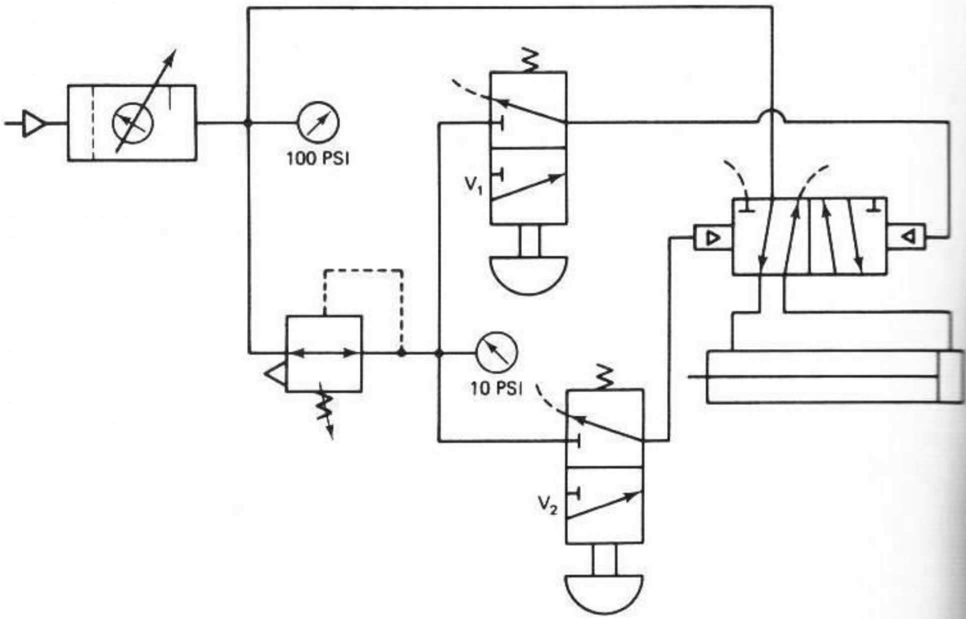



**Figure 11-6.** Air pilot control of a double-acting cylinder.

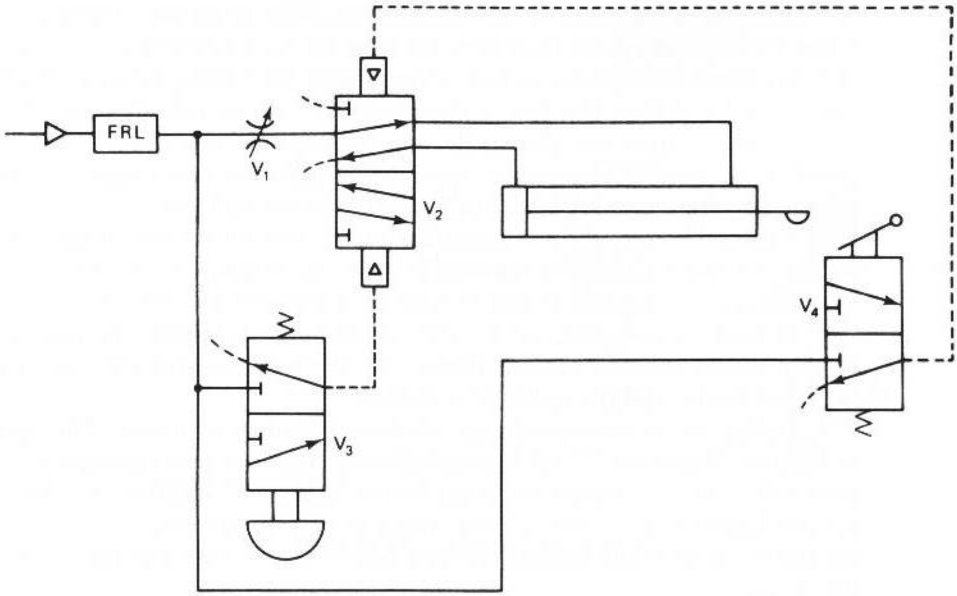



**Figure 11-7.** Cylinder cycle timing system.

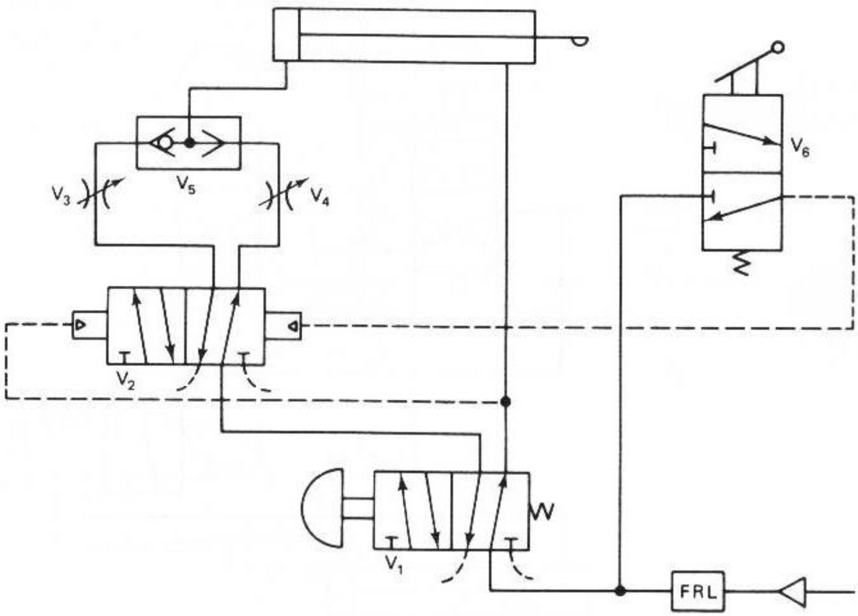



**Figure 11-8.** Two-step speed control.

rate than valve $V4$. Initially the cylinder is fully retracted. When push-button valve $V1$ is actuated, air flow goes through valves $V2$, $V3$, and the shuttle valve ($V5$) to extend the cylinder at high speed. When the piston rod cam actuates valve $V6$, valve $V2$ shifts. The flow is therefore diverted to valve $V4$ and through the shuttle valve. However, due to the low flow setting of valve $V4$, the extension speed of the cylinder is reduced. After the cylinder has fully extended, valve $V1$ is released by the operator to cause retraction of the cylinder.

Figure 11-9 shows a two-handed safety control circuit. Both palm-button valves ($V1$ and $V2$) must be actuated to cause the cylinder to extend. Retraction of the cylinder will not occur unless both palm buttons are released.

If both palm-button valves are not operated together, the pilot air to the three-position valve is vented. Hence, this three-way valve goes into its spring-centered mode, and the cylinder is locked.

In Fig. 11-10 we see a circuit used to control an air motor. The operation is as follows. When the START push-button valve is actuated momentarily, the air pilot valve shifts to supply air to the motor. When the STOP push-button valve is actuated momentarily, the air pilot valve shifts into its opposite mode to shut off the supply of air to the motor. The flow control valve is used to adjust the speed of the motor.

Figure 11-11 shows a circuit that provides an adjustable deceleration air cushion at both ends of the stroke of a cylinder when it drives a load of large weight. The operation is as follows.

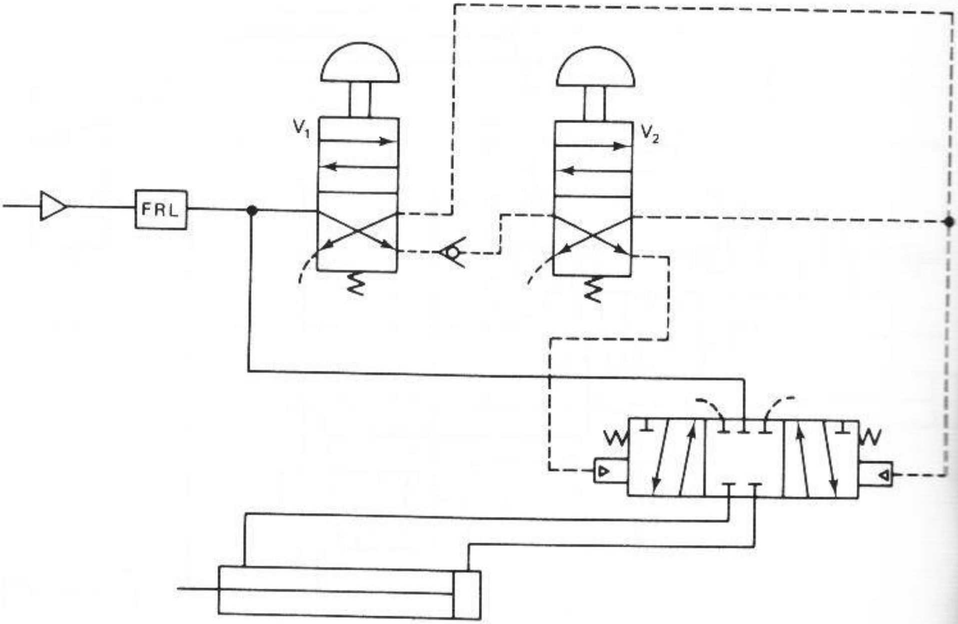



**Figure 11-9.** Two-handed safety control circuit.

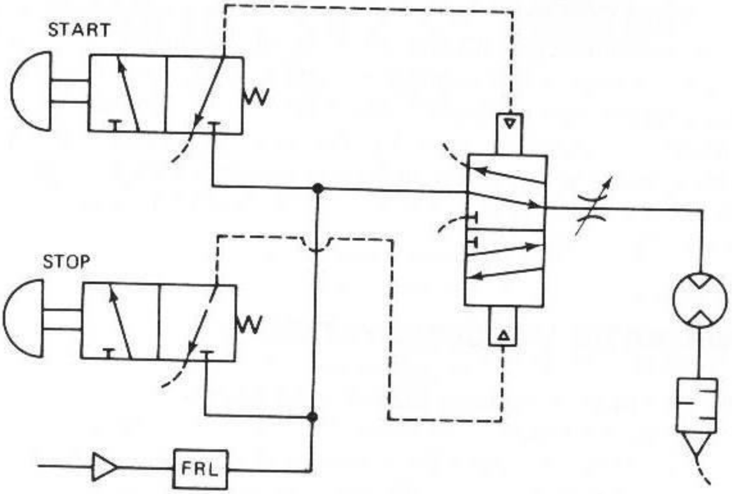



**Figure 11-10.** Control of an air motor.

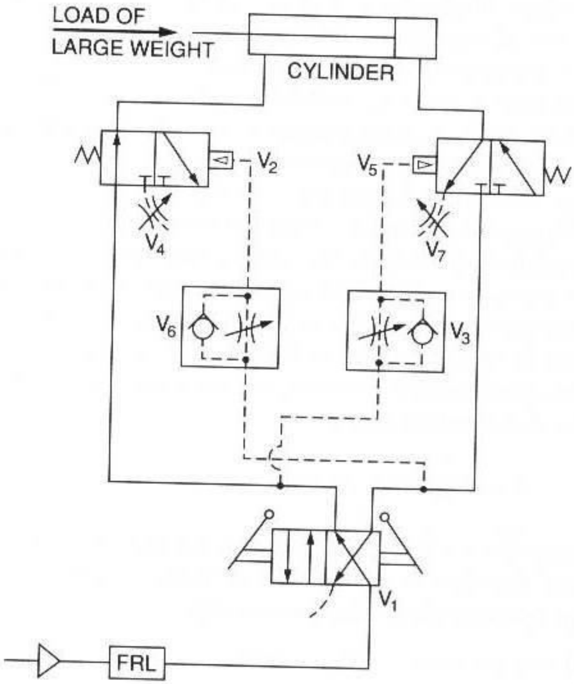



**Figure 11-11.** Deceleration air cushion of a pneumatic cylinder.

Valve *V*1 supplies air to the rod end of the cylinder and to the pilot of valve *V*5 through flow control valve *V*3. Free air exhausting from the blank end of the cylinder permits a fast cylinder-retraction stroke until valve *V*5 operates due to increased pressure at its pilot. When valve *V*5 is actuated, the cylinder blank end exhaust is restricted by valve *V*7. The resulting pressure buildup in the blank end of the cylinder acts as an air cushion to gradually slow down the large weight load. For the extension stroke, valves *V*2, *V*4, and *V*6 behave in a similar fashion to valves *V*5, *V*7, and *V*3.

## 11.6 PNEUMATIC VACUUM SYSTEMS

When we think of the force caused by a fluid pressure acting on the surface area of an object, we typically envision the pressure to be greater than atmospheric pressure. However, there are a number of applications where a vacuum air pressure is used to perform a useful function. Industrial applications where a vacuum pressure is used include materials handling, clamping, sealing, and vacuum forming.

In terms of materials-handling applications, a pneumatic vacuum can be used to lift smoothly objects that have a flat surface and are not more than several hundred pounds in weight. Examples of such objects include glass plates, sheet metal, sheets of paper, and floor-covering materials, such as ceramic tile and sheets of linoleum. The weight limitation is due to the fact that the maximum suction pressure equals 1 atm of pressure in magnitude.

Figure 11-12 shows a materials-handling application where a vacuum cup (sometimes called a suction cup) is used to establish the force capability to lift a flat sheet. The cup is typically made of a flexible material such as rubber so that a seal can be made where its lip contacts the surface of the flat sheet.

A vacuum pump (not shown) is turned on to remove air from the cavity between the inside of the cup and top surface of the flat sheet. As the pressure in the cavity falls below atmospheric pressure, the atmospheric pressure acting on the bottom of the flat sheet pushes the flat sheet up against the lip of the cup. This action results in vacuum pressure in the cavity between the cup and the flat sheet that causes an upward force to be exerted on the flat sheet. The magnitude of this force can be determined by algebraically summing the pressure forces on the top and bottom surfaces of the flat sheet as follows:

$$F = P_{\text{atm}} A_o - P_{\text{suction}} A_i \tag{11-4}$$

where $F$ = the upward force the suction cup exerts on the flat sheet (lb, N),
$P_{\text{atm}}$ = the atmospheric pressure in absolute units (psia, Pa abs)
$A_o$ = the area of the outer circle of the suction cup lip
$= \frac{\pi}{4} D_o^2$ (in.$^2$, m$^2$)

| S. No. | Hydraulic System | Pneumatic System |
|---|---|---|
| 1. | It employs a pressurized liquid as a fluid | It employs a compressed gas, usually air, as a fluid |
| 2. | An oil hydraulic system operates at pressures up to 700 bar | A pneumatic system usually operates at 5–10 bar |
| 3. | Generally designed as closed system | Usually designed as open system |
| 4. | The system slows down when leakage occurs | Leakage does not affect the system much |
| 5. | Valve operations are difficult | Valve operations are easy |
| 6. | Heavier in weight | Lighter in weight |
| 7. | Pumps are used to provide pressurized liquids | Compressors are used to provide compressed gases |
| 8. | The system is unsafe to fire hazards | The system is free from fire hazards |

## Piezoelectric actuators

Background:

**Piezoelectricity,** Greek for "pressure" electricity, was discovered by the Curie brothers more than 100 years ago. They found that quartz changed its dimensions when subjected to an electrical field, and conversely, generated electrical charge when mechanically deformed. One of the first practical applications of the technology was made in the 1920's by another Frenchman, Langevin, who developed a quartz transmitter and receiver for underwater sound - the first SONAR. Before World

A **piezoelectric actuator** converts an electrical signal into a precisely controlled physical displacement (stroke). If displacement is prevented, a useable force (blocking force) will develop. The precise movement control afforded by piezoelectric actuators is used to finely adjust machining tools, lenses, mirrors, or other equipment. A piezo actuator can be used to control hydraulic valves, act as a small-volume pump or special-purpose motor, and in other applications requiring movement or force.

Piezoelectric materials are: **Quartz, Ceramics, PZT(lead zirconate titanate).**

Two different types of piezo actuators are **stack actuators and stripe actuators.**

**Stack Actuator:** Stack actuators offer low stroke and a high blocking force. Based upon the user's requirements stack actuators can be either discrete or co-fired.

Discrete Stack Actuators

Discrete stacks (high-voltage stack actuators) are composite structures made by stacking separately finished piezoelectric ceramic discs or rings and metal electrode foils with an adhesive. Operating voltages ranging from 500 V thru 1,000 V are typical.

Co-fired multilayer stack actuators, also called "monolithic stacks", involve no adhesive, but rather a high temperature sintering of the complete ceramic and electrode pile. Operating

voltages of a co-fired stack are up to 200 V. Rectangular cross sections are typical due to the ease of cutting processes in production.
Both the discrete and co-fired stacks can be insulated with a coating material — a bare stack — or encased in stainless steel when protection from mechanical stress and environmental extremes are needed.

**Stripe Actuator:** A Stripe actuator, also called a bending actuator, is designed to produce a relatively large mechanical deflection in response to an electrical signal. This deflection offers a large stroke and avery limited blocking force when compared to a stack actuator.
Bending Actuators
In a stripe actuator, thin two layers of piezoelectric ceramic are bonded together, usually with the direction of polarization coinciding, and are electrically connected in parallel. When electrical input is applied, once ceramic layer expands and the other contracts causing the actuator to flex.

**Application**

- The first serious application for piezoelectric materials appeared during World War I
- This work is credited to Paul Langevin and his co-workers in France, who built an ultrasonic submarine detector
- The transducer they built was made of a mosaic of thin quartz crystals that was glued between two steel plates in a way that the composite system had a resonance frequency of 50 *KHz*
- *The device was used to transmit a high-frequency signal* into the water and to measure the depth by timing the return echo
- Their invention, however, was not perfected until the end of the war.