MODULE V

AUTOMATION SYSTEMS

SYLLABUS

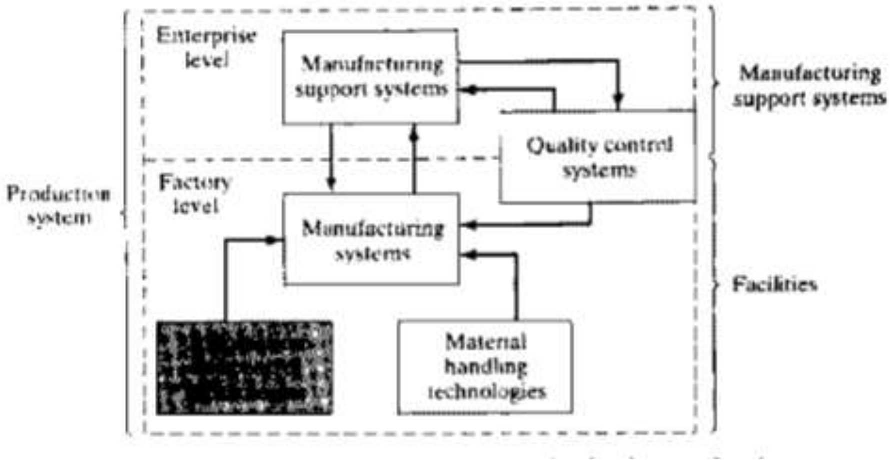
Over view of the Automation System - Architecture of Industrial Automation Systems, Different devices used in Automation Actuators, definition, types, selection. Pneumatic, Hydraulic, Electrical, Electro-Pneumatic and valves , shape memory alloys

QUESTION BANK

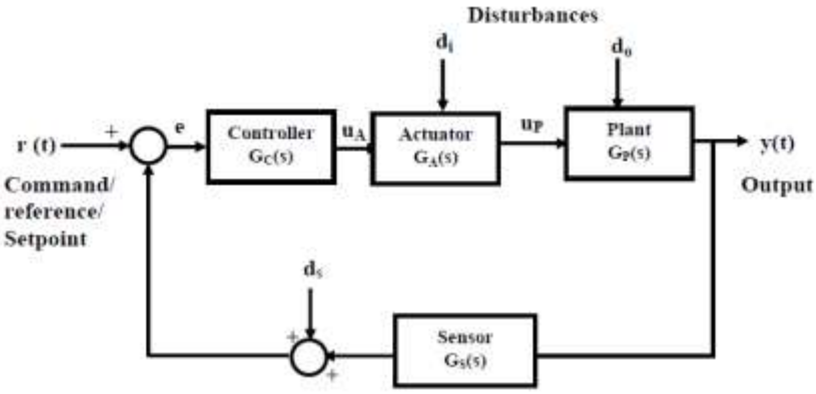
1. What you mean by shape memory alloys? Explain in detail
2. What is actuator? Why Actuators are used in Automation Functions?
3. What are the applications of shape memory alloys
4. Mention the advantages and disadvantages of shape memory alloys
5. Define valve? Explain with help of diagram
6. What are the classification of automation actuator? Different types of actuators with different characteristic and their importance's in automation
7. Define automation
8. Draw and explain architecture of automation
9. Explain levels of automation and control in manufacturing.
10. Explain in detail about mechanical, pneumatic actuactors

Automation is the technology by which a process or procedure is performed with minimum human assistance. Automation or automatic control is the use of various control systems for operating equipment such as machinery, processes in factories, boilers and heat treating ovens, switching on telephone networks, steering and stabilization of ships, aircraft and other applications and vehicles with minimal or reduced human intervention

Automation is the technology by which a process or procedure is accomplished without human assistance. It is implemented using a program of instructions combined with a control system that executes the instructions, To automate a process.power is required, both to drive the process itself and to operate the program and control system. Although automation can be applied in a wide variety of areas, it is most closely associated with the manufacturing industries.



BASIC ELEMENTS OF AN AUTOMATED SYSTEM



Power for Automation

An **automated system** is used to operate some process, and power is required to drive the process as well as the controls. The principal source of power in automated systems is electricity.

Process refers to the manufacturing operation that is performed on a work unit.

<u>Controller unit</u>. Modern industrial controllers are based on digital computers, which require electrical power to read the program of instructions, make the control calculations, and execute the instructions by transmitting the proper commands to the actuating devices.

Program instructions

The actions performed to an automated process arc defined by a program of instructions.Whether the manufacturing operation involves low, medium, or high production each part or product style made in the operation requires one or more processing steps that are unique to that style, These processing steps are performed during a work cycle. The particular processing steps for the work cycle are specified in a work cycle program

Control system

The control element of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function. which for our purpose is to carry out some manufacturing operation.The controls is an automated system can be either closed loop or open loop. A closed loop control system, also known as a feedback control system. is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input

ADVANCED AUTOMATION FUNCTIONS

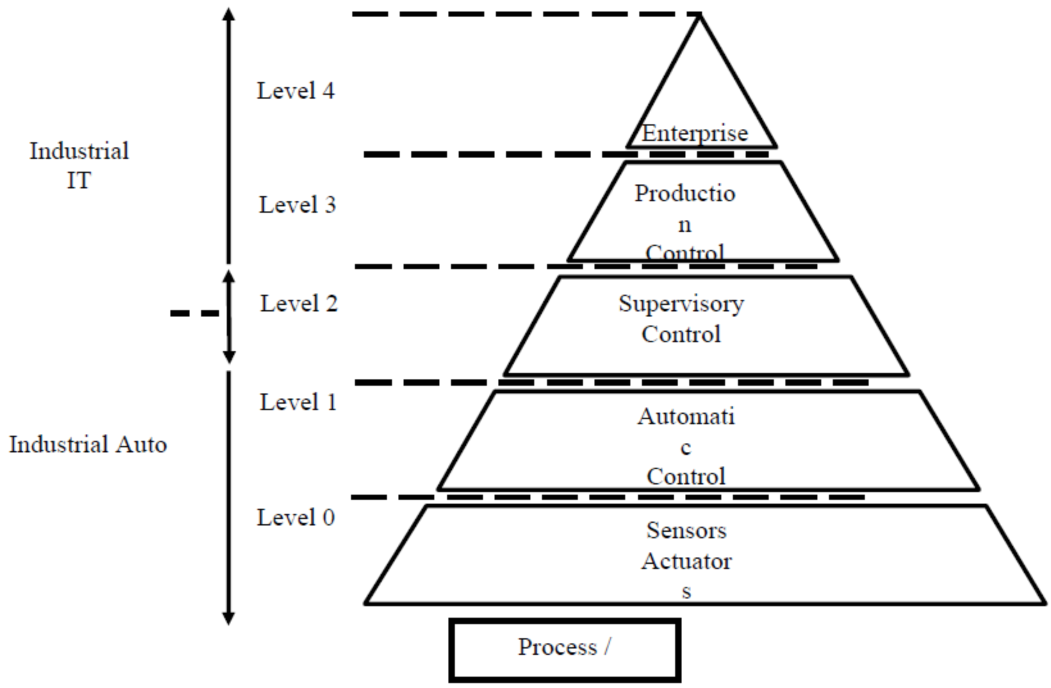
- safety monitoring,
- maintenance and repair diagnostics,
- error detection and recovery.
- complete stoppage of the automated system
- sounding an alarm
- reducing the operating speed of the process
- taking corrective actions to recover from the safety violation

Maintenance and repair diagnostics

- Maintenance and repair diagnostics refers to the capabilities of an automated system to assist in the identification of the source of potential or actual malfunctions and failures of the system. Three. modes of operation are typical of a modern maintenance and repair diagnostics subsystem
- Status monitoring
- Failure diagnostics
- Recommendation of repair procedure.

Architecture of Automation System: The Automation Pyramid

- Industrial automation systems are very complex having large number of devices with a number of technologies working in synchronization. In order to know the performance of the system we need to understand the various parts of the system.
- Industrial automation systems are organized hierarchically. Various components in an industrial automation system can be explained using the automation pyramid.
- Here, various layers represent the wideness (in the sense of no. of devices), and fastness of components on the time-scale.



- **Sensors and Actuators Layer:** This layer is closest to the processes and machines, used to translate signals so that signals can be derived from processes for analysis and decisions and hence control signals can be applied to the processes. This forms the base layer of the pyramid also called 'level 0' layer.
- **Automatic Control Layer:** This layer consists of automatic control and monitoring systems, which drive the actuators using the process information given by sensors.
- **Supervisory Control Layer:** This layer drives the automatic control system by setting target/goal to the controller. Supervisory Control looks after the equipment, which may consist of several control loops. This is called as 'level 2' layer.
- **Production Control Layer:** This solves the decision problems like production targets, resource allocation, task allocation to machines, maintenance management etc. This is called 'level 3' layer. Here most of the operations are performed by humans with the aid of tools that help people to perform the production control functions.
- **Enterprise Control Layer:** This deals less technical and more commercial activities like management of supply, demand, cash flow, product marketing etc. This is called as the 'level 4' layer.

The lowest level is faster in the time scale and the higher levels are slower. The aggregation of information over some time interval is taken at higher levels.From level 2 upward, it is not true that computer based automation is needed/present for functioning the performing on that level, some functions may be done by human being All the layers are connected by various types of communication systems.

- **Device level.** This is the lowest level in our automation hierarchy. It includes the actuators, sensors, and other hardware components that comprise the machine level.
- **Machine level**. Hardware at the device level is assembled into individual machines. Examples include CNC machine tools and similar production equipment, industrial robots, powered conveyors, and automated guided vehicles.

- **Cell or system level**. This is the manufacturing cell or system level, which operates under instructions from the plant level. A manufacturing cell or system is a group of machines or workstations connected and supported by a material handling system, computer. and other equipment appropriate to the manufacturing process. Production lines arc included in this level
- **Plum level**. This is the factory or production systems level. It receives instructions from (he corporate iufornnation system and translates them into operational plans for production.
- **Enterprise level.** This is the highest level.consisting of the corporate information systern

Actuators

Actuation systems convert the input signals computed by the control systems into forms that can be applied to the actual process and would produce the desired variations in the process physical variables.

Convert the controller output, which is essentially information without the power, and in the form of electrical voltages (or at times pneumatic pressure) in two ways.

Firstly, it converts the form of the variable into the appropriate physical variable, such as torque, heat or flow. Secondly, it amplifies the energy level of the signal manifold to be able to causes changes in the process variables.

In industrial control systems, an actuator is a hardware device that converts a controller command signal into a change in a physical parameter. The change in the physical parameter is usually mechanical such as position or velocity change.

The controller command signal is usually low level, and so an actuator may also include an amplifier to strengthen the signal sufficiently to drive the actuator.

With the increasing utilization of automated machinery/systems, there has also been a rise in the demands for actuators, which play a vital role in the automation process.

Actuators, which are responsible for moving, controlling or positioning a mechanism or system, make the working of automated equipment seamless and easy

There are several areas wherein actuators play a crucial role in automated systems.

- **Process Industries:** Control the operation of various equipment in an industry.
- **Solar:** The industry utilizes several types of actuators including ball screw and ACME actuators to automate the functioning of various solar tracking devices, solar power concentration equipment, photovoltaic device, and photovoltaic concentration equipment, among several others.
- **Military:** These military actuators are basically equipped in tanks, cannon carriers, airplanes, fighter planes, helicopters, ships, and robots, because they offer complete movement. Actuators for the military industries are ruggedly built to withstand harsh environmental conditions, extreme weathers, and severe attacks.
- **Satellite:** The use of several linear and rotational actuators help automate the working of several equipment. These include dish antennas, sensors, earth-imaging equipment,

and so on. Specially designed and high quality satellite actuators are sought after for precise positioning and motion control for the industry.

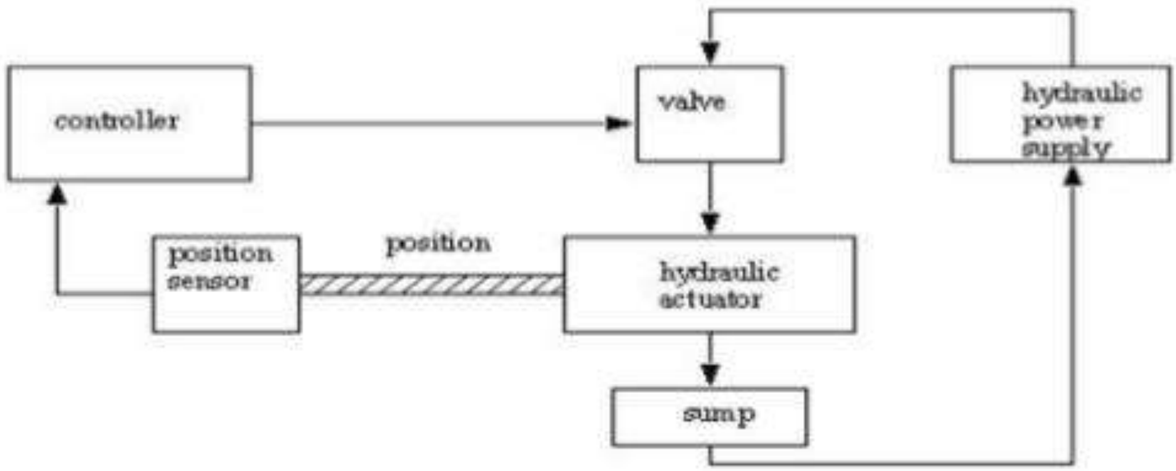
- **Construction:** The industry depends on high speed automated machines/systems to carry out several dangerous and tedious tasks. Actuators of varied types are used in these systems, because they are known to delivering powerful movements to heavy duty machineries like loading trucks, towing trucks, and cranes. Actuators for the construction industry are built to offer durable, reliable and long-lasting performance

Hydraulic Actuating System

It uses fluid power to produce mechanical force. Fluid power is technology that deals with the generation, control and transmission of forces responsible for movement of mechanical element.

The fluid used in hydraulic actuator is highly incompressible so that pressure applied can be transmitted instantaneously to the member attached to it.

Hydraulics is based on Pascal's law which states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container. Pressure applied to a confined fluid at any point is transmitted undiminished and equally throughout the fluid in all directions and acts upon every part of the confining vessel at right angles to its interior surfaces. In simple words intensity of pressure in fluid is equal in all direction. Hydraulic actuators are used where high speed and large forces are required.



Various components of Hydraulic Actuators are given in brief below:

Pump: Hydraulic power generation system. Pump pressurizes fluid to the level required by an actuating system.

Valve: Controls the direction, pressure, flow rate of hydraulic fluid. It basically acts as a regulating system.

Actuator: Converts the fluid pressure into mechanical movement either linear or

rotary. Pipes: Used to connect various elements of actuating system with each other.

Accumulator, Reservoir and Filter: Filter is used to filter the hydraulic fluid to prevent damage to system components by contaminants. Reservoir & accumulator is use for storage purposes.

Sensors: Crucial part of any automation process. Provide some kind of feedback signal to evaluate the end result by controller.

Control Device: Control whole actuating system by providing signals. (Microcontroller or PLC are popularly used)

Hydraulic Actuators, as used in industrial process control, employ hydraulic pressure to drive an output member. The fluid used in hydraulic actuator is highly incompressible so that pressure applied can be transmitted instantaneously to the member attached to it.

A hydraulic actuator consists of a cylinder or fluid motor that uses hydraulic power to facilitate mechanical operation. The mechanical motion gives an output in terms of linear, rotary or oscillatory motion. Because liquids are nearly impossible to compress, a hydraulic actuator can exert considerable force.

Principle Used in Hydraulic Actuator System

Pascal's Law:

Pressure applied to a confined fluid at any point is transmitted undiminished and equally throughout the fluid in all directions and acts upon every part of the confining vessel at right angles to its interior surfaces.

Amplification of Force:

Since pressure P applied on an area A gives rise to a force F, given as,

$$F = P \times A$$

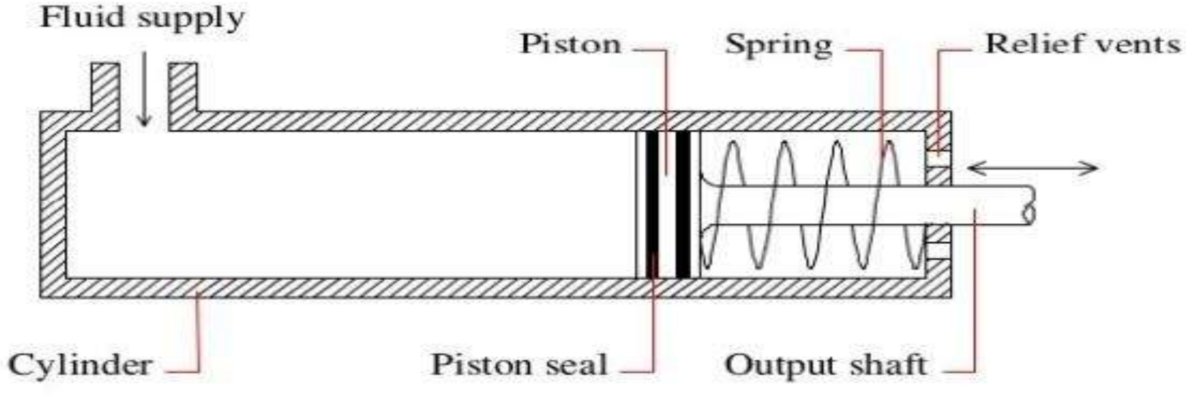
Thus, if a force is applied over a small area to cause a pressure P in a confined fluid, the force generated on a larger area can be made many times larger than the applied force that crated the pressure. This principle is used in various hydraulic devices to such hydraulic press to generate very high forces.

Hydraulic Actuators are of three types

- Linear Actuator
  - Single Acting cylinder
  - Double Acting cylinder
- Rotary Actuator
- Oscillatory Actuator

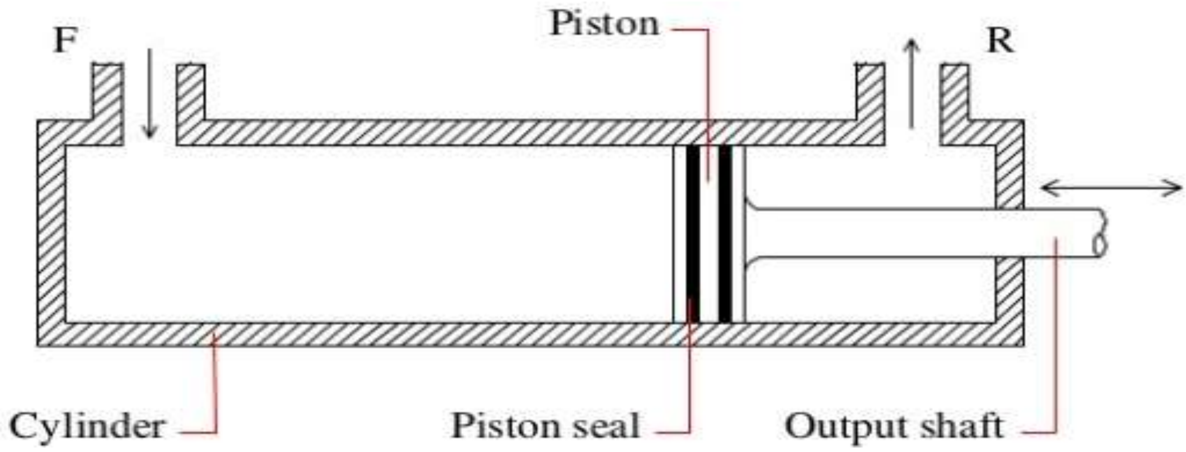
Linear Actuator: Single Acting Cylinder

In single acting cylinder actuator, there is only one opening for the fluid to enter and leave. The forward motion is due to the hydraulic pressure of the fluid entering through the opening, while the reverse motion is due to the spring.



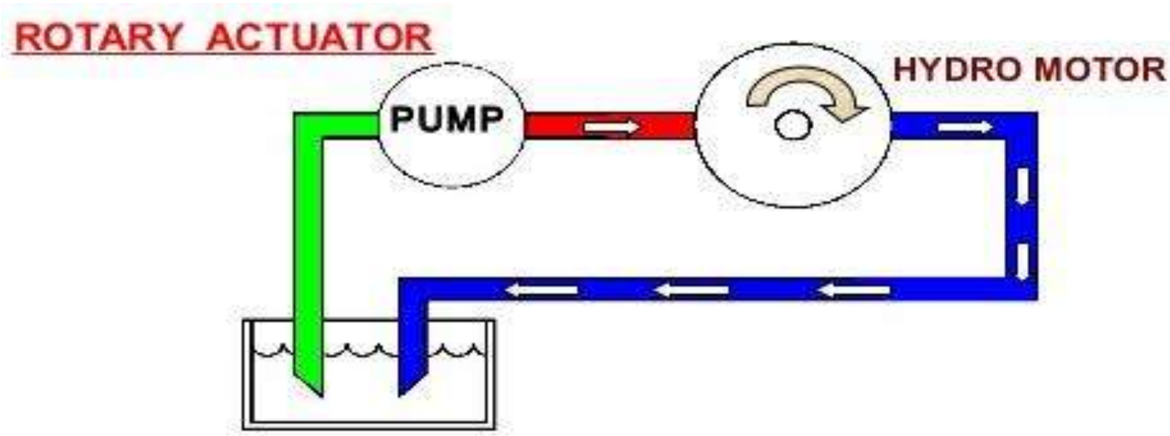
Double Acting Cylinder

In double acting cylinder actuator, there are two openings for the fluid to enter and leave. The forward motion is due to the hydraulic pressure of the fluid entering through one opening, while the reverse motion is due to the hydraulic pressure of the fluid entering through one opening.



Rotary Actuator

In rotary actuator, the linear motion of fluid inside the pipe is converted into rotary motion by a hydro motor.

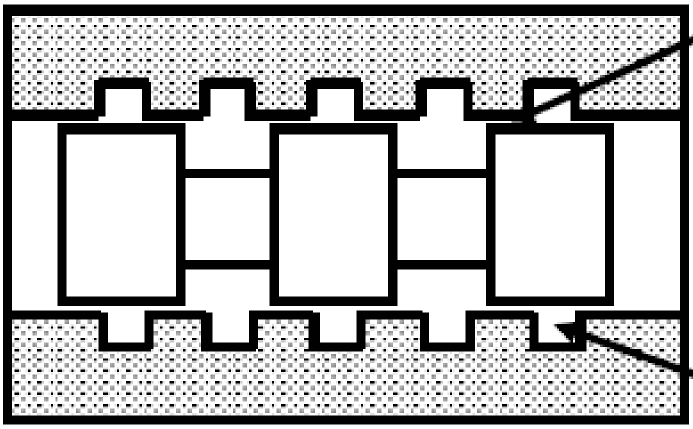


Components of Hydraulic Actuation Systems

Hydraulic Fluid

- Hydraulic Fluid transmit the fluid power from the reservoir to the actuator cylinder.
- Hydraulic fluid must be essentially non-compressible to be able to transmit power instantaneously from one part of the system to another.
- It should lubricate the moving parts to reduce friction loss and cool the components so that the heat generated does not lead to fire hazards.
- It also helps in removing the contaminants to filter.
- The other desirable property of oil is its lubricating ability.
- The fluid also acts as a seal against leakage inside a hydraulic component.

- The most common liquid used in hydraulic systems is petroleum oil because it is only very slightly compressible.

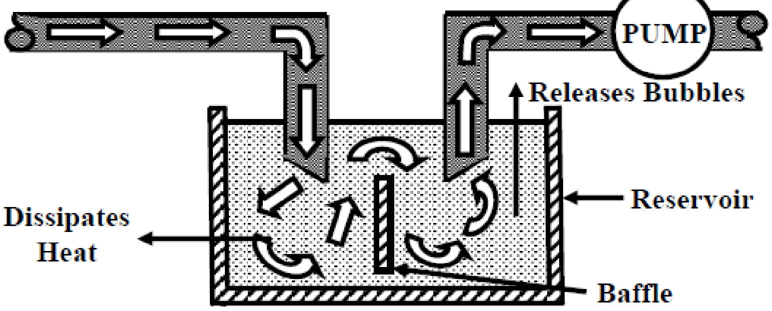


The Fluid Delivery Subsystem

It consists of the components that hold and carry the fluid from the pump to the actuator. It consists of reservoir, filter, line, fittings and seals, pump, motor, accumulator etc.

Reservoir

It holds the hydraulic fluid to be circulated and allows air entrapped in the fluid to escape. This is an important feature as the bulk modulus of the oil, which determines the stiffness of hydraulic system, deteriorates considerably in the presence of entrapped air bubbles. It also helps in dissipating heat.



Filter

The hydraulic fluid is kept clean in the system with the help of filters and strainers. It removes minute particles from the fluid, which can cause blocking of the orifices of servo-valves or cause jamming of spools.

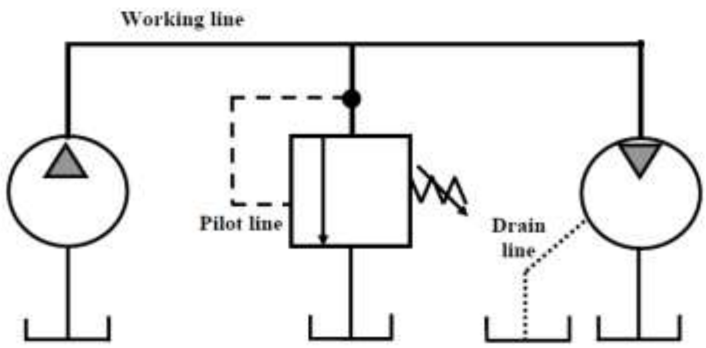
Line

- Pipe, tubes and hoses, along with the fittings or connectors, constitute the conducting lines that carry hydraulic fluid between components.
- Lines convey the fluid and also dissipate heat.

- Lines are one of the disadvantages of hydraulic system that we need to pay in return of higher power to weight ratio. They need return path
- In contrast, for Pneumatic Systems, no return path for the fluid, which is air, is needed, since it can be directly released into the atmosphere.

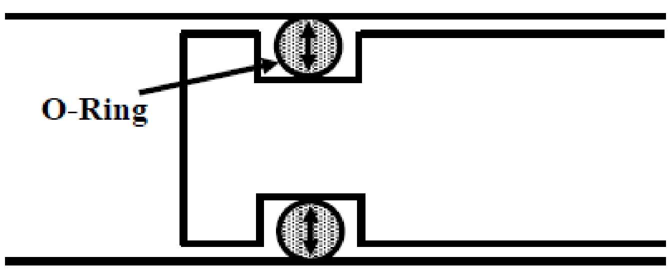
There are various kinds of lines in a hydraulic system.

- The working lines carry the fluid that delivers the main pump power to the load.
- The pilot lines carry fluid that transmit controlling pressures to various directional and relief valves for remote operation or safety.
- Drain lines carry the fluid that inevitably leaks out, to the tank.



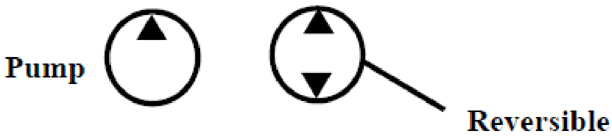
Fittings and Seals

- Various additional components are needed to join pipe or tube sections, create bends and also to prevent internal and external leakage in hydraulic systems.
- Although some amount of internal leakage is built-in, to provide lubrication, excessive internal leakage causes loss of pump power since high pressure fluid returns to the tank, without doing useful work.
- External leakage, on the other hand, causes loss of fluid and can create fire hazards, as well as fluid contamination.
- Various kinds of sealing components are employed in hydraulic systems to prevent leakage.



Hydraulic Pumps

The pump converts the mechanical energy of its prime-mover to hydraulic energy by delivering a given quantity of hydraulic fluid at high pressure into the system. Generically, all pumps are divided into two categories, namely, hydrodynamic or non-positive displacement and hydrostatic or positive displacement. Hydraulic systems generally employ positive displacement pumps only.



Hydrostatic or Positive Displacement Pumps: These pumps deliver a given amount of fluid for each cycle of motion, that is, stroke or revolution. Their output in terms of the volume flow rate is solely dependent on the speed of the prime-mover and is independent of outlet pressure notwithstanding leakage. There are various types of pumps used in hydraulic systems such as Gear Pumps, Vane Pumps, Piston Pumps, Radial Piston Pumps etc.

Motors

Motors work exactly on the reverse principle of pumps. In motors fluid is forced into the motor from pump outlets at high pressure. This fluid pressure creates the motion of the motor shaft and finally go out through the motor outlet port and return to tank. All three variants of motors, already described for pumps, namely Gear Motors, Vane Motors and Piston motors are in use.

Accumulators

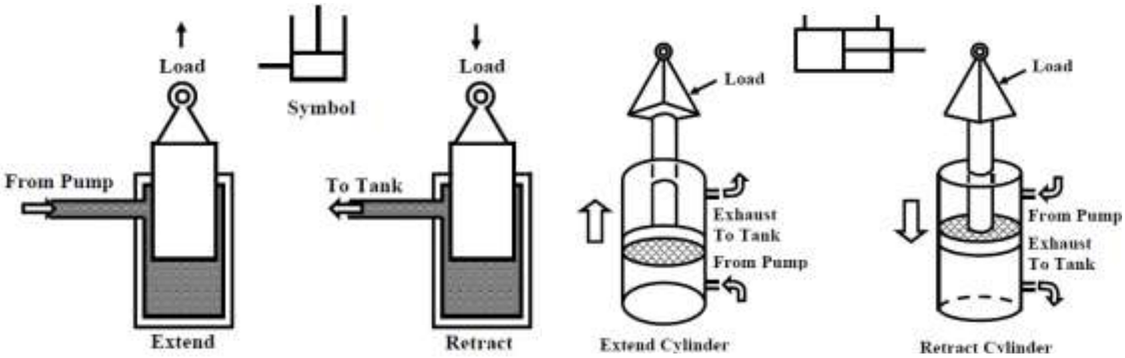
Unlike gases the fluids used in hydraulic systems cannot be compressed and stored to cater to sudden demands of high flow rates that cannot be supplied by the pump. An accumulator in a hydraulic system provides a means of storing these incompressible fluids under pressure created either by a spring, or compressed gas. Any tendency for pressure to drop at the inlet causes the spring or the gas to force the fluid back out, supplying the demand for flow rate.

There are two types of accumulators: Spring-Loaded Accumulators, Gas Charged Accumulator

Cylinders

Cylinders are linear actuators, that is, they produce straight-line motion and/or force. Cylinders are classified as single-or double-acting with the graphical symbol for each type.

There are two types of cylinders such as Single Acting Cylinder and Double-Acting Cylinder



Advantages of Hydraulic Actuator Systems

- Variable Speed and Direction: The actuator (linear or rotary) of a hydraulic system, can be driven at speeds that vary by large amounts and fast, by varying the pump delivery or using a flow control valve. A hydraulic actuator can be reversed instantly while in full motion without damage. This is not possible for most other prime movers.
- Power-to-weight ratio: Hydraulic components, because of their high speed and pressure capabilities, can provide high power output with vary small weight and size.
- Stall Condition and Overload Protection: A hydraulic actuator can be stalled without damage when overloaded, and will start up immediately when the load is reduced. The pressure relief valve in a hydraulic system protects it from overload damage. During stall, or when the load pressure exceeds the valve setting, pump delivery is directed to tank with definite limits to torque or force output.
- Hydraulic actuators are rugged and suited for high-force applications. They can produce forces 25 times greater than pneumatic cylinders of equal size. They also operate in pressures of up to 4,000 psi.
- Hydraulic motors have high horsepower-to-weight ratio by 1 to 2 hp/lb greater than a pneumatic motor.
- A hydraulic actuator can hold force and torque constant without the pump supplying more fluid or pressure due to the incompressibility of fluids
- Hydraulic actuators can have their pumps and motors located a considerable distance away with minimal loss of power.

Drawbacks

- Hydraulics will leak fluid. Like pneumatic actuators, loss of fluid leads to less efficiency. However, hydraulic fluid leaks lead to cleanliness problems and potential damage to surrounding components and areas.
- Hydraulic actuators require many companion parts, including a fluid reservoir, motors, pumps, release valves, and heat exchangers, along with noise-reduction equipment. This makes for linear motions systems that are large and difficult to accommodate.

Pneumatic Actuating System

- Devices used for converting pressure energy of compressed air into the mechanical energy to perform useful work.
- Actuators are used to perform the task of exerting the required force at the end of the stroke or used to create displacement by the movement of the piston.
- The pressurized air from storage is supplied to pneumatic actuator to do work.
- The air cylinder is a simple and efficient device for providing linear thrust or straight line motions.
- Pneumatic actuator consists of a piston and rod moving inside a closed cylinder.
- This actuator can be sub-divided into two types based on the operating principle: single acting and double acting.

The principle is based on the concept of pressure as force per unit area.

If we imagine that a net pressure difference is applied across a diaphragm of surface area A, then a net force acts on the diaphragm given by $F = A(P_1 - P_2)$.

$P_1 - P_2$ = pressure difference (Pa)

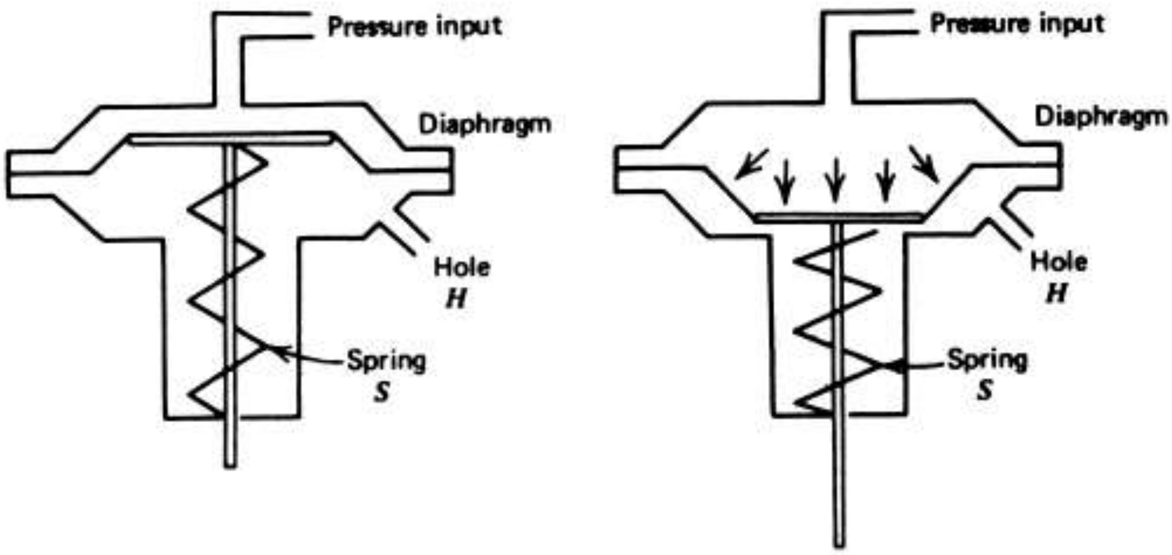
A = diaphragm area (m^2)

F = force (N)

If we need to double the available force for a given pressure, it is merely necessary to double the diaphragm area.

Very large forces can be developed by standard signal-pressure ranges of 3 to 15 psi (20 to 100 kPa).

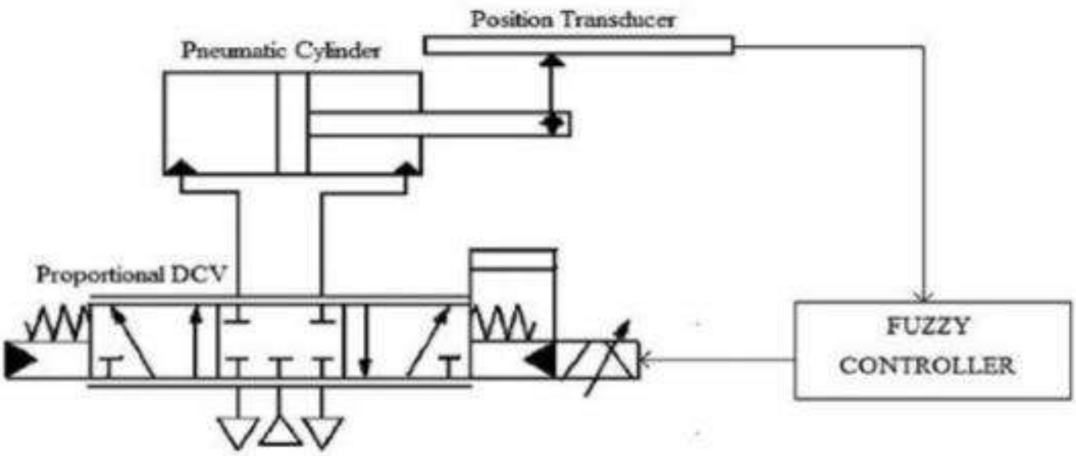
Many types of pneumatic actuators are available, but perhaps the most common are those associated with control valves.



Widely used in automation filed because of its low weight and compact size.

Control of pneumatics system is slightly difficult as compare to hydraulic system because of compressed air governing equations of pneumatics are nonlinear in nature.

More used in automation industry as discrete device such as gripper

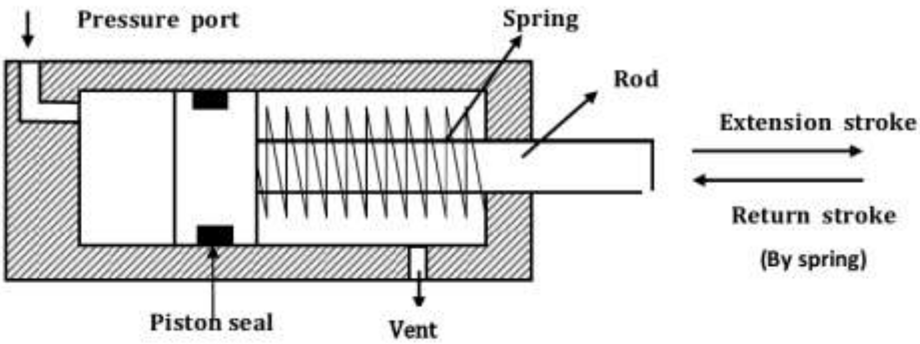


Types of Pneumatics Actuators are:

- Linear Actuator or Pneumatic cylinders
    - Single acting cylinder
    - Double acting cylinder
- Rotary Actuator or Air motors
- Limited angle Actuators

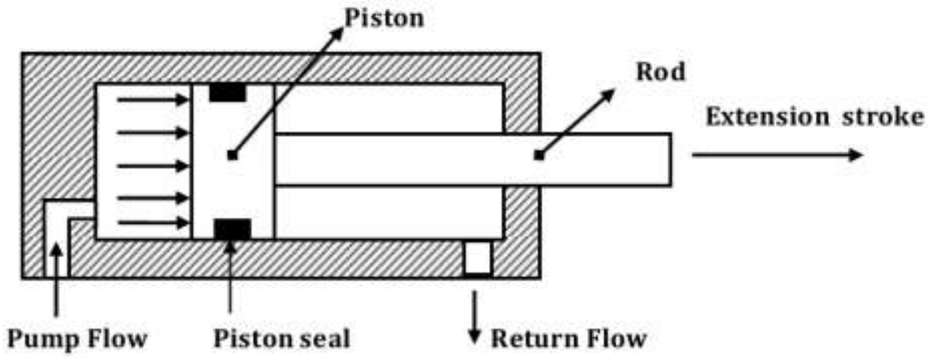
<u>Single Acting Cylinder</u>

- Cylinders have single air inlet line- One working port.
- Forward motion of the piston is obtained by supplying compressed air to working port while return motion of piston is obtained by spring placed on the rod side of the cylinder.
- Used where force is required to be exerted only in one direction such as clamping, feeding, sorting, locking, ejecting, braking etc.
- Available in short stroke lengths [maximum length up to 80 mm] due to the natural length of the spring.
- Single acting cylinders require only about half the air volume consumed by a double acting cylinder for one operating cycle.

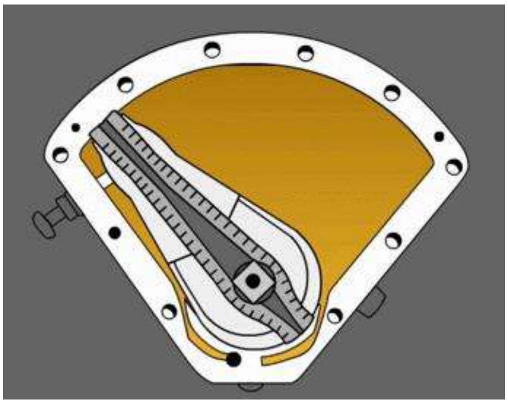


Double Acting Cylinder

- Cylinders have two air inlet lines- Two working ports- one on the piston side and the other on the rod-side.
- To achieve forward motion of the cylinder, compressed air is admitted on the piston side and the rod side is connected to exhaust.
- During return motion supply air admitted at the rod side while the piston side volume is connected to the exhaust.
- Force is exerted by the piston both during forward and return motion of cylinder.
- Double acting cylinders are available in diameters from few mm to around 300 mm and stroke lengths of few mm up to 2 meters.



Limited Angle Actuators



Components of Pneumatic Actuating System

Compressor: Acts as power source for pneumatic system.

Air Treatment Unit: Consist of Filter Regulator Lubricator(FRL) unit which comprises of filter to filter the compressed air, a pressure regulator to regulate a flow of compressed air and a lubricator to lubricate air.

Valve: Controls the direction and regulates the air flowing to actuating system

Actuator: Convert the pneumatic force or compressed air pressure into mechanical fore or movement.

Pipes: Used to connect various elements of actuating system with each other.

Sensors: It act as feedback element for a controller in pneumatic system.

Controller: Monitors whole system to provide required output.

Applications

- Tied rod cylinders,
- Rotary actuators, grippers,
- Rod-less actuators with magnetic linkage or rotary cylinders,
- Rod-less actuators with mechanical linkage,
- Pneumatic artificial muscles,
- Speciality actuators that combine rotary and linear motion (frequently used for clamping operations)
- Vacuum generators.

Advantages

- High force rating
- Pneumatic actuators generate precise linear motion by providing accuracy, for example, within 0.1 inches and repeatability within .001 inches.
- Pneumatic actuators typical applications involve areas of extreme temperatures. A typical temperature range is -40°F to 250°F.
- In terms of safety and inspection, by using air, pneumatic actuators avoid using hazardous materials. They meet explosion protection and machine safety requirements because they create no magnetic interference due to their lack of motors.
- In recent years, pneumatics has seen many advances in miniaturization, materials, and integration with electronics and condition monitoring.
- The cost of pneumatic actuators is low compared to other actuators.
- Pneumatic actuators are also lightweight, require minimal maintenance, and have durable components that make pneumatics a cost-effective method of linear motion.

Drawbacks

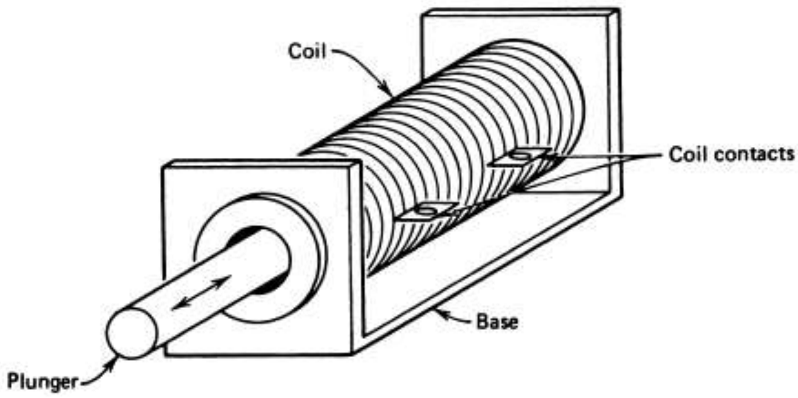
- Pressure losses and air's compressibility make pneumatics less efficient than other linear-motion methods. Compressor and air delivery limitations mean that operations at lower pressures will have lower forces and slower speeds. A compressor must run continually operating pressure even if nothing is moving.
- To be truly efficient, pneumatic actuators must be sized for a specific job. Hence, they cannot be used for other applications. Accurate control and efficiency requires proportional regulators and valves, but this raises the costs and complexity.
- Even though the air is easily available, it can be contaminated by oil or lubrication, leading to downtime and maintenance. Companies still have to pay for compressed air, making it a consumable, and the compressor and lines are another maintenance issue.

Electromechanical/Electrical Actuating System

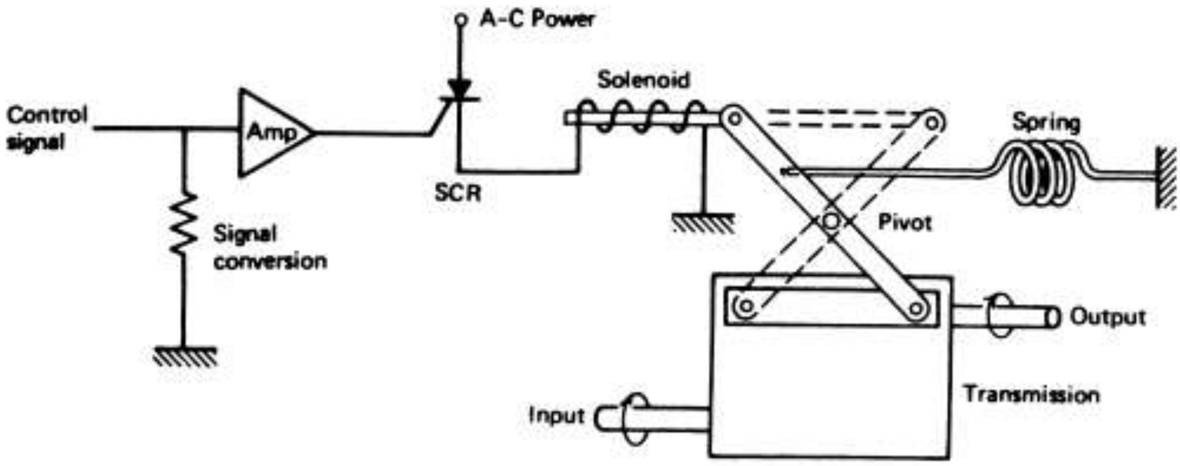
- This type of actuators converts electrical energy into mechanical energy.
- There are different ways to achieve this conversion. Includes all motors, responsible for moving or controlling a mechanism.
- One of the popular method which is used by many electromechanical actuators is by generating magnetic field in which “when current carrying conductor is placed in magnetic field it experiences mechanical force” - Lorentz’s Law of Electromagnetic Force. This generated force will further be converted into mechanical motion.
- DC and AC motors, solenoids, voice coils, Active materials (piezoelectric, electrostrictive etc.) and MEMS.

Solenoid

- A solenoid is an elementary device that converts an electrical signal into mechanical motion, usually rectilinear.
- Consists of a coil and plunger. The plunger may be freestanding or spring loaded.
- The coil will have some voltage or current rating and may be dc or ac.
- Solenoid specifications include the electrical rating and the plunger pull or push force when excited by the specified voltage.
- Are used when a large, sudden force must be applied to perform some job.



Solenoid is used to change the gears of a two-position transmission as shown below.



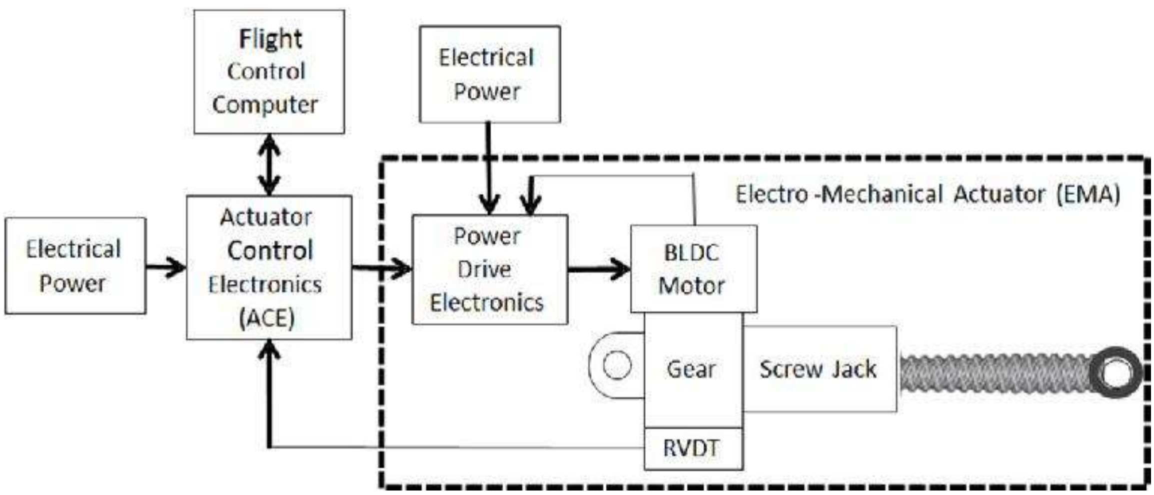
Electrical Motors

- Electrical motors are devices that accept electrical input and produce a continuous rotation as a result.
- Motor styles and sizes vary as demands for rotational speed (revolutions per minute, or rpm), starting torque, rotational torque, and other specifications vary.
- Most common control situation is where motor speed drives some part of a process, and must be controlled to control some variable in the process- e.g.: the drive of a conveyor system
- There are many types of electrical motors, each with its special set of characteristics- dc motor, ac motor, stepping motor etc.

Components of Electric Motor

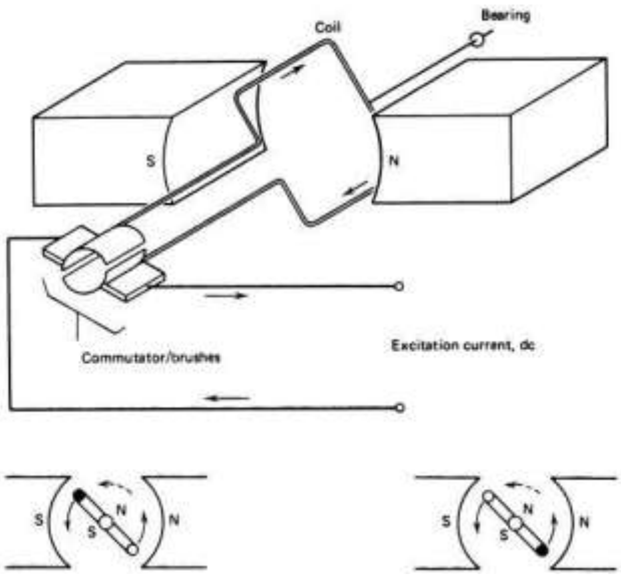
- Electric Motor- Electric motors has wide applications in the industrial as well as in automation sector and popularly used in robotics application because of its high speed of response, finer speed control capability. The magnetic field of stator interacts with magnetic field of rotor to produce rotating torque. There are two basic types of electric motor - AC & DC motor which consist of basic element such as
- Stator– It is stationery outer part of motor made up of permanent magnet or coli winding.
- Rotor – It is rotating part of motor made up of permanent magnet or ferromagnetic coil.
- Armature–Rotor winding that generates rotor magnetic field.
- Field Coil – Part of stator which generates stator magnetic field.
- Air Gap – Small gap between stator and rotor where two magnetic fields interact with each other to generate mechanical torque.

Block Diagram of Motor Based Electrical Actuator System



DC Motor

The rotation of a dc motor is produced by the interaction of two constant magnetic fields.



Many dc motors use an electromagnet instead of a PM to provide the static field. The coil used to produce this field is called the field coil. This kind of dc motor is called a wound field motor. There are different types of wound field DC motor based on the way in which the field winding is connected.

- Series Field DC motors: This motor has large starting torque but is difficult to speed control. Good in applications for starting heavy, non-mobile loads and where speed control is not important, such as for quick-opening valves.
- Shunt Field DC motors: This motor has a smaller starting torque, but good speed-control characteristics produced by varying armature excitation current. Good in applications where speed is to be controlled, such as in conveyor systems.
- Compound Field DC motors: This motor attempts to obtain the best features of both of the two previous types. Generally, starting torque and speed-control capability fall predictably between the two pure cases.

Applications of DC Motor

- The use of dc motors in control systems ranges from very low energy, delicate control applications, to heavy-duty control operations in elevators and vehicles.
- In general, PM types are used for motors of less than 10 hp (7.5 kW) and wound field types for units up to about 100 to 200 hp (75 to 150 kW).
- Control of the speed and torque of these large machines requires very high power dc electricity. Such power is derived from the power electronics devices.
- In general, three-phase ac power is rectified using switching technology to produce the required high-voltage, high-current dc electricity.
- Control is often made possible by variation of the voltage amplitude.

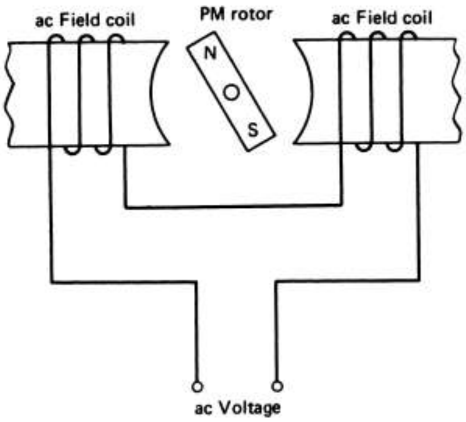
AC Motors

The basic operating principle of ac motors still involves the interaction between two magnetic fields. In this case, however, both fields are varying in time in consonance with the ac excitation voltage. Therefore, the force between the fields is a function of the angle of the rotor but also the phase of the current passing through the coils.

There are two basic types of ac motors, synchronous and induction. The primary motor for application to the control industry is the induction motor.

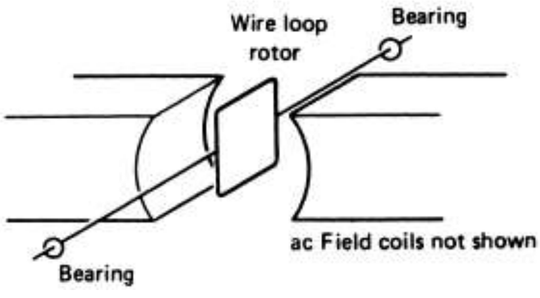
Synchronous Motor

- In a synchronous motor the ac voltage is applied to the field coils, called the stator in an ac motor.
- This means the magnetic field is changing in time in phase with the impressed ac voltage.
- The armature, called the rotor for ac motors, is either a permanent magnet or a dc electromagnet, and possesses a fixed magnetic field.
- Synchronous motors can be operated using single-phase ac but such units are used for only very low power (0.1 hp) and suffer from very low starting torque.
- When operated from three-phase, ac synchronous motors can be operated at very high power, up to 50,000 hp.



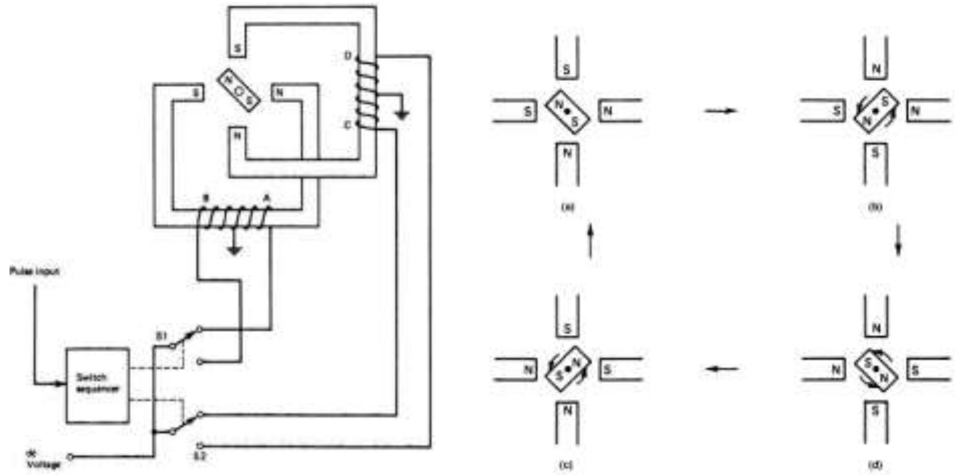
Induction Motors

- Induction ac motors are characterized by a rotor which is neither a PM nor a dc excited electromagnet.
- Instead current induced in a coil wound on the rotor generates the interacting magnetic field of the rotor.
- This current is induced from the stator coils.
- Single-phase induction motors are used for applications of relatively low power, say less than 5 hp (< 3.7 kW). Such motors are typical of those found in household appliances, for example.
- For higher power we use three-phase ac excitation. Such motors are available up to 10,000 hp.



Stepping Motor

- The stepping motor has increased in importance in recent years because of the ease with which it can be interfaced with digital circuits.
- A stepping motor is a rotating machine that actually completes a full rotation by sequencing through a series of discrete rotational steps.
- Each step position is an equilibrium position in that, without further excitation, the rotor position will stay at the latest step.
- Thus, continuous rotation is achieved by the input of a train of pulses, each of which causes an advance of one step.
- It is not really continuous rotation, but discrete, stepwise rotation.
- The rotational rate is determined by the number of steps per revolution and the rate at which the pulses are applied.
- A driver circuit is necessary to convert the pulse train into proper driving signals for the motor.



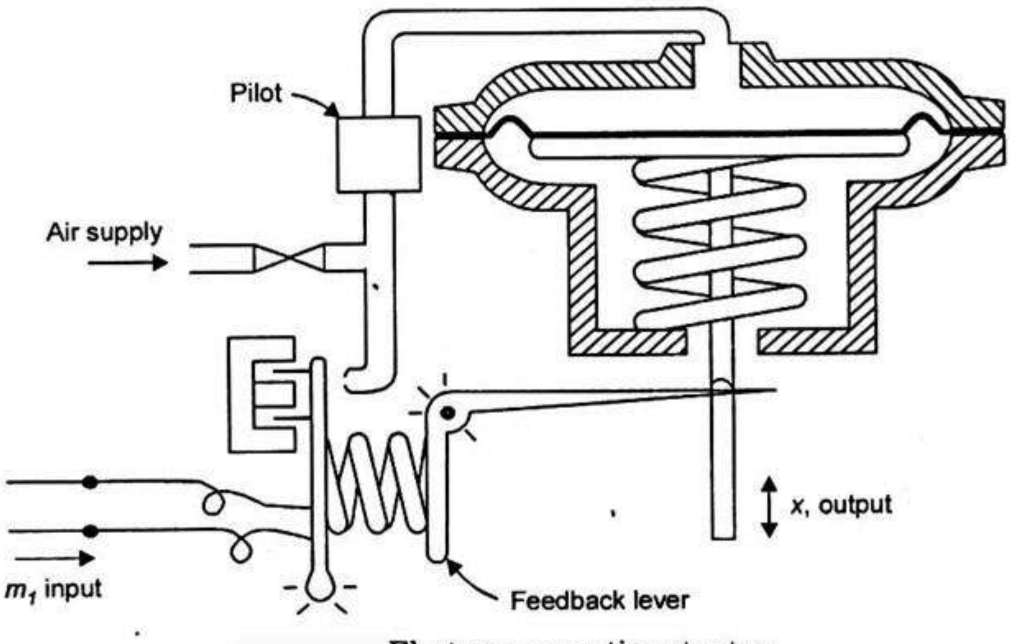
- Most common stepper motor does not use a PM, but rather a rotor of magnetic material (not a magnet) with a certain number of teeth.
- This rotor is driven by a phased arrangement of coils with a different number of poles so that the rotor can never be in perfect alignment with the stator.
- The direction of rotation of stepper motors can be changed just by changing the order in which different poles are activated and deactivated.

Electro-Pneumatic Actuator

Electro pneumatics is now commonly used in many areas of Industrial low cost automation. They are also used extensively in production, assembly, pharmaceutical, chemical and packaging systems.

There is a significant change in controls systems. Relays have increasingly been replaced by the programmable logic controllers in order to meet the growing demand for more flexible automation.

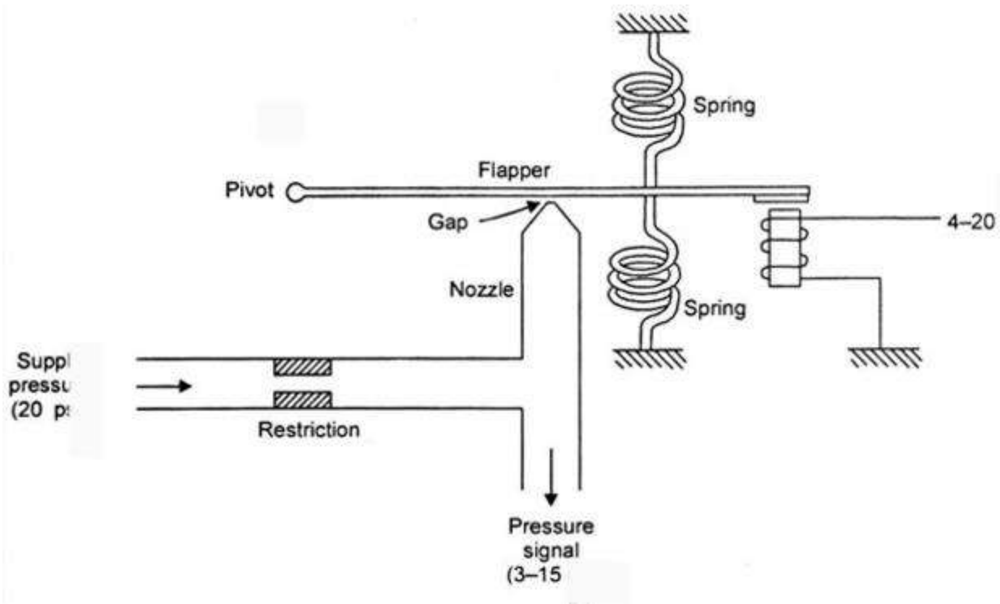
Electro-pneumatic control consists of electrical control systems operating pneumatic power systems. In this solenoid valves are used as interface between the electrical and pneumatic systems. Devices like limit switches and proximity sensors are used as feedback elements.



Electro-pneumatic actuator

Electro Pneumatic control integrates pneumatic and electrical technologies, is more widely used for large applications. In Electro Pneumatics, the signal medium is the electrical signal either AC or DC source is used. Working medium is compressed air. Operating voltages from around 12 V to 220 Volts are often used. The final control valve is activated by solenoid actuation The resetting of the valve is either by spring [single Solenoid] or using another solenoid [Double solenoid Valve]. More often the valve actuation/reset is achieved by pilot assisted solenoid actuation to reduce the size and cost of the valve

Control of Electro Pneumatic system is carried out either using combination of Relays and Contactors or with the help of Programmable Logic Controllers [PLC]. A Relay is often used to convert signal input from sensors and switches to number of output signals [either normally closed or normally open]. Signal processing can be easily achieved using relay and contactor combinations A Programmable Logic Controller can be conveniently used to obtain the out puts as per the required logic, time delay and sequential operation. Finally, the output signals are supplied to the solenoids activating the final control valves which controls the movement of various cylinders.



In electro-pneumatic actuators, the current in the solenoid is converted into pressure using the arrangement shown above. When an electrical actuating current of 4-20 mA is passed through the solenoid, it attracts the flapper fixed on a pivot. So, when the solenoid is activated, the flapper moves as per the magnitude of current through the solenoid, which will control the opening of the nozzle. Depending on the opening and closing of nozzle, the pressure signal is varied between 3-15 psi. When the electrical signal in the solenoid is 4 mA, the nozzle output is minimum, thus the pressure signal is maximum (15psi). When the current signal in the solenoid is maximum, i.e., 20 mA, the nozzle is opened to maximum leading to maximum fluid flow through the nozzle and thus minimum pressure (3 psi) of the pressure signal.

The greatest advantage of electro pneumatics is the integration of various types of proximity sensors [electrical] and PLC for very effective control. As the signal speed with electrical signal, can be much higher, cycle time can be reduced and signal can be conveyed over long distances.

In Electro pneumatic controls, mainly three important steps are involved:

- Signal input devices -Signal generation such as switches and contactor, Various types of contact and proximity sensors
- Signal Processing – Use of combination of Contactors of Relay or using Programmable Logic Controllers
- Signal Out puts – Out puts obtained after processing are used for activation of solenoids indicators or audible alarms

Seven basic electrical devices used in electro pneumatic actuators are

- Manually actuated push button switches
- Limit switches
- Pressure switches
- Solenoids
- Relays
- Timers
- Temperature switches

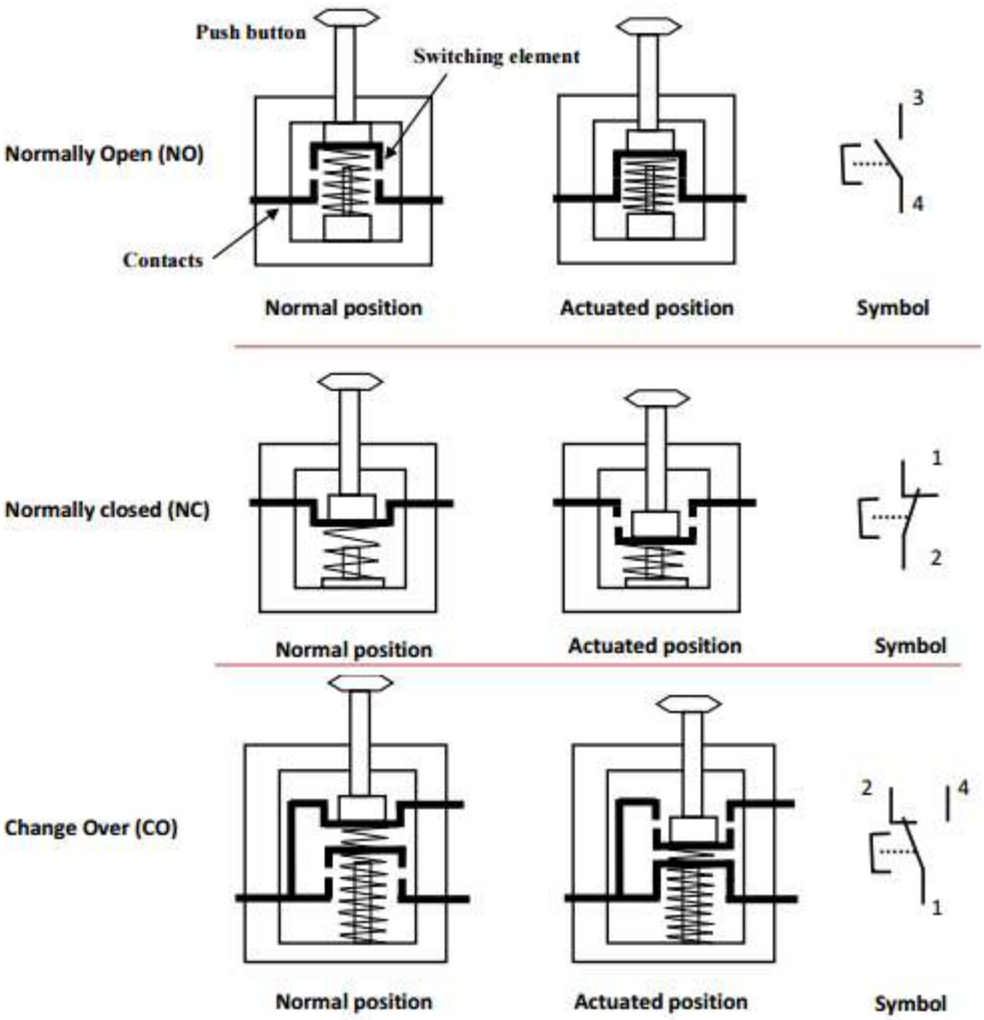
Push button switches: A push button is a switch used to close or open an electric control circuit. They are primarily used for starting and stopping of operation of machinery. They also provide manual override when the emergency arises. Push button switches are actuated by pushing the actuator into the housing. This causes set of contacts to open or close.

Push buttons are of two types

- Momentary push button: return to their unactuated position when they are released
- Maintained contact or detent push button: Has a latching mechanism to hold it in the selected position

The contact of the push buttons, distinguished according to their functions,

i. Normally open (NO) type
ii. Normally closed (NC) type
iii. Change over (CO) type.



Limit Switches: Any switch that is actuated due to the position of a fluid power component (usually a piston rod or hydraulic motor shaft or the position of load is termed as limit switch. The actuation of a limit switch provides an electrical signal that causes an appropriate system response. Limit switches perform the same function as push button switches. Push buttons are manually actuated whereas limit switches are mechanically actuated.

There are two types classification of Limit switches depending upon method of actuations of contacts

i. Lever actuated contacts
ii. Spring loaded contacts

Pressure switches: A pressure switch is a pneumatic-electric signal converter. Pressure switches are used to sense a change in pressure, and opens or closes an electrical switch when a predetermined pressure is reached. Bellow or diaphragm is used to sense the change of pressure. Bellows or Diaphragm is used to expand or contract in response to increase or decrease of pressure. Figure 1.3 shows a diaphragm type of pressure switch. When the pressure is applied at the inlet and when the pre-set pressure is reached, the diaphragm expands and pushes the spring loaded plunger to make/break contact.

Solenoids: Electrically actuated directional control valves form the interface between the two parts of an electro-pneumatic control.

The most important tasks of electrically actuated DCVs include.

- Switching supply air on or off
- Extension and retraction of cylinder drives

Electrically actuated directional control valves are switched with the aid of solenoids. They can be divided into two groups:

- Spring return valves only remain in the actuated position as long as current flows through the solenoid
- Double solenoid valves retain the last switched position even when no current flows through the solenoid.

Relays: A relay is an electro magnetically actuated switch. It is a simple electrical device used for signal processing. Relays are designed to withstand heavy power surges and harsh environment conditions. When a voltage is applied to the solenoid coil, an electromagnet field results. This causes the armature to be attracted to the coil core. The armature actuates the relay contacts, either closing or opening them, depending on the design. A return spring returns the armature to its initial position when the current to the coil is interrupted.

Timer or Time delay relays: Timers are required in control systems to effect time delay between work operations. This is possible by delaying the operation of the associated control element through a timer. Most of the timers we use is Electronic timers.

There are two types of time relay

i. Pull in delay (on –delay timer)
ii. Drop –out delay (off delay timer)

Temperature Switch: Temperature switches automatically senses a change in temperature and opens or closes an electrical switch when a predetermined temperature is reached. This switch can be wired either normally open or normally closed.

Temperature switches can be used to protect a fluid power system from serious damage when a component such as a pump or strainer or cooler begins to malfunction.

Electro-pneumatic actuator can be briefed as below:

- Integrates pneumatic and electrical technologies, consists of electrical control systems operating pneumatic power systems.
- The signal medium is the electrical signal either AC or DC source is used. Working medium is compressed air.
- In this solenoid valves are used as interface between the electrical and pneumatic systems. i.e.: The final control valve is activated by solenoid actuation.
- Operating voltages from around 12 V to 220 Volts are often used.
- Devices like limit switches and proximity sensors are used as feedback elements.
- More widely used for large applications.

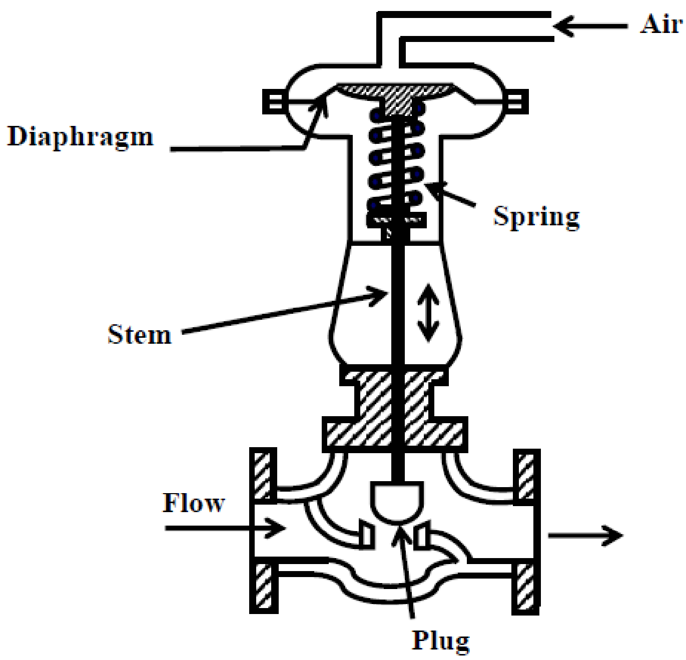
Types of Actuators and Their Characteristics

Criteria	**Mechanical actuators**	**Electromechanical actuators**	**Pneumatics actuators**	**Hydraulics actuators**
I/O energy source	Electric Motor, IC Engines.	Water/gas turbine	Presser tank/Compressor.	IC engines, electric motor, Hydraulic Pump
Energy transmission Element	Gears, shafts, levers.	Electric cables	Pipes & hoses	Pipe & hoses
Speed of response	Fair	Best	Good	Good
Control	Fair	Best	Fair	Good
Cost	High cost	Very cheap	Cheap	Very costly
Output motion	Liner/rotary	Mostly Rotary	Liner/rotary	Liner/rotary

Actuator types	Advantages	Disadvantages
Electrical(servomotor or stepping motor)	Direct interface with computer system. Simple design.	Low thrust. Slow speed. No mechanical fail safe hazardous.
Electromechanical(Motors combined with gear boxes)	High thrust High stiffness coefficient Flexible adaptation	Complex design No mechanical fail safe Large, heavy structure Hazardous
Hydraulic and Electro hydraulic	High thrust Fast speed High stiffness coefficient Self lubrication	Complex design Large, heavy structure Hazardous Fluid Viscosity Sensitive
Pneumatic and Electro-pneumatic	Low cost Mechanical Fail safe Simple design Small package Suitable for highly hazardous areas also Good control with control device	Slow speed Lack of stiffness Instability Moderate trust Quality air requirement

Control Valves

- The control action in any control loop system, is executed by the final control element.
- The most common type of final control element used in chemical and other process control is the control valve.
- A control valve is normally driven by a diaphragm type pneumatic actuator that throttles the flow of the manipulating variable for obtaining the desired control action.
- A control valve essentially consists of a plug and a stem.
- The stem can be raised or lowered by air pressure and the plug changes the effective area of an orifice in the flow path.
- When the air pressure increases, the downward force of the diaphragm moves the stem downward against the spring.



Classification of Control Valves

Control valves are available in different types and shapes.

They can be classified in different ways based on

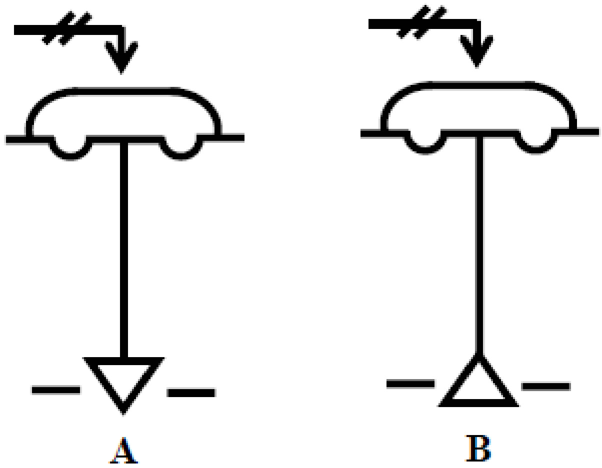
- Action
- Number of plugs
- Flow characteristics.

<u>Classification of Control Valves based on Action</u>

Air to Open: If the air supply fails, the control valve will be fully closed

Air to Close: If the air supply fails, the control valve will be fully open.

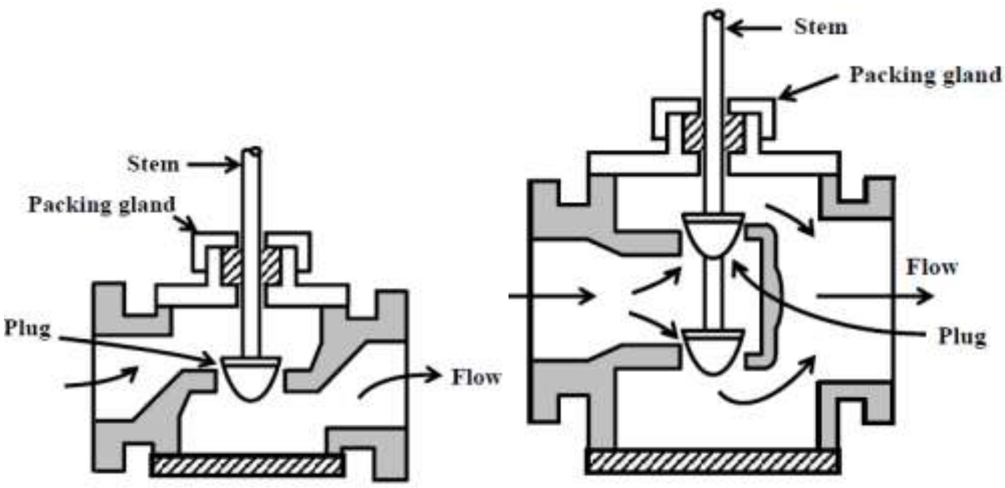
Control valves operated through pneumatic actuators can be either (i) air to open, or (ii) air to close. They are designed such that if the air supply fails, the control valve will be either fully open, or fully closed, depending upon the safety requirement of the process. For example, if the valve is used to control steam or fuel flow, the valve should be shut off completely in case of air failure. On the other hand, if the valve is handling cooling water to a reactor, the flow should be maximum in case of emergency. The schematic arrangements of these two actions are shown in Figure below. Valve A are air to close type, indicating, if the air fails, the valve will be fully open. Opposite is the case for valve B.



- **Fail open or Air to close : A**
- **Fail closed or Air to open : B**

<u>Classification of Control Valves based on Number of Plugs</u>

Control valves can also be characterized in terms of the number of plugs present, as single-seated valve and double-seated valve. The difference in construction between a single seated and double-seated valve are illustrated in Fig.



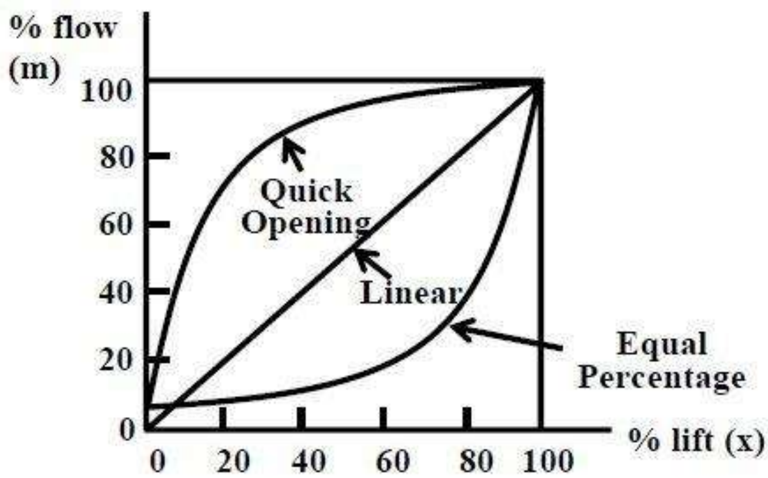
Here, only one plug is present in the control valve, so it is single seated valve. The advantage of this type of valve is that, it can be fully closed and flow variation from 0 to 100% can be achieved. But looking at its construction, due to the pressure drop across the orifice a large upward force is present in the orifice area, and as a result, the force required to move the valve against this upward thrust is also large. Thus this type of valves is more suitable for small flow rates. On the other hand, there are two plugs in a double-seated valve; flow moves upward in one orifice area, and downward in the other orifice. The resultant upward or downward thrust is almost zero. As a result, the force required to move a double-seated valve is comparatively much less.

But the double-seated valve suffers from one disadvantage. The flow cannot be shut off completely, because of the differential temperature expansion of the stem and the valve seat. If one plug is tightly closed, there is usually a small gap between the other plug and its seat. Thus, single-seated valves are recommended for when the valves are required to be shut off completely. But there are many processes, where the valve used is not expected to operate near shut off position. For this condition, double-seated valves are recommended.

Classification of Control Valves based on Flow Characteristics

Flow Characteristics describes how the flow rate changes with the movement or lift of the stem. The shape of the plug primarily decides the flow characteristics. The flow characteristic of a valve is normally defined in terms of Inherent characteristics and Effective characteristics. An inherent characteristic is the ideal flow characteristics of a control valve and is decided by the shape and size of the plug. When the valve is connected to a pipeline, its overall performance is decided by its effective characteristic.

Based on inherent/ideal characteristics, control valves are classified into three such as Quick opening, Linear and Equal Percentage.

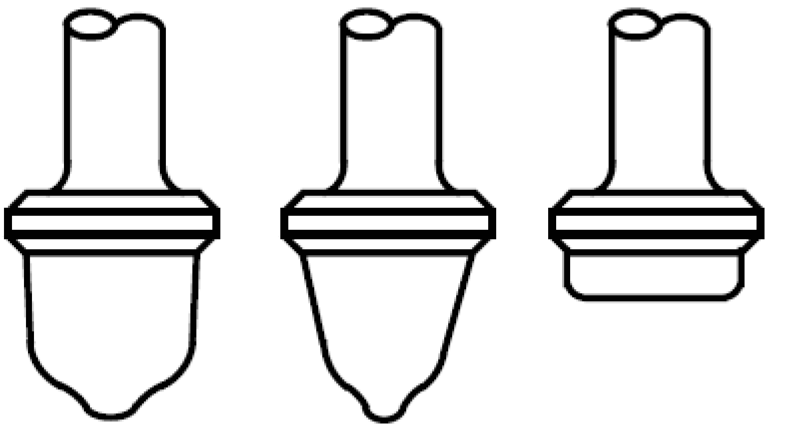


The shape of the plug decides, how the flow rate changes with the stem movement, or lift when the pressure drop across the valve is assumed to be held constant. This classification is basically done on relationship between the valve stem position and the flow rate through the valve. As the stem and plug move with respect to the seat/orifice, the shape of the plug determines the amount of actual opening of the valve.

Quick Opening Type: This type of valve is used predominantly for full ON/full OFF control applications. The valve characteristics shows that a relatively small motion of the valve stem results in maximum possible flow rate through the valve. Such a valve, for example, may allow 90% of maximum flow rate with only a 30% travel of the stem.

Linear Type: This type of valve has a flow rate that varies linearly with the stem position. It represents the ideal situation where the valve alone determines the pressure drop.

Equal Percentage Type: A very important type of valve employed in flow control has a characteristic such that a given percentage change in stem position produces an equivalent change in flow—that is, an equal percentage. Generally, this type of valve does not shut off the flow completely in its limit of stem travel. Thus, Q_{min} represents the minimum flow when the stem is at one limit of its travel. At the other extreme, the valve allows a flow Q_{max} as its maximum, open-valve flow rate.



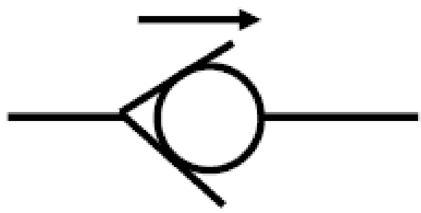
Directional Control Valves

In directional control valves, it is basically the directions of the flows that are controlled and not the magnitudes.

Directional valves can be characterized depending on the number of ports, the number of directions of flow that can be established, number of positions of the valve etc. They are mainly classified in terms of the number of flow directions, such as one-way, two way or four-way valves. Directional valves are often operated in selected modes using hydraulic pressure from remote locations. Such mechanisms are known as pilots. Thus a valve that may be blocking the flow in a certain direction in absence of pilot pressure, may be allowing flow, when pilot pressure is applied.

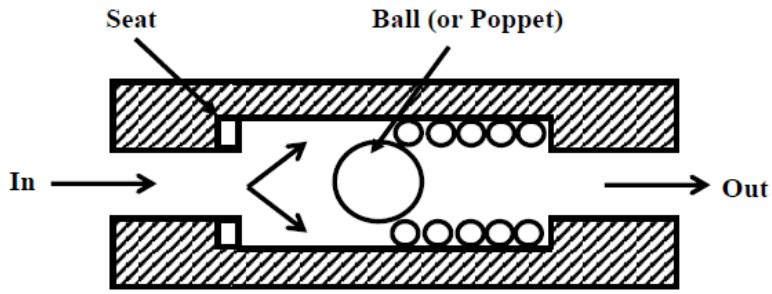
Check Valve

In its simplest form, a check valve is a one-way directional valve. It permits free flow in one direction and blocks flow in the other. It is analogous to the electronic diode. Symbol of check valve is shown below. The direction of the arrow shows the direction for free flow.

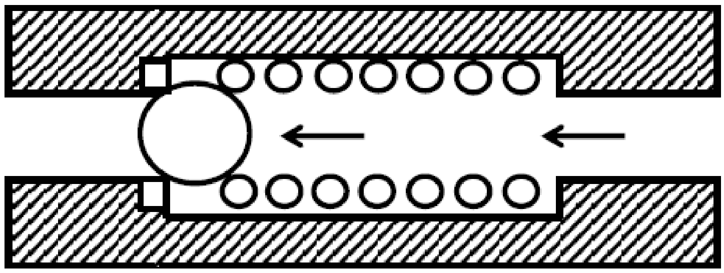


In its simplest form of construction, a check valve is realized as an in-line ball and spring.

Pressure from the left moves the ball from its seat so to permit unobstructed flow. Pressure from right pushes the ball tight on to the seat, and flow is blocked. In some valves a poppet is used in place of the ball. In some other construction, the valve inlet and outlet ports are made at right angles.



When flow is from left to right, valve is open

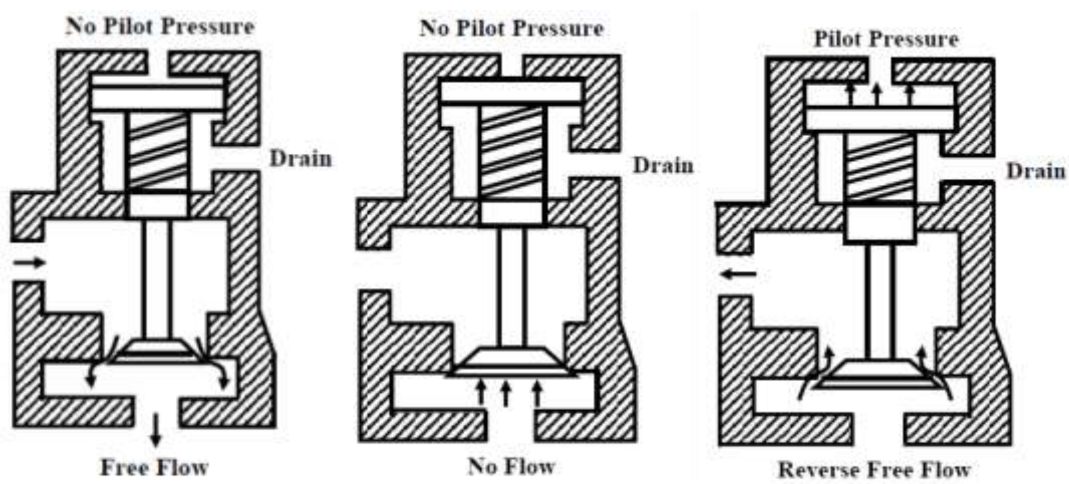


When flow is from right to left, the valve is closed

<u>Pilot-operated Check Valves</u>

Pilot-operated check valves are designed to permit free flow in one direction and to block return flow, unless pilot pressure is applied. However, under pilot pressure, flow is permitted in both directions. They are used in hydraulic presses as prefill valves – to permit the main ram to fill by gravity during the "fast approach" part of the stroke. They also are used to support vertical pistons which otherwise might drift downward due to leakage past the directional valve spool.

With no pilot pressure, the valve functions as a normal check valve. Flow to bottom is permitted but the reverse is blocked. If pilot pressure is applied, the valve is open at all times, and flow is allowed freely in both directions.

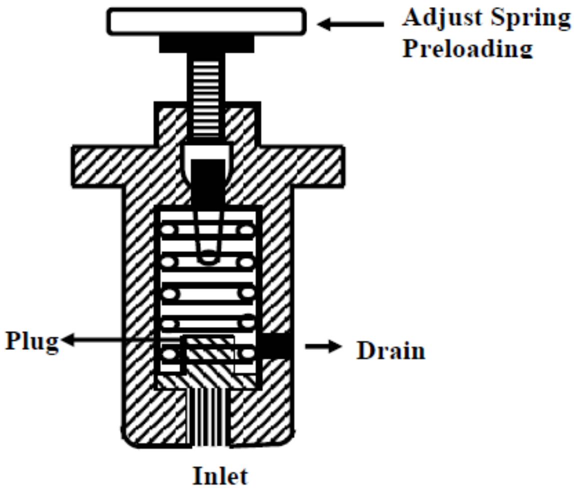


The check valve poppet has the pilot piston attached to the poppet stem. A light spring holds the poppet seated in a no-flow condition by pushing against the pilot piston. A separate drain port is provided to prevent oil from creating a pressure build-up on the underside of the piston. Reverse flow can occur only when a pressure that can overcome the pressure in the outlet chamber is applied.

Possible application of the valve can be to permit free flow to the accumulator, while blocking flow out of it. If the pilot is actuated the accumulator can discharge if the pressure at the inlet port is lower than the accumulator pressure.

Relief Valves

Relief valves are used for regulation of pressure in hydraulic systems for protection of equipment and personnel. The spring keeps the valve shut until a pressure set by an adjustable spring tension is reached which pushes the spring up to relief the pressure by connecting the inlet to the drain.



Symbol of relief valve

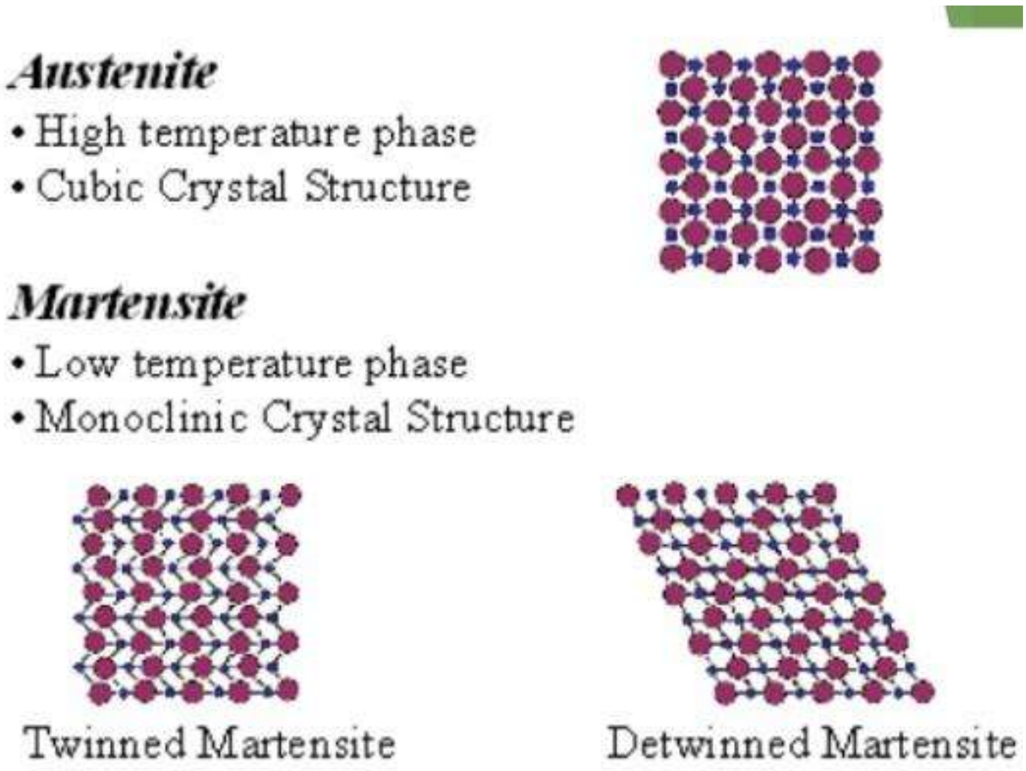
Shape Memory Alloys

Certain classes of metallic alloys have a special ability to memorize their shape at a high temperature, and recover large deformations imparted at a low temperature on thermal activation. The recovery of strains imparted to the material at a lower temperature, as a result of heating, is called the Shape Memory Effect(SME).They can remember the parent state with respect to the high temperature.Whatever is done with the metallic alloy at low temperature, the moment it is taken back to high temperature, it will get back to the parent shape Happens because of very regular crystal structure- most of the time a body centred cubic.SME 1st observed in 1932 in Gold Cadmium Alloy. They were expensive and not much large shape memory effect was seen in them

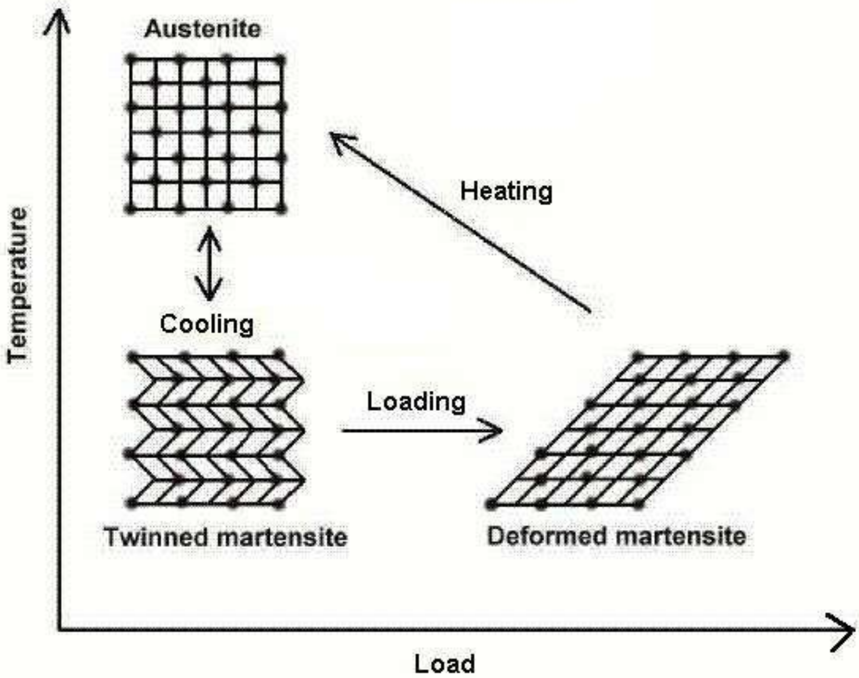
- Three types of SMA are currently popular
  - Cu Zn Al
  - Cu Al Ni
  - Ni Ti- Commercially available as NiTiNOL. (NOL: Naval Ordinance Laboratory)
- The shape memory alloys have two stable phases- the high temperature phase called austenite (After English metallurgist William Chandler Austen) and the low temperature phase called martensite (After German metallographer Adolf Martens)
- The martensite phase can be of two forms
  - Twinned martensite
  - Detwinned martensite

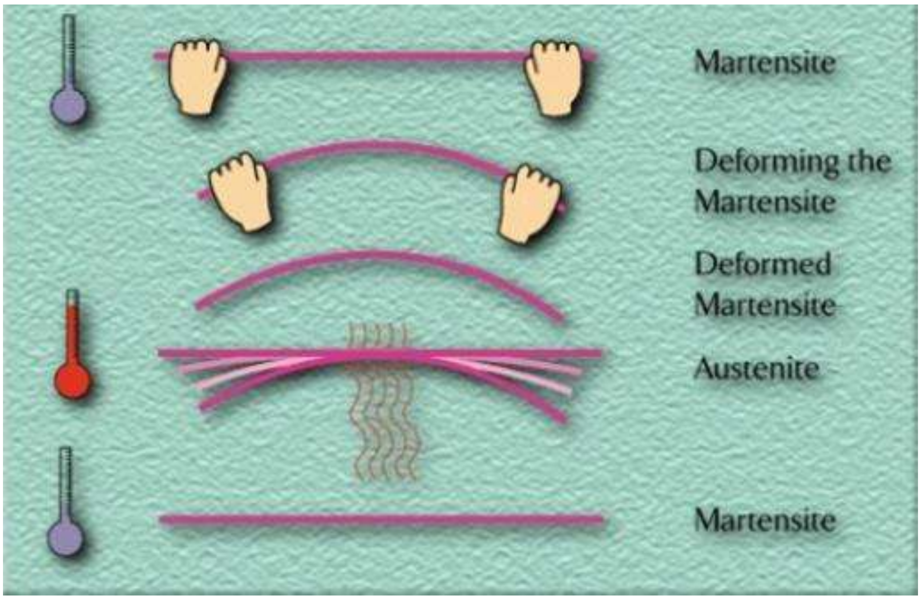
A phase transformation which occurs between these two phases upon heating/cooling is the basis for the unique properties of the SMAs.Deformed shape + Heat = Original Shape

The shape change involves a solid state phase change involving a molecular rearrangement between martensite and austenite.Upon cooling in the absence of applied load, the material transforms from austenite to twinned martensite (No observable macroscopic change occurs)If a mechanical load is applied to the material in twinned martensite phase (at low temperature), it is possible to detwin the martensite.Upon releasing of the load, the material remains deformed.A subsequent heating of the material to a temperature above the austenite finish temperature (Af) will result in a reverse phase transformation (martensite to austenite) and will lead to complete shape recovery.SMA remembers the shape when it has austenitic structure.So, if we need SMA to remember and regain/recover certain shape, the shape should be formed when the structure is austenite.The un-deformed Martensite phase is the same size and shape as the cubic Austenite phase on a macroscopic scale.No change in size or shape is visible in shape memory alloys until the Martensite is deformed.The high temperature causes the atoms to arrange themselves into the most compact and regular pattern possible resulting in a rigid cubic arrangement (austenite phase).They can be formed into various shapes like bars, wires, plates and rings thus serving various functions

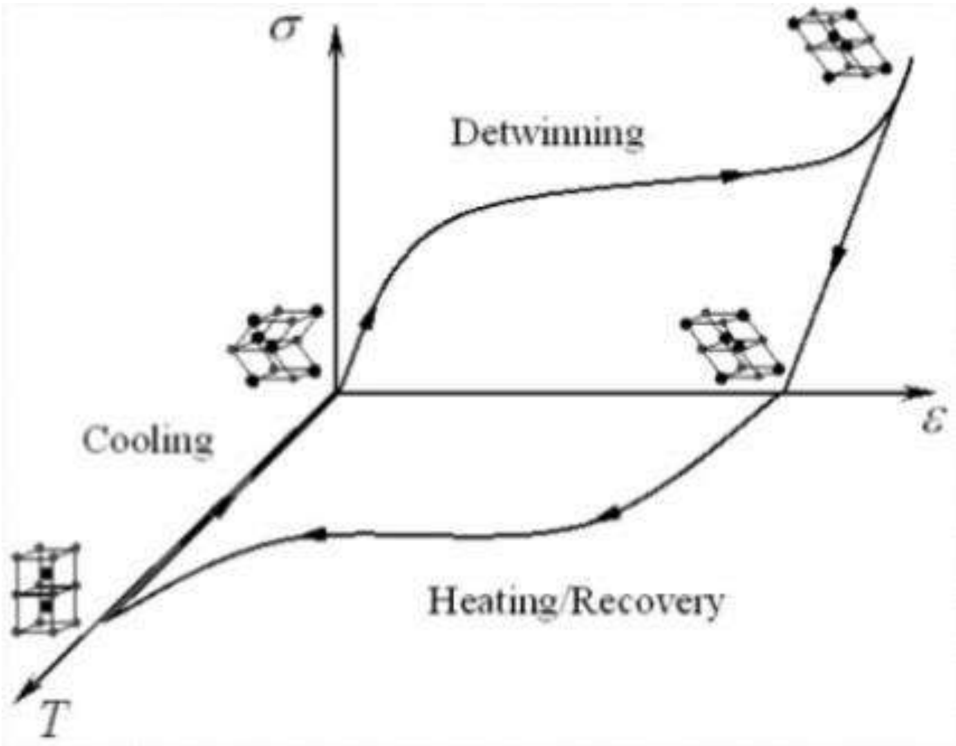


Phase Transformation in SMA





Hysteresis Curve of SMA



SME Temperatures

M_s: Temperature at which austenite begins to transform to martensite upon cooling

M_f: Temperature at which transformation of austenite to martensite is complete upon cooling

A_s: Temperature at which martensite begins to transform to austenite upon heating

A_f: Temperature at which transformation of martensite to austenite is complete upon heating

$$M_f < M_s < A_s < A_f$$

Types of SME

One-way shape memory: The material always remembers the shape at Parent always remembers the shape at Parent State (Austenite Phase). When the metal cools again it will remain in the hot shape, until deformed again.

Two-way shape memory: The deformed shape is remembered during cooling, in addition to the original shape being remembered during heating, i.e., memory is with both austenite and martensite phases. The material remembers two different shapes: one at low temperatures, and one at the high-temperature shape.

Advantages

Bio-compatibility

Diverse field of application

Good mechanical properties(strong, corrosion resistant)

Disadvantages

Expensive

Poor fatigue properties: Repeated use of shape memory effect leads to functional fatigue.

Overstress

Applications of Shape Memory Alloys

- The one well developed application of SMA is for simple and leak proof coupling of pneumatic and hydraulic lines.
- The alloys have also been exploited in mechanical and electromechanical control systems to provide a precise mechanical response to a small and repeated temperature changes.
- Also used in a wide range of medical and dental applications like healing broken bones, misaligned teeth etc.
- Various thermal actuators
- Biomedical
- Civil engineering of mega structures
- Self-expandable cardiovascular stent
- Blood clot filters
- Actuators for smart systems
- Flaps that change direction of airflow depending upon temperature (for air conditioners)
- Couplings
- Control of aerodynamic surfaces