UNIT-I

Chemical analysis: To find out the chemical composition of any matter is called chemical Analysis. It may be Quantitative, Qualitative, Surface or Structural Analysis.

- **Quantitative Analysis:** This type of analysis finds out the total amount of the particular species present in a given sample.
- **Qualitative Analysis:** This type of analysis just identifies one or more species present in a given sample.
- **Surface Analysis:** This type of analysis helps to obtain information regarding surface-related physical properties such as depth profiling, orientation of molecules, topography, etc.
- **Structural Analysis:** This type of analysis helps in finding the spatial arrangement of atoms in a molecule and the presence or position of certain organic functional groups in a given sample.

Fundamentals of Analytical Instruments

Analytical instruments provide information on the composition of a sample of matter. They are used to to obtain qualitative or quantitative information about the presence or absence of one or more components in a given sample. In the broadest sense, an analytical instrument consists of the following four basic units:

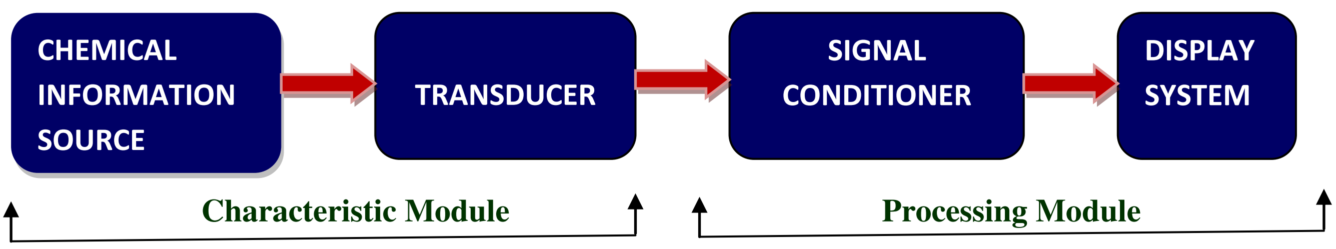


Fig.1 Elements of an analytical instrument

Chemical information source: This part of analytical instrument generates a set of signals containing necessary information. The source may be in the sample itself. For example, the yellow radiation emitted by heated sodium atoms constitutes the source of the signal in a flame photometer.

Transducer: This device converts non-electrical signals into electrical quantities, so this converts the nature of the signal. There are lot of advantages in measurement of electrical signals instead of non-electrical signals hence it is the usual practice to convert all non-electrical phenomena associated with the analysis of a given sample into electrical quantities. For example a photocell converts light into electric signal.

Signal conditioner: Sometimes the original signal or signal received from the transducer is very week. It is needed to converts the output of the transducer into an electrical quantity suitable for operation of the display system. Signal conditioner help increase the sensitivity of instruments by amplifying the original signal or the signal received from the transducer. Signal conditioners may vary in complexity from a simple resistance network, or impedance matching device, to multi-stage amplifiers and other complex electronic circuitry.

Display system: A visible representation of the quantity is provided by display system as a displacement on a linear or non-linear scale, or on the chart of a recorder, or on the screen of a cathode ray tube, or in numerical form.

Characteristic module: The first two blocks i.e. chemical information source and transducer constitute the characteristic module an instrument. Each one of the components of the characteristic module contributes to the performance specifications of an instrument. For Example: the constituents of the characteristic module in a UV-Vis spectrophotometer are a source of radiant energy, a monochromator, the sample holder and photo detector. By choosing a photomultiplier tube with the broadest spectral response available, good sensitivity is ensured for detection from 190 nm to beyond 800 nm. The higher its gain and the lower its noise, the better the possibility of working at trace concentration levels. The transducer also determines the limits of detection of measurement. Similarly, the monochromator fixes the resolution, signal-to-noise ratio, and level of stray light.

Processing module: The last two blocks i.e. signal conditioner and display system constitute the processing module an instrument. The signal amplitude produced by a transducer is processed in the processing module. After adequate amplification, the processing can be carried out with the signal still in analog form (a signal of varying amplitude) or converted into digital form (a series of pulses whose number indicates the signal amplitude) by the use of an analog-to-digital (A/D) converter. This conversion ordinarily gives higher precision and accommodates the use of a microprocessor or computer for processing steps and instrument control.

So, all analytical instruments can thus be split into the above indicated four blocks. Some examples of the instruments along with their blocks are given below.

Instrument	Characteristic Module		Processing Module	
	Information Source	Input Transducer	Signal Processor	Display
Photometer	Attenuated light beam	Photocell (electrical current)	None	Current meter
pH meter	Hydrogen ion activity	Glass-calomel electrodes (electrical potential)	Amplifier, A/D converter	Digital Display
Atomic emission spectrometer	UV or visible radiation	Photomultiplier tube (electrical potential)	Amplifier, demodulator	Display

UNIT-II

Some Definitions

Spectroscopy:

Spectroscopy is the study of the interaction between light and matter where the absorption and emission of light or other radiation by the matter are studied and measured. Spectroscopy mainly deals with the dispersion of light and other radiations that is caused by an object which allows the study of various properties of the object.

The measurement in spectroscopy is a function of the wavelength of the radiation being observed. It has been widely exploited as it allows the determination of composition, physical and electronic structure to be determined of various particles of molecular or atomic levels.

What is a spectrometer?

The spectrometer is a scientific instrument that is used to measure the variation or differences in various properties caused by an object over a particular range. The property observed by a spectrometer varies with the type of spectrometer being used.

NMR spectrometer measures the variation in nuclear resonance frequencies, mass spectrometer measure the difference in mass to charge ratio whereas an optical spectrometer measures the variation in the electromagnetic radiation. Based on the measurement of these variations, different properties of particles can be measured and observed.

What is a spectrophotometer?

The spectrophotometer is a particular type of spectrometer that measures the interaction (absorption, reflection, scattering) of electromagnetic radiation from a sample or the emission (fluorescence, phosphorescence, electroluminescence) of electromagnetic radiation by various sample.

It is also termed electromagnetic spectrometer as it deals with the measurement of different properties of light and its interaction with matter. These are commonly used in laboratories to measure the concentration of various samples on the basis of total light absorbed by the sample.

What is a spectroscope?

A spectroscope or optical spectrometer is a device that measures different properties of light over a specific range in the spectrum used for the analysis of various objects. The property measured is mostly the intensity of light, although polarization of light is also measured under some conditions.

Spectroscopes are commonly used in studies regarding astronomy and chemistry for the analysis of various samples. Traditionally, prisms were used as spectroscopes, however, nowadays, diffraction gratings, mobile slit, and photo detectors are used. These are mostly used to deduce the chemical composition of objects based on the radiation produced by different objects.

What is a spectrograph?

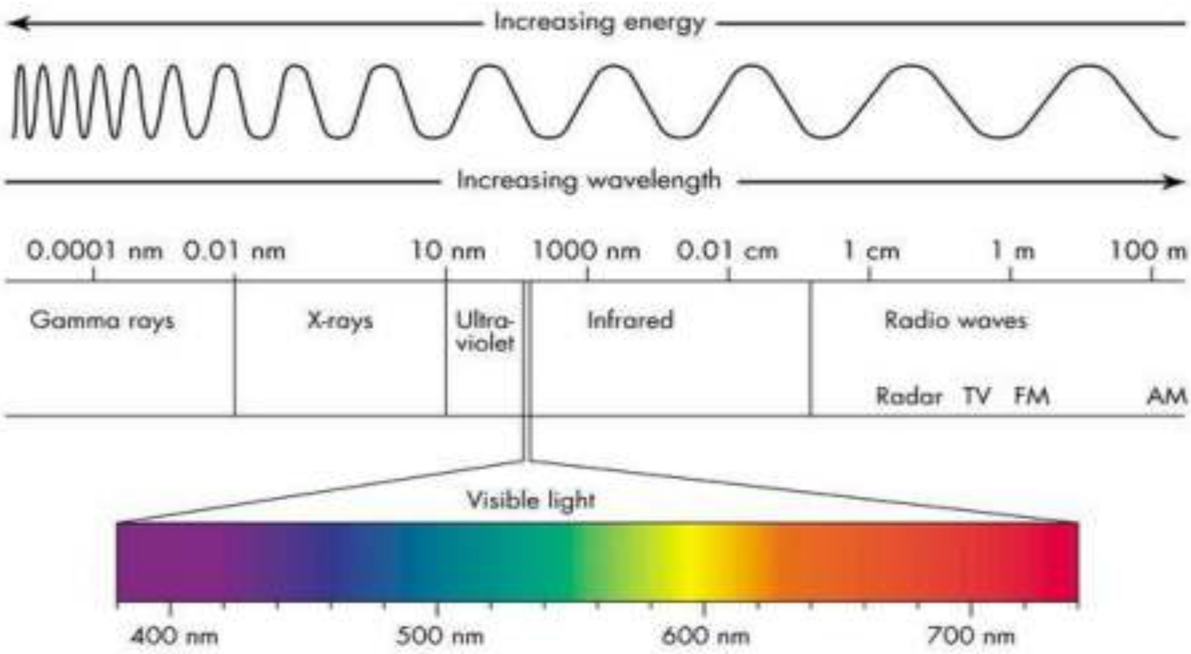
The spectrograph is a scientific instrument that detects different light and separates them by their wavelength or frequencies which are recorded by multi detectors. These are mostly used for obtaining and recording the astronomical spectrum. Spectrographs are used for astronomical studies as telescopes. In a spectrograph, the light rays transfer into the spectrograph through the telescope which is provided with a mirror that functions to makes all light rays parallel to each other. The rays then reach the diffraction grating that disperses the light into different wavelengths which are passed to the detectors for the analysis of the individual wavelengths. These are highly useful to analyze the incoming light from various astronomical objects for the analysis of the chemical composition of those objects.

What are spectra?

Spectra, singular spectrum, in optics, are the colors observed when white light is dispersed through a prism. Spectrum refers to the range of various variables associated with light and other waves.

In light, the electromagnetic spectrum is the most commonly used. The electromagnetic spectrum includes the range of frequencies of electromagnetic radiation that are used to characterize the distribution of electromagnetic radiation absorbed or emitted by an object.

Besides, the mass spectrum is also used in spectroscopy based on the ion abundance as a function of the mass to charge ratio. Electron spectrum is another spectrum used in physics that is the number or intensity of particle beam depending on the particle energy.



Absorption Spectroscopy:

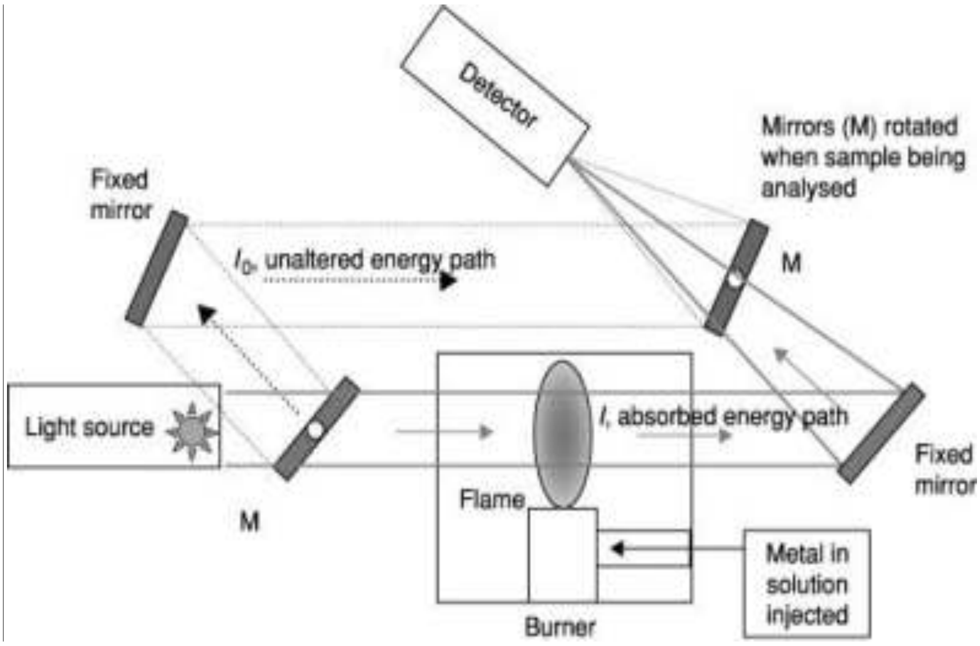
Absorption spectroscopy is a spectroscopic technique that measures the frequency of wavelength of absorbed light as a result of the interaction between the light and a sample

Principle of Absorption spectroscopy

Absorption spectroscopy is based on the principle that materials have an absorption spectrum which is a range of radiation absorbed by the material at different frequencies. The absorption spectrum of materials depends on the atomic and molecular composition of that material.

The frequency of light radiation absorbed by a material is dependent on the energy difference between the two energy states of the molecules. The absorption results in the formation of an absorption line, which, together with other lines, form an absorption spectrum. Thus, when a photon with sufficient energy reaches an object, the energy is absorbed by the electrons causing them to bump into a higher energy state.

The amount of photon (radiation) absorbed results in an absorption spectrum which can then be measured in terms of absorbance. The absorbance of a sample is dependent on the number of excited electrons which in turn is dependent on the concentration of molecules in the sample.



Steps of Absorption spectroscopy

- Solvent liquid and the sample solution are taken in two transport vessels, also termed as cuvettes.
- The vessel with solvent liquid is then placed in the spectrometer to determine the light loss due to scattering and absorbance by the solvent. Any absorbance observed in this process is to be subtracted from the absorbance of the sample.
- The cuvette with the sample solution is then placed in the spectrometer.
- The absorbance of the sample is noted in different frequencies which usually ranges from 200-800 nm.
- A similar spectrum is formed from a different concentration of the samples.
- A graph of the absorbance measured against the concentration of the sample is plotted, which can then be used for the determination of the unknown concentration of the sample.

Uses of Absorption spectroscopy

- Absorption spectroscopy is used to determine the presence of a particular substance in a sample and then to quantify the present substance.
- This technique has been applied in remote sensing, which allows the determination of the concentration of hazardous substances without the direct interaction of the instrument and the sample.
- Absorption spectroscopy is also used for the determination of the atomic and molecular structure of various substances.

Mass Spectroscopy Mass spectroscopy is an analytical method useful for calculating the mass-to – charge ratio (m / z) of one or more molecules in the sample. Such measurements may also often be used to determine the precise molecular weight of the sample components. Mass spectroscopy is an analytical method to find the molecular mass of a compound and indirectly helped to prove the identity of isotopes.

Principle of Mass Spectroscopy

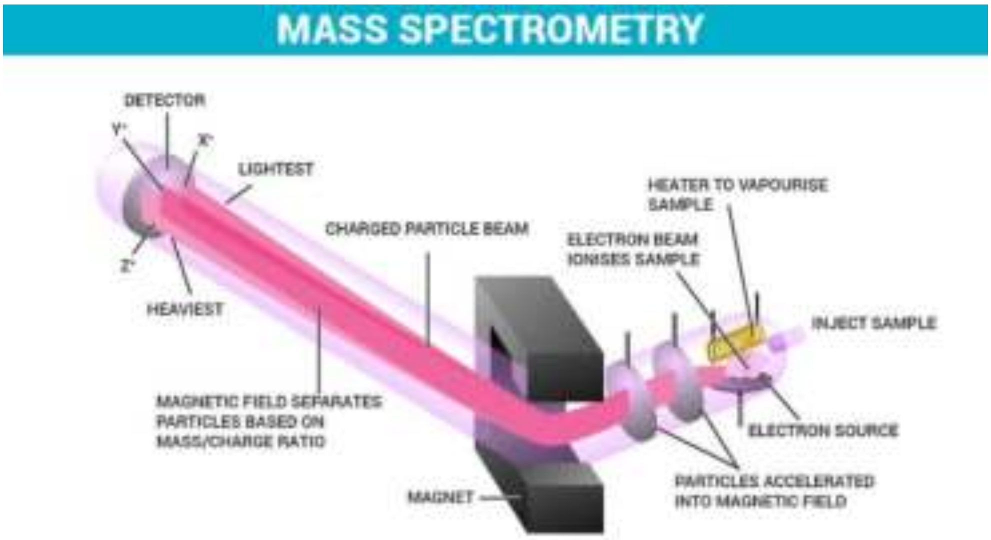
Based on Newton's second law of motion and momentum, a mass spectrometer uses this property of matter to plot ions of varying masses on a mass spectrum. From the law, we infer how much mass is relevant to the inertia and acceleration of a body. This principle is applied to the aspect where ions with different mass to charge ratios are deflected by different angles in an electric or magnetic field.

Mass Spectrum

A mass spectrum is a graph obtained by performing mass spectroscopy. It is a relation between the mass to charge ratio and ion signal.

Mass Spectroscopy Diagram

- Inlet system
- Ionization
- Deflector
- Ion detector



Mass spectroscopy Instrumentation

Mass Spectroscopy Detectors

At different deflections a detector counts the number of ions. The data are plotted as a graph or continuum of various masses. Detectors function by recording the induced charge or current generated by an ion hitting or passing through a surface. Since the signal is very small it is possible to use an electron amplifier, Faraday cup, or ion-to-photon detector. To generate a spectrum the signal is greatly amplified.

The Mass Analyzer

When ionized, the ions are sorted and divided according to the mass-to – charge (m / z) ratio. A variety of mass analyzers are currently available, each of which has trade-offs related to speed of operation, separation resolution and other technical criteria. The different forms in use at the Broad Institute are described in the following section. The mass analyzer often works in concert with the ion detection system.

What is a Quadrupole?

Mass spectroscopy determines the chemical by calculating the typical mass fragments formed by the ionization of the material. Test molecules are ionized by an electron beam, and the resulting molecular ion and component ions travel into a mass analyzer where their masses are measured.

Mass spectroscopy is generally considered the benchmark for identification of unknown organic chemicals because it is highly sensitive and selective, and mass spectra are easily searchable against vast reference databases.

Mass Spectroscopy Instrumentation:

The four main parts of mass spectroscopy are discussed below:

1. **Ionizer –** The bombarding of the sample is done by the electrons. These electrons move between cathode and anode. When the sample passes through the electron stream between the cathode and anode, electrons with high energy knock electrons out of the sample and form ions.
2. **Accelerator –** The ions placed between a set of charged parallel plates get attracted to one plate and repel from the other plate. The acceleration speed can be controlled by adjusting the charge on the plates.

3. **Deflector** – Magnetic field deflects ions based on its charge and mass. If an ion is heavy or has two or more positive charges, then it is least deflected. If an ion is light or has one positive charge, then it is deflected the most.
4. **Detector** – The ions with correct charge and mass move to the detector. the ratio of mass to charge is analyzed through the ion that hits the detector.

How does Mass Spectroscopy Work?

In a regular mass spectrometer, we initially have the material to be analyzed, but we need it to be ionized to pass through the spectrometer with enough energy. Thus, the sample is bombarded by electrons to ionize it.

This ionized beam is now passed through a series of electric or magnetic fields depending on the type of the sample and its properties. The ions are deflected by the field through which they are passed through in such a way that the ions with the same mass to signal ratio will follow the same path to the detector.

These charged and deflected ions are now incident onto a detector which is capable of distinguishing the charged particles falling on it. Based on the mass spectrum produced by the charged ions, we can identify the atoms or molecules constituting the sample by comparing them with known masses or through a characteristic fragmentation pattern.

Applications of Mass Spectroscopy

Mass spectroscopy is a efficient method to elucidate the chemical composition of a sample or molecule. More recently, it has been used to classify biological products, in particular proteins and protein complexes, in a number of species. Usually, mass spectrometers can be used to classify unknown substances by molecular weight measurement, to measure known compounds, and to determine the structure and chemical properties of molecules.

- Due to its capability to distinguish between substances, Mass spectroscopy is used to determine unknown substances.
- To identify the isotopes of a substance.
- In analytical laboratories that study the chemical, physical and biological properties of substances. It is preferred over several other analytical techniques as it has less background interference since it is performed in a vacuum.

Mass Spectroscopy Advantages and Disadvantages

Mass spectroscopy is used for both qualitative and quantitative study of chemical substances. These can be used to classify a sample's elements and isotopes, to determine molecular masses, and as a tool for helping to classify chemical structures. This can calculate the purity of the samples and the molar mass.

A big advantage of mass spec is that it is incredibly sensitive (parts per million) over many other techniques. It is an excellent tool for identifying or confirming presence of unknown components in a sample. The disadvantages of mass spec are that identifying hydrocarbons that produce similar ions is not very good and it is not able to separate optical and geometric isomers. The disadvantages are offset by combining MS with other methods, for example gas chromatography. One disadvantage of mass spectroscopy is over hydrocarbons. The method fails to distinguish between hydrocarbons producing similarly fragmented ions.

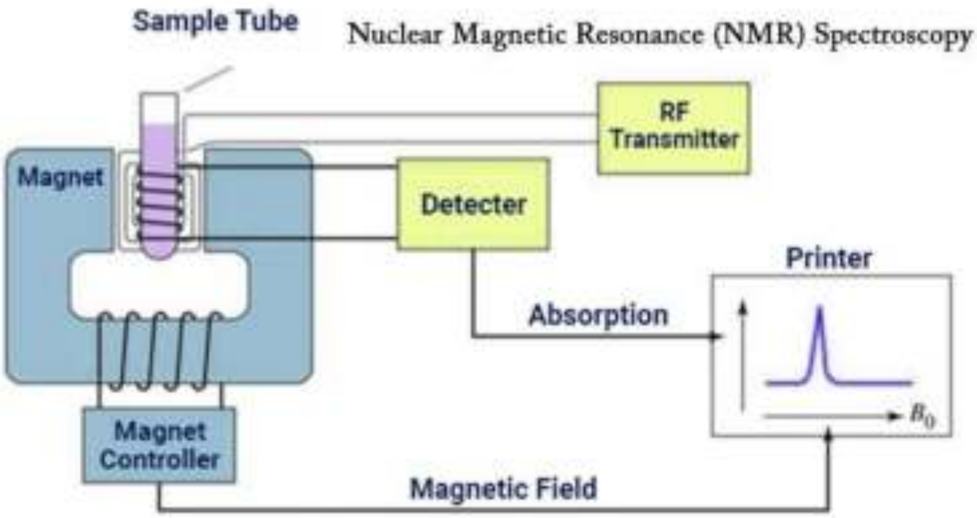
Nuclear magnetic resonance (NMR) spectroscopy

Nuclear magnetic resonance spectroscopy is a technique that utilizes the magnetic resonance of the nucleus to determine the structure of various compounds.

Principle of NMR spectroscopy

Nuclear magnetic resonance spectroscopy is based on the fact that the nuclei in the atoms, molecules, or ions are charged and have spin. When a molecule or compound is placed in a magnetic field, the spin of the nucleus can align in two different states.

If the spin is aligned in the direction of the magnetic field, it results in a lower energy state, whereas the opposite alignment of the magnetic field results in a higher energy state. As a result, the nucleus can move between these two energy states by either absorbing or emitting photons of energy resulting in a resonance condition. The spectrum produced during this absorption is passed to the detectors for the analysis of the nuclear structures of the sample.



Steps of NMR spectroscopy

- The NMR instrument is turned on and warmed up for 30 minutes. The necessary parameters are set in the NMR.
- Calibration is performed by adding an empty NMR tube to ensure no background signals from the tube or the instrument is present.
- The sample is then placed in the NMR tube, and the NMR spectrum is measured.

Uses of NMR spectroscopy

- NMR spectroscopy is used in quality control.
- It is also used in the determination of the content and purity of the sample while detecting the structure of the compounds.
- Solid-state NMR spectroscopy is performed to determine the molecular structure of solids.
- It can also be used for the determination of protein structure.

UNIT-III

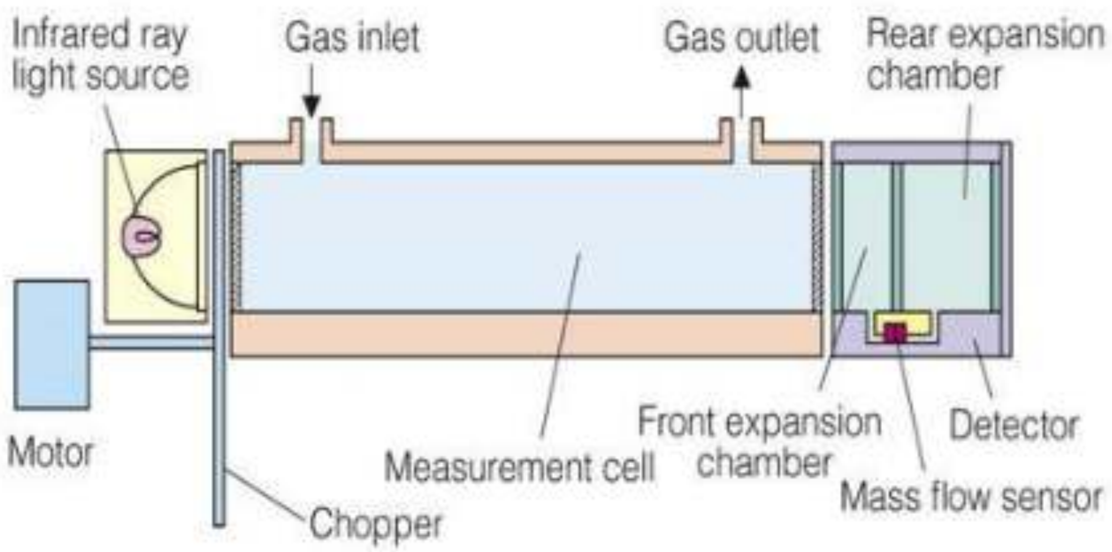
Infrared gas analyzer

An **infrared gas analyzer** is used to measure the quantity of various gas. An infrared gas analyzer measures trace gases by determining the absorption of an emitted infrared light source through a certain air sample. Trace gases found in the Earth's atmosphere get excited under specific wavelengths found in the infrared range.

The concept behind the technology can be understood as testing how much of the light is absorbed by the air. Different molecules in the air absorb different frequencies of light. Air with lots of a certain gas will absorb more of a certain frequency, allowing the sensor to report a high concentration of the corresponding molecule.

Infrared gas analyzers usually have two chambers, one is a reference chamber while the other chamber is a measurement chamber. The amount of gas is determined by the amount of a particular frequency of light absorbed by the gas when the light is passed through the gas. Infrared light is emitted from some type of source on one end of the chamber, passes through a series of chambers that contain given quantities of the various gases in question.

Different molecules in the air absorb different frequencies of light, measuring the absorbed frequency clearly gives the relation to the amount of particular gas in the air.



Principles of Operation

The absorption spectrum of infrared radiation absorbed by gas is unique to the type of gas, In every absorption-type, optical analyzer, the fundamental equation relating photon absorption to substance concentration is the Beer-Lambert Law (sometimes called the Lambert-Beer Law).

The amount of infrared ray absorbed in the measurement cell is detected with a mass flow sensor. The low impedance sensor has high noise immunity. The sensor with no movable parts has a high resistance to vibration and thus can be used semi-permanently. Infrared ray absorption by measured gas component is converted into electric signals.

The invention of 1975 has as many detectors as the number of gases to be measured. Each detector has 2 chambers which both have an optically aligned infrared source and detector, and are both filled with one of the gases in the sample of air to be analyzed. Lying in the optical path are two cells with transparent ends. One contains a reference gas and one will contain the gas to be analyzed. Between the infrared source and the cells is a modulator which interrupts the beams of energy.

There are two tubes in the analyzer one is filled with reference gas and other with the sample gas or process gas which absorbs light. The reference gas is usually gassed like nitrogen which will not absorb light. The output from each detector is combined with the output from any other detector which is measuring a signal opposite to the principal signal of each detector. The amount of signal from other detectors is the amount that will offset the proportion of the total signal that corresponds to the interference. This interference is from gases with a principal lower absorption band that is the same as the principal band of the gas being measured.

Advantages:

- The gas molecule doesn't interact directly with the gas.
- Non-destructive analysis.
- Infrared gas analyzers are standard detectors for the measurement of gas in any given environment.
- Monitoring emission levels over longer periods of time.

Disadvantages:

- A simple measurement becomes a complex measurement
- Cost of measuring the gas normalization parameter is greater than the cost of primary dust measurement

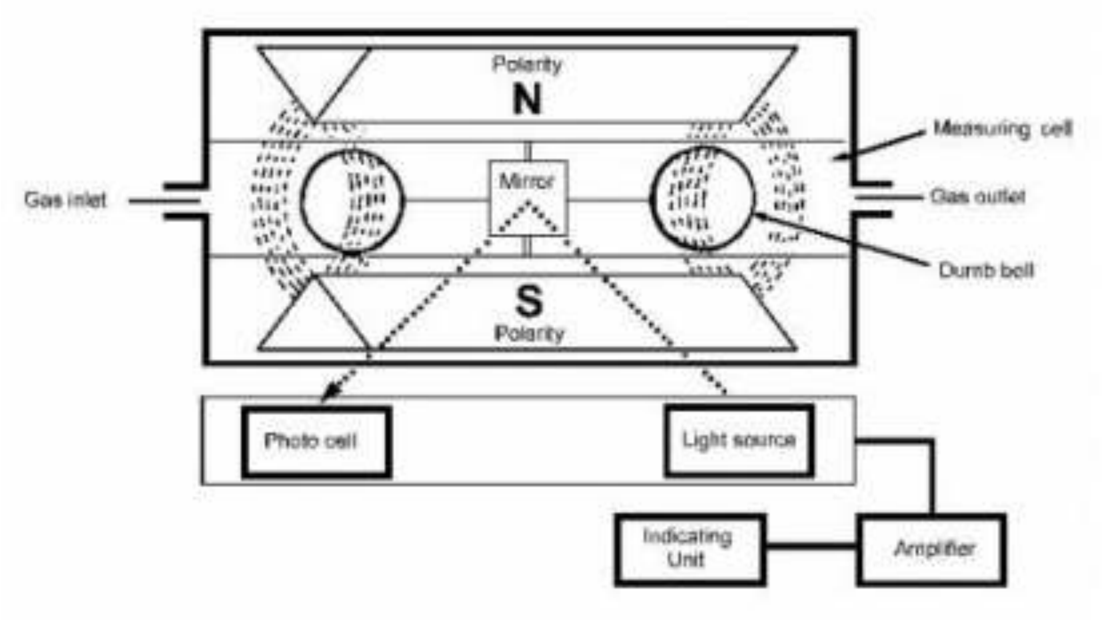
Paramagnetic Oxygen Analyser

Oxygen is a paramagnetic gas and is attracted into a strong magnetic field. Because this measurement is a purely physical effect, nothing is consumed and in principle the cell has an unlimited life. However, contamination of the cell by dust, dirt, corrosives or solvents can lead to deterioration. Measurement range is typically 0.05% to 100% O_2.

Theory:

The operating principle of the paramagnetic sensor is the paramagnetic susceptibility of the oxygen molecule, a physical property which distinguishes oxygen from most other gases.

The sensor incorporates two nitrogen-filled glass spheres mounted on a rotating suspension. This assembly is suspended in a strong magnetic field. The oxygen in the surrounding gas is attracted to the magnetic field, resulting in a force on the glass spheres. The strength of the torque acting on the suspension is proportional to the oxygen content of the surrounding gases.



Principle of Operation

As shown in above figure, the measuring system is "null-balanced". First the "zero" position of the suspension assembly, as measured in nitrogen, is sensed by a photo-sensor that receives light reflected from a mirror attached to the suspension assembly. The output from the photo-sensor is fed back to a coil around the suspension assembly. This feedback achieves two objectives.

First, when oxygen is introduced to the cell, the torque acting upon the suspension assembly is balanced by a re-storing torque due to the feedback current in the coil. The feedback current is directly proportional to the volume magnetic susceptibility of the sample gas and hence, after calibration, to the partial pressure of oxygen in the sample. Therefore, the current gives an accurate measurement of the concentration of oxygen in the gas mixture.

Second, the electromagnetic feedback "stiffens" the suspension, damping it heavily and increasing its natural frequency, making the suspension resilient to shock.

B.K.N GOVT POLYTECHNIC NARNAUL

DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: 5.4 PROCESS CONTROL

NAME OF FACULTY: Mrs. RAJNI

SEMESTER-5th

UNIT-1 Basic control Loops and Characteristics

1.1 Basic Process Control System (BPCS) is a system which handles process control and monitoring for a facility or piece of equipment. It takes inputs from sensors and process instrumentations to provide an output based on an approved design control strategy. The Basic Process Control System (BPCS) is responsible for the proper operation of the plant, and in many instances is used in the first layer of protection against unsafe conditions. A simple example of a basic process control loop is shown in the system shown below. A level transmitter (LT), a level controller (LC), and a control valve (LV) are used to control the liquid level in a process tank.

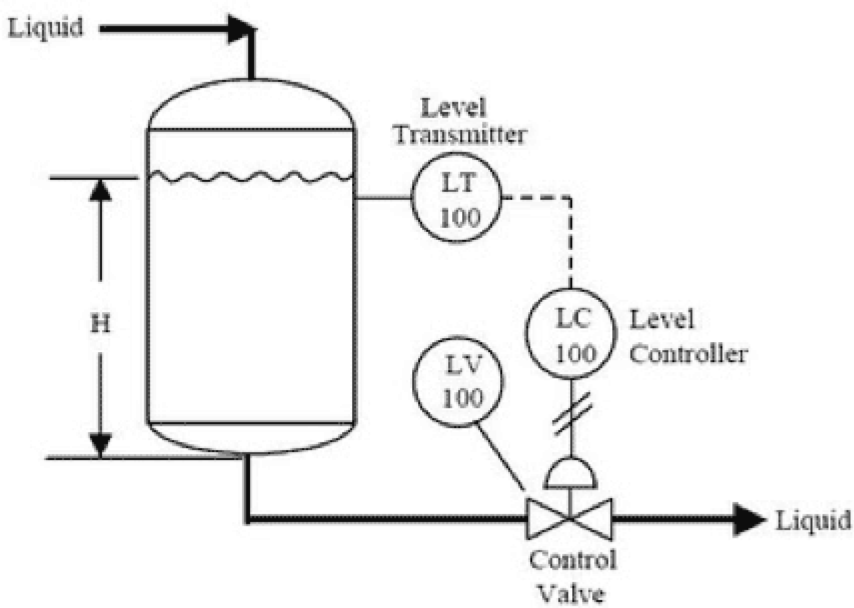


Figure- Basic of process Control System (BPCS)

1.2 Different process Variables

Instruments are used to monitor and control a process to keep the process within a correct limit. The parameters or quantities that we wish to control at the correct limit are called Process Variables. A variable is something that can vary or change. Because process variables can and do change, instrumentation systems measure the variable then control the variable to keep the variable within the given limits.

Types of Process Variables

The main **three process variables** in industries

1. Pressure Variable
2. Temperature Variable
3. Flow Variable

The **level** is an another process variable in industries.

1.2.1 Pressure Variable

Pressure is a term used to describe the amount of force applied to a specific unit area. Below shows a flow channel of fluid from a compressor.

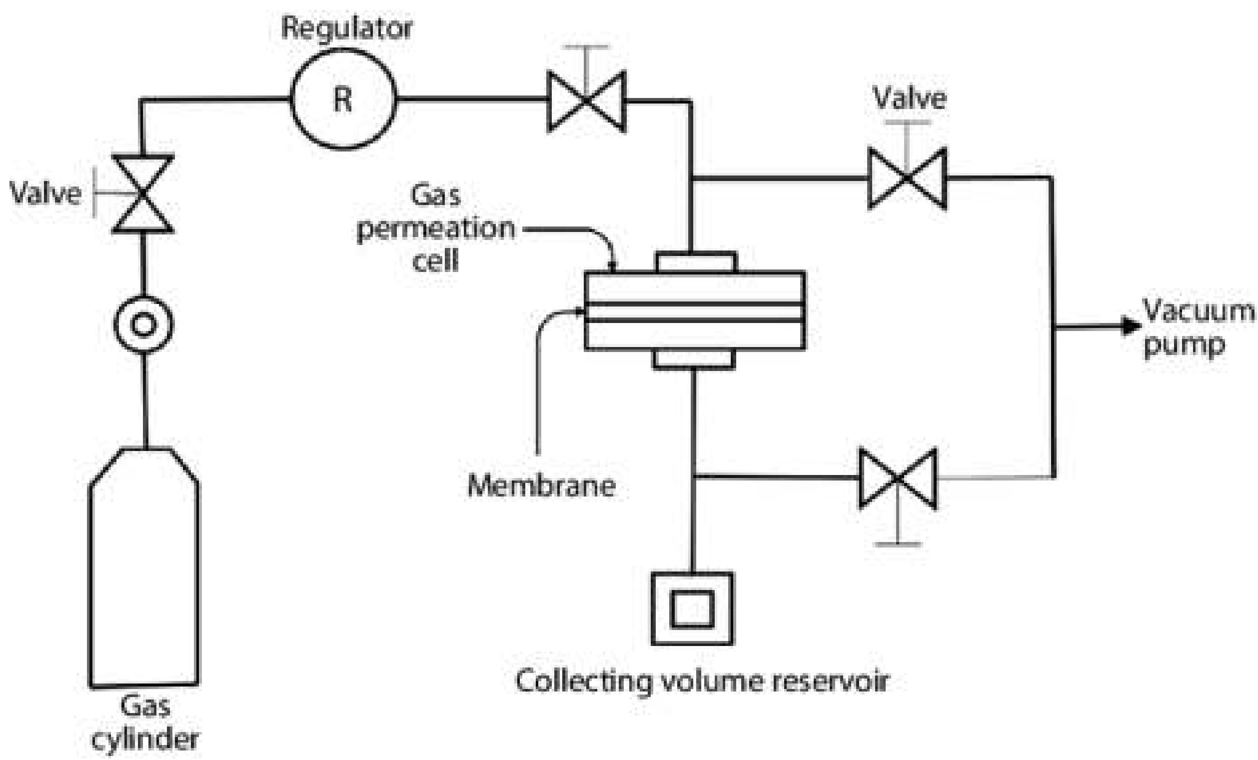


Figure – Pressure Variable

If you open the block valve, air is released to the atmosphere, so the pressure inside the receiver decreases. If you close the control valve, you keep the air inside the receiver and the pressure increases. The process variable that we are controlling is called PRESSURE.

1.2.2. Temperature Variable

Temperature is a measurement of how hot or how cold an object is. Below figure shows a temperature control unit.

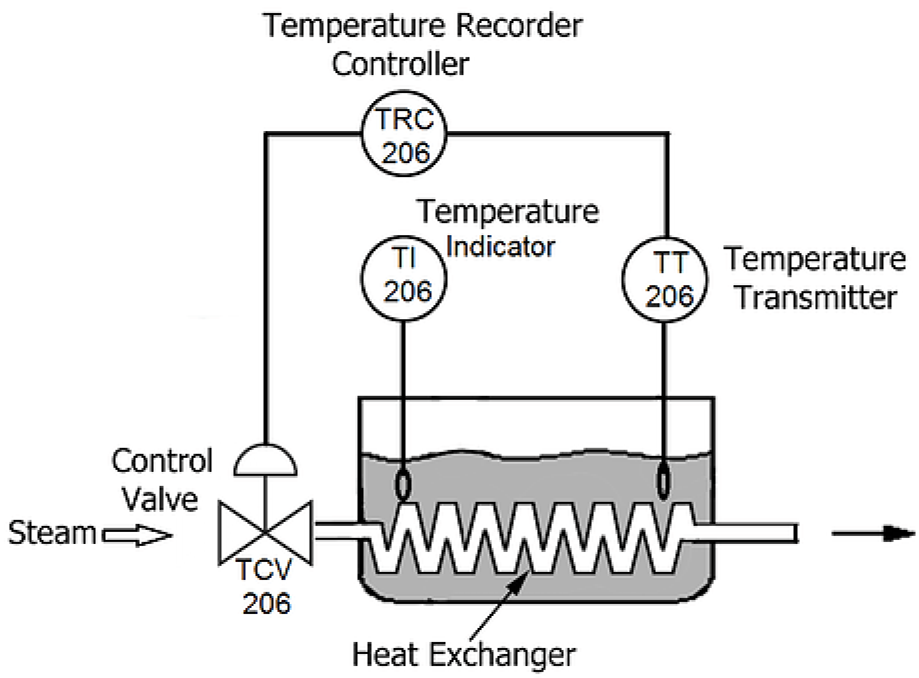


Figure- Temperature variable

Water in the vessel is heated by the heat exchanger. Measuring the temperature the steam flow to the exchanger is controlled. Temperature changes when the amount of steam is changed. The process variable is called Temperature.

1.2.3. Flow Variable

Flow is the movement of fluid inside a pipe in a given direction. Figure below shows the flow control loop.

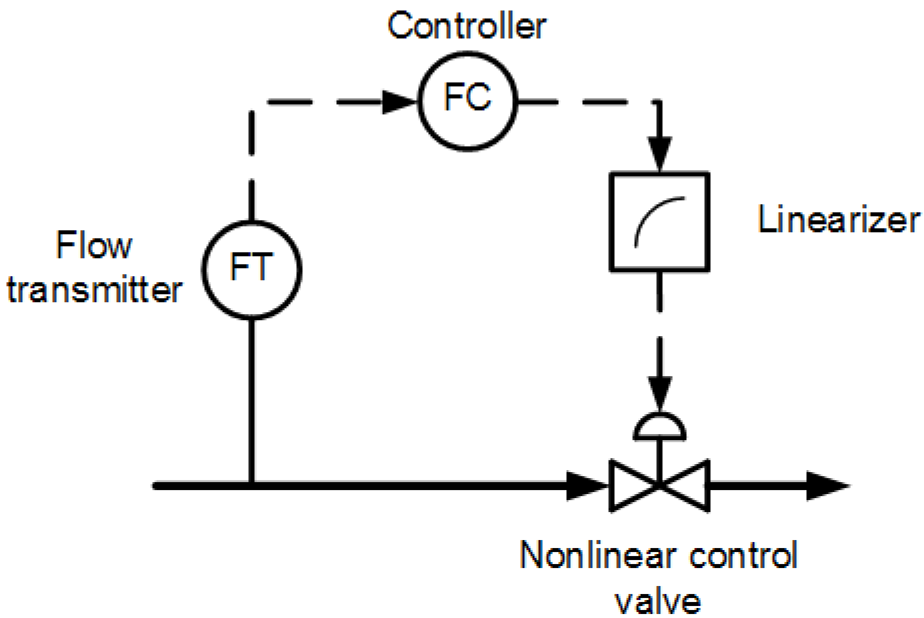


Figure- Flow Variable

A valve in the flow channel controls the flow through the pipeline. The greater the valve opening the greater the water flow inside the pipe. Here we are controlling the flow the fluid passing through the pipeline, so the process variable is flow.

Level Variable

The level in the tank change up and down depending up the fluid in the tank. A control valve is installed in the output line to control the level of the tank.

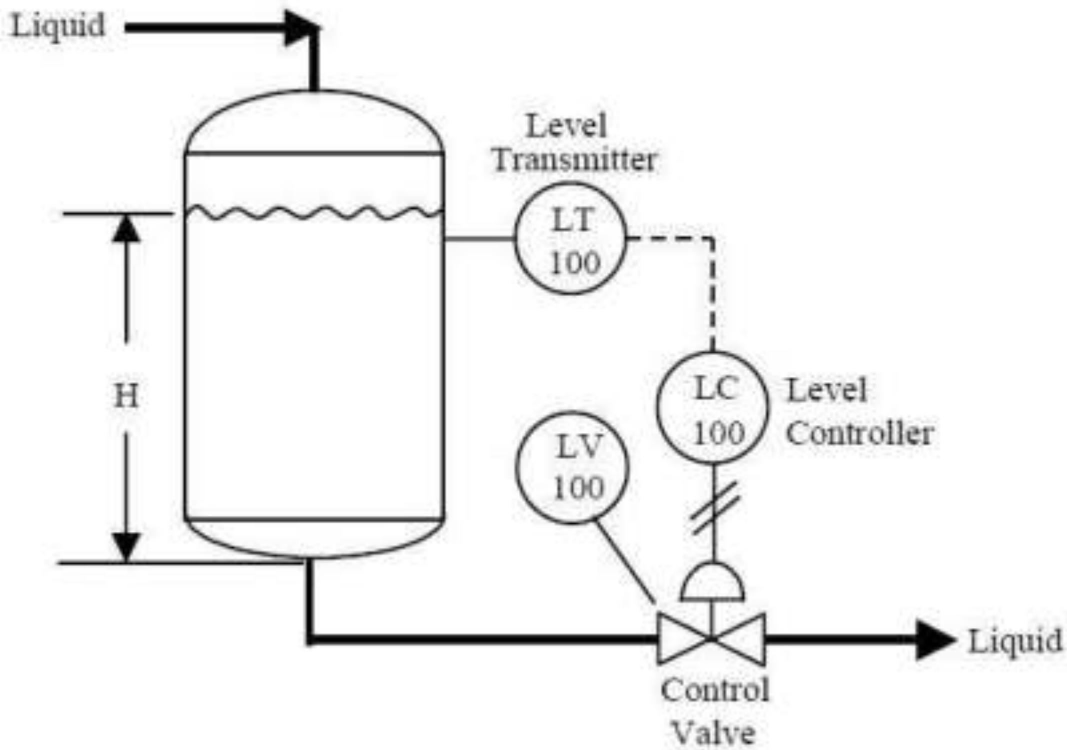


Figure- Level variable

The process variable is level. You can change the level by closing or opening the control valve. If you close the valve, the level increases. If you open the valve, the level decreases.

1.3 Single loop temperature control system

Single loop controllers are cost effective and easy to use devices used in temperature and other processes to control one specific variable. From basic devices with core functions, to those with advanced features, a range of single loop controllers are available to ensure precise control for demanding applications. Typically, single loop controllers are front-of-panel products. Many of our controllers have a high visibility display for increased clarity that enables vital process information and alarm messages to be viewed at a glance. These features allow the single loop controller to control process variables in a wide variety of applications that include industrial and lab ovens, sealers, kilns, food processing, extruder barrel heating, and heat presses, to name a few.

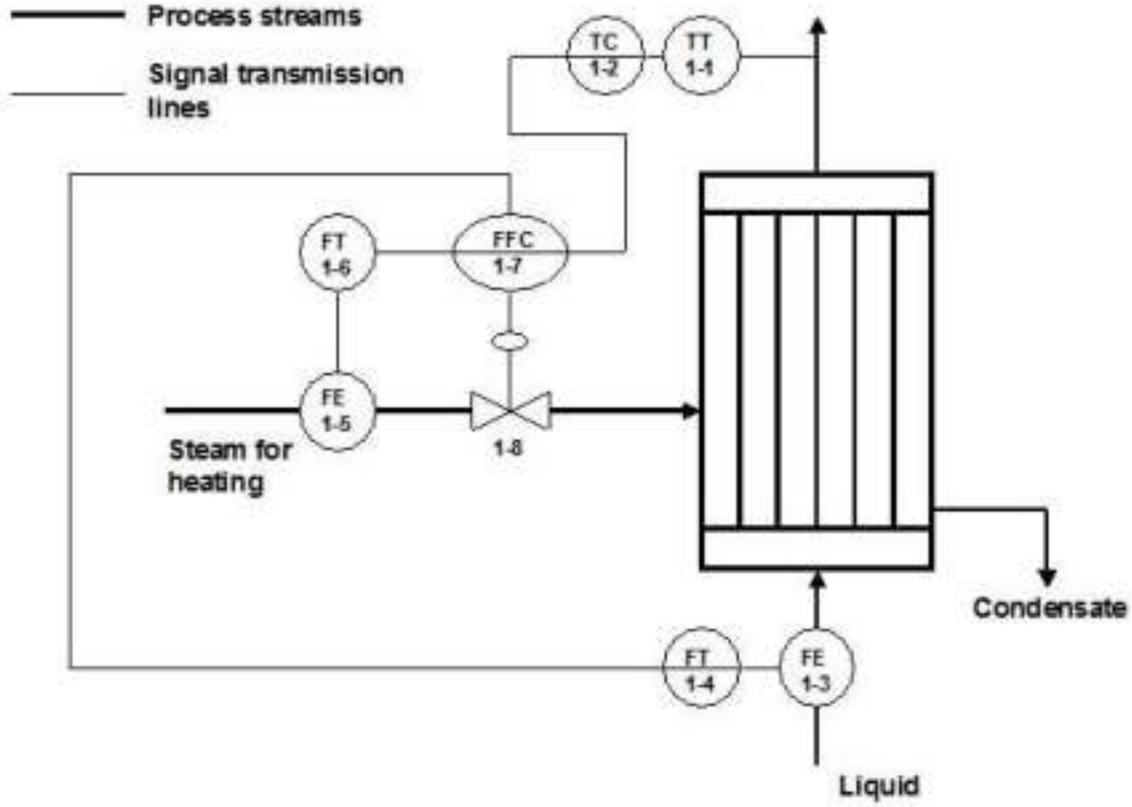


Figure – Single loop temperature control system

1.4 Single loop pressure control system

A pressure sensor is always used to convert pressure into a mechanical or electrical signal. This signal is then used for process indication or to generate a scaled transmitted signal that a controller can use to control a process. Before discussing pressure elements or sensor types, we need to define pressure and other terms used in pressure measurement.

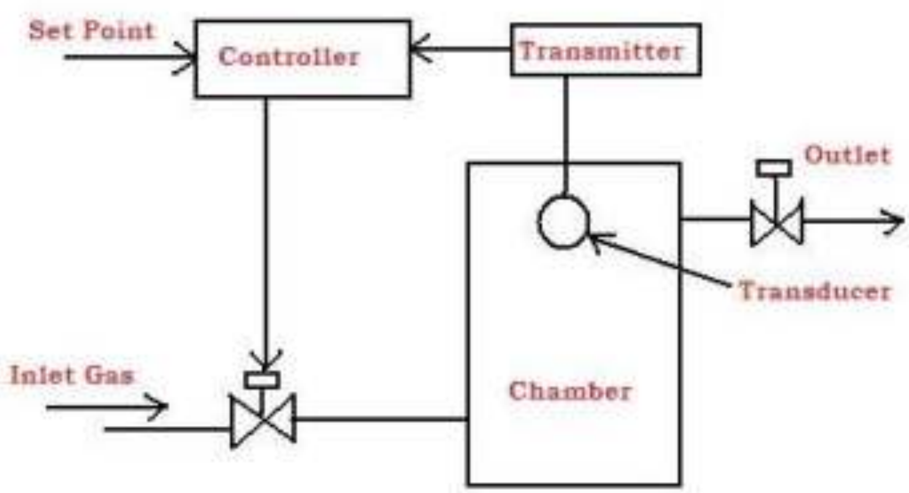


Figure – Single loop pressure control system

A pressure control valve is used to automatically control the pressure at a certain point in a pipeline. In this respect, it is similar to a pressure regulator discussed next. Whereas the pressure regulator is generally used to maintain a constant downstream pressure, a pressure control valve is used to control the upstream pressure. The upstream and downstream are relative to the location of the valve on the pipeline. Generally, a bypass piping system around the control valve is installed to isolate the control valve in the event of an emergency or for maintenance work on the control valve.

1.5 Flow loop Control system

A **liquid flow control loop** consisting of a flow transmitter (FT) to sense liquid flow rate through the pipe and output an electronic signal corresponding to the flow.
A flow controller (FC) to sense the flow signal (from FT) and decide which way the control valve should move, a current-to-air (I/P) transducer (FY) to convert the controller's electronic output signal into a variable air pressure, and an air-operated flow control valve (FV) to throttle the liquid flow.

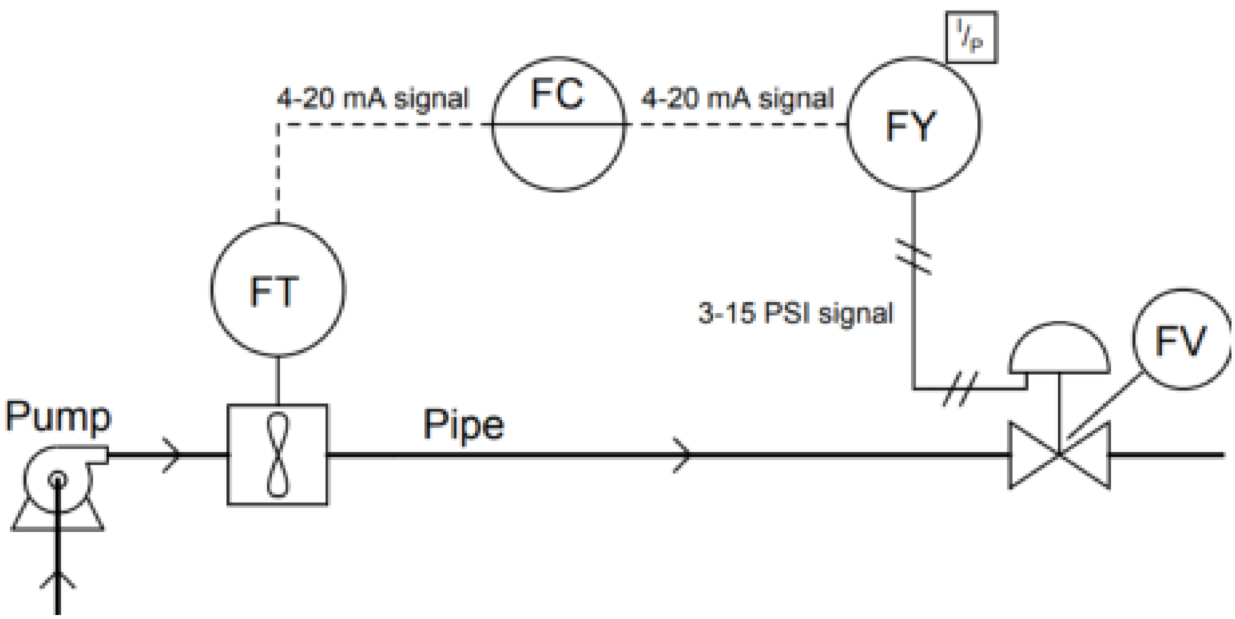


Figure – Flow loop control system

The actions of each instrument are shown here:

- FT: increasing liquid flow = increasing current signal
- FC: increasing process variable (input) signal = decreasing output signal
- FY: increasing current input signal = increasing pneumatic output signal
- FV: increasing pneumatic signal = open more

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DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: 5.4 PROCESS CONTROL

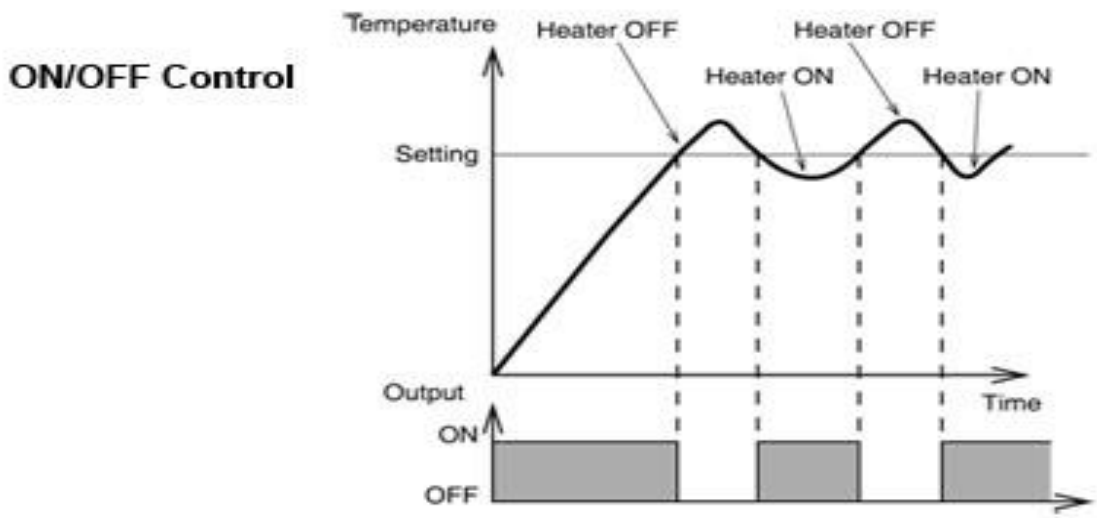
NAME OF FACULTY: Mrs. RAJNI

SEMESTER-5th

UNIT -2 Basic Controller Modes and Characteristics

2.1 Concept of on-off control, advantage and disadvantages

The control element has only two positions either it is fully closed or fully open. This control element does not operate at any intermediate position, i.e. partly open or partly closed position. The control system made for controlling such elements is known as the **on-off** control theory.
On off control is like operating a switch. This type of temperature controller will turn on the heat when the process variable is below the set point and turn it off when the process variable is above the set point. These controllers normally include a delay, hysteresis and or a cycle time to reduce the cycling or "hunting" when the process variable is close to the set point. In truth, they are closer to thermostats than controllers, because they do not balance heat loss with heat gain at the desired value.



On/Off control is simple to understand, but forces a compromise between good controls, long warm up times and increased cost. This compromise happens when you select the power rating of your heating element.

If it has too much power. An on/off temperature controller will struggle to provide tight temperature control because the heating element will store and deliver too much heat before the temperature reached the "off" point. As a result the temperature will overshoot.

If the heating element is specified with enough heat without too much overshoot, then warm up times from cold will be lengthened, leading to longer batch times and less production.

In both cases manufacturing costs are increased.

Tighter temperature control and cost savings can be achieved by using PID or Fuzzy Logic control.

Advantage of On-Off Controller

- It is most easiest and intuitive method to implement.
- It is a basic method and very simple.
- Low initial cost
- Plain structure
- Quick response
- No tuning required for start-up.

Disadvantage of On-Off Controller

- It is unable to control moving processes with time delays.
- It is accurate enough.
- It does not have enough quality.
- PID controller should be used for reducing the fluctuation produced by On-Off controller but parameter's setting for PID controller is difficult.
- Accept only binary input.
- More energy is used by valves.

2.2 Proportional, Integral, Derivative action and their combinations PI, PD and PID controls, their example, merits and demerits

2.2.1 Proportional Controllers

All controllers have a specific use case to which they are best suited. We cannot just insert any type of controller at any system and expect a good result – there are certain conditions that must be fulfilled. For a **proportional controller,** there are two conditions and these are written below:

1. The deviation should not be large; i.e. there should not be a large deviation between the input and output.
2. The deviation should not be sudden.

As we know in proportional controller output is directly proportional to the error signal, writing this mathematically we have,

$$A(t) \propto e(t)$$

Removing the sign of proportionality we have,

$$A(t) = K_p \times e(t)$$

Where K_p is proportional constant also known as controller gain.
It is recommended that K_p should be kept greater than unity. If the value of K_p is greater than unity (>1), then it will amplify the error signal and thus the amplified error signal can be detected easily.

Advantages of Proportional Controller

Now let us discuss some advantages of the proportional controller.

1. The proportional controller helps in reducing the steady-state error, thus makes the system more stable.
2. The slow response of the over damped system can be made faster with the help of these controllers.

Disadvantages of Proportional Controller

Now there are some serious disadvantages of these controllers and these are written as follows:

1. Due to the presence of these controllers, we get some offsets in the system.
2. Proportional controllers also increase the maximum overshoot of the system.

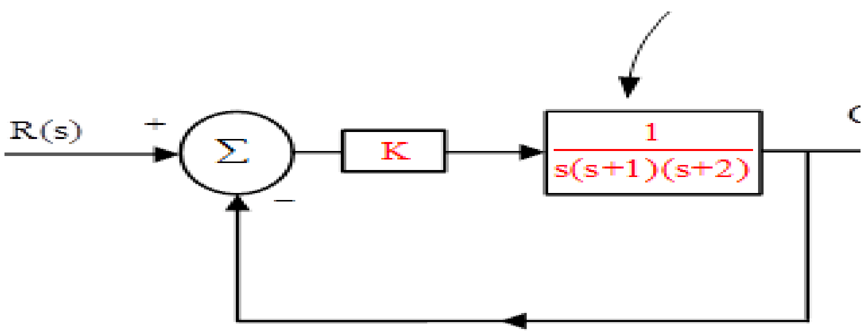


Figure- A Feedback Control System with Proportional Controller

'K' is called a proportional controller (also called error amplifier). Characteristics equation of this control system can be written as:

$$s^3+3s^2+2s+K=0$$

2.2.2 Integral Controllers

As the name suggests in **integral controllers** the output (also called the actuating signal) is directly proportional to the integral of the error signal. Now let us analyze integral controller mathematically. As we know in an integral controller output is directly proportional to the integration of the error signal, writing this mathematically we have,

$$A(t) \propto \int_0^t e(t)dt$$

Removing the sign of proportionality we have,

$$A(t) = K_i \times \int_0^t e(t)dt$$

Where Ki is an integral constant also known as controller gain. The integral controller is also known as reset controller.

Advantages of Integral Controller

Due to their unique ability, Integral Controllers can return the controlled variable back to the exact set point following a disturbance that's why these are known as reset controllers.

Disadvantages of Integral Controller

It tends to make the system unstable because it responds slowly towards the produced error.

2.2.3 Derivative Controllers

We never use **derivative controllers** alone. It should be used in combinations with other modes of controllers because of its few disadvantages which are written below:

1. It never improves the steady-state error.
2. It produces saturation effects and also amplifies the noise signals produced in the system.

Now, as the name suggests in a derivative controller the output (also called the actuating signal) is directly proportional to the derivative of the error signal. Now let us analyze the derivative controller mathematically. As we know in a derivative controller output is directly proportional to the derivative of the error signal, writing this mathematically we have,

$$A(t) \propto \frac{de(t)}{dt}$$

Removing the sign of proportionality we have,

$$A(t) = K_d \times \frac{de(t)}{dt}$$

Where, K_d is proportional constant also known as controller gain. The derivative controller is also known as the rate controller.

Advantages of Derivative Controller

The major advantage of a derivative controller is that it improves the transient response of the system.

2.2.1.1 Proportional and Integral Controller(PI)

As the name suggests it is a combination of proportional and an integral controller the output (also called the actuating signal) is equal to the summation of proportional and integral of the error signal. Now let us analyze proportional and integral controller mathematically. As we know in a proportional and integral controller output is directly proportional to the summation of proportional of error and integration of the error signal, writing this mathematically we have,

$$A(t) \propto \int_0^t e(t)dt \; + \; A(t) \propto e(t)$$

Removing the sign of proportionality we have,

$$A(t) = K_i \int_0^t e(t)dt \; + \; K_p e(t)$$

Where, K_i and k_p proportional constant and integral constant respectively.
Advantages and disadvantages are combinations of the advantages and disadvantages of proportional and integral controllers.

Through the PI controller, we are adding one pole at origin and one zero somewhere away from the origin (in the left-hand side of complex plane). As the pole is at the origin, its effect will be more, hence PI controller may reduce the stability; but its main advantage is that it reduces steady-state error drastically, due for this reason it is one of the most widely used controllers.

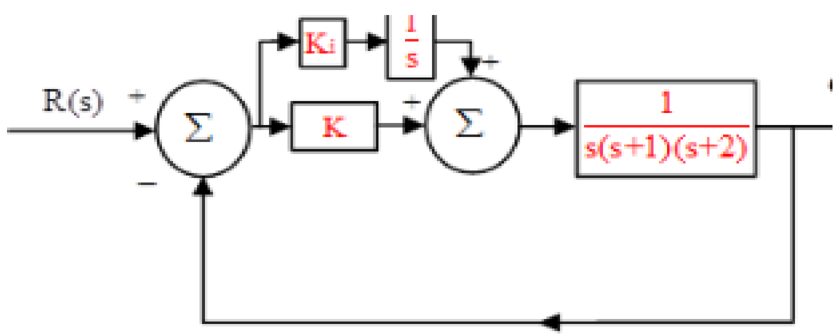


Figure- The closed loop control system with PI Controller

2.2.2.2 Proportional and Derivative Controller(PD)

As the name suggests it is a combination of proportional and a derivative controller the output (also called the actuating signal) is equals to the summation of proportional and derivative of the error signal. Now let us analyze proportional and derivative controller mathematically. As we know in a proportional and derivative controller output is directly proportional to the summation of proportional of error and differentiation of the error signal, writing this mathematically we have,

$$A(t) \propto \frac{de(t)}{dt} + A(t) \propto e(t)$$

Removing the sign of proportionality we have,

$$A(t) = K_d \frac{de(t)}{dt} + K_p e(t)$$

Where, K_d and K_p proportional constant and derivative constant respectively. Advantages and disadvantages are combinations of advantages and disadvantages of proportional and derivative controllers.
Readers should note that adding 'zero' at the proper location in the open-loop transfer function improves stability, while the addition of pole in the open-loop transfer function may reduce the stability. The words "at proper location" in the above sentence are very important & it is called designing of the control system (i.e. both zero & pole should be added at proper points in the complex plane to get the desired result).

Inserting the PD controller is like the addition of zero in open-loop transfer function [G(s)H(s)]. Diagram of PD Controller is shown in Fig.

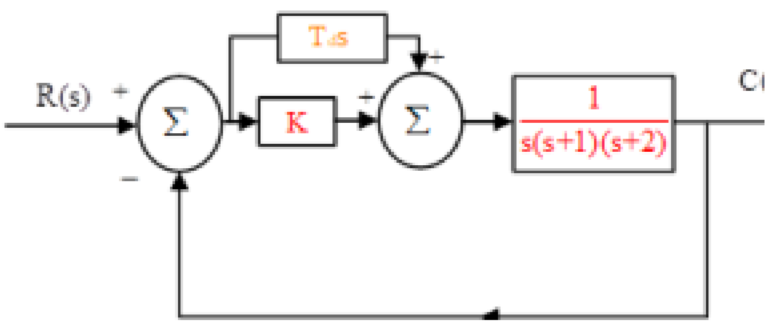


Figure- Closed-loop control system with PD Controller

2.2.2.3 Proportional plus Integral plus Derivative Controller (PID Controller)
Proportional-integral-derivative control is a combination of all three types of control methods. PID-control is most commonly used because it combines the advantages of each type of control. This includes a quicker response time because of the P-only control, along with the decreased/zero offset from the combined derivative and integral Controllers. This offset was removed by additionally using the I-control. The addition of D-control greatly increases the controller's response when used in combination because it Predicts disturbances to the system by measuring the change in error. On the contrary, as mentioned previously, when used individually, it has a slower response time compared to the quicker P-only control. However, although the PID controller seems to be the most adequate controller, it is also the most expensive controller. Therefore, it is not used

unless the process requires the accuracy and stability provided by the PID controller. A PID controller is generally used in industrial control applications to regulate temperature, flow, pressure, speed, and other process variables.

Mathematical Equations

PID-control correlates the controller output to the error, integral of the error, and derivative of the error. This PID-control behavior is mathematically illustrated

$$c(t) = K_c \left(e(t) + \frac{1}{T_i}\int e(t)dt + T_d\frac{de}{dt}\right) + C$$

c(t) = controller output
Kc = controller gain
e(t) = error
Ti = integral time
Td = derivative time constant
C = initials value of controller

As shown in the above equation, PID control is the combination of all three types of control. In this equation, the gain is multiplied with the integral and derivative terms, along with the proportional term, because in PID combination control, the gain affects the I and D actions as well. Because of the use of derivative control, PID control cannot be used in processes where there is a lot of noise, since the noise would interfere with the predictive, feedforward aspect. However, PID control is used when the process requires no offset and a fast response time. A graphical representation of the PID-controller output for a step increase in input at time t0 is shown below in Figure. This graph resembles the qualitative combination of the P-only, I-only, and D-only graphs.

Figure (a)

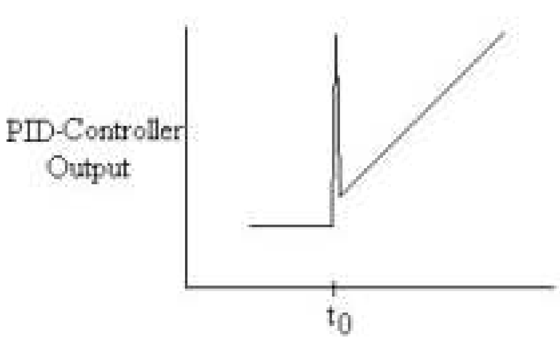


Figure (a) PID-controller output for step input.

In addition to PID-control, the P-, I-, and D- controls can be combined in other ways. These alternative combinations are simplifications of the PID-control.

Advantages and disadvantages of controls

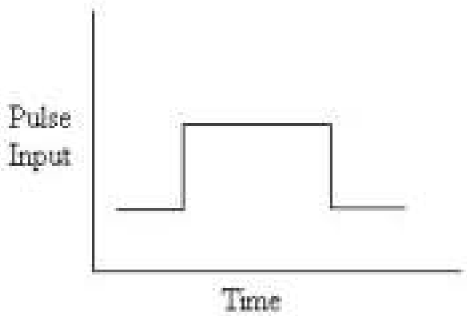
	Proportional (P)	Integral (I)	Derivative (D)
Advantages	+ Fast response time + Minimizes fluctuation	+ Contains small offset + Returns system to steady state	+ Keeps system at consistent setting + Controls processes with rapidly changing outputs
Disadvantages	- Contains large offset - Does not bring system to desired set point	- Slow response time	- Slow response time - Requires combined use with another controller

Typical uses of P, I, D, PI, and PID controllers

Controller	Estimates	When to use	Examples
P	Present	Systems with slow response, systems tolerant to offset	Float valves, thermostats, humidistat
I	Back	Not often used alone, as is too slow	Used for very noisy systems
D	Forward	Not used alone because it is too sensitive to noise and does not have set point	None
PI	Present & back	Often used	Thermostats, flow control, pressure control
PID	All time	Often used, most robust, but can be noise sensitive	Cases where the system has intertia that could get out of hand: i.e. temperature and concentration measurements on a reactor to avoid runaway.

Example PID Controller

Having taken your advice, your boss at Hypothetical Industries decides to install a PID Controller to control the level in the batch reactor. When you first start up the reactor, the controller initially received a step input. As the reactor achieves steady state, the level in the reactor tends to fluctuate, sending pulse inputs into the controller. For a pulse input, **provide a grahical representation of the PID controller output.**



Figure(i) Pulse input.

SOLUTION:

The PID-controller output will be a combination of the P-only, I-only and D-only controller outputs. Analogous to the P-controller output for the step input, the Pcontroller output for the pulse input will exactly resemble the input.

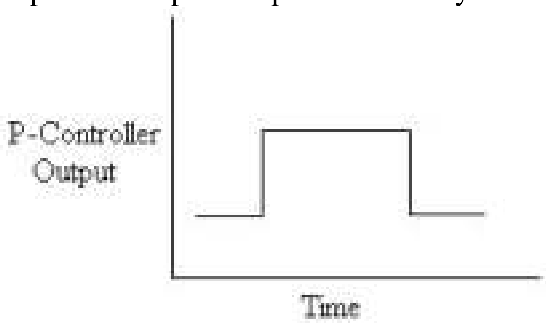
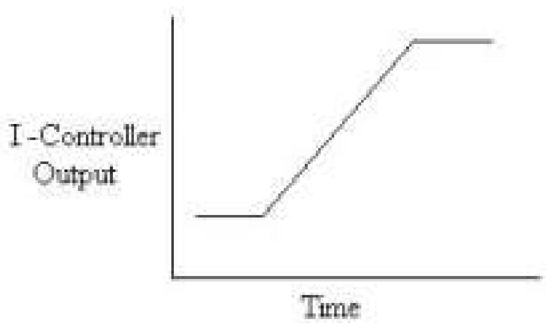


Figure (ii) P-controller output for pulse input

The I-controller output represents the area under the input graph. Unlike the step input, the area under the pulse input graph dropped back down to zero once the pulse has passed. Therefore, rather than continually increase, the I-controller output graph will level off in the end.



Figure(iii) I-controller output for pulse input.

The D-controller output represents the derivative of the input graph. The derivative at the first discontinuity of the graph would be positive infinity. The derivative of the second downward discontinuity is negative infinity.

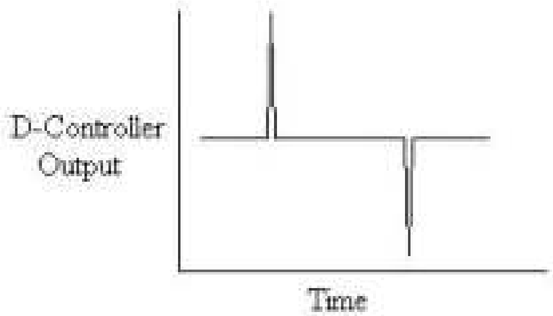


Figure (iv) D-controller output for pulse input.

Combining the qualitative characteristics of all three graphs we can determine the PIDcontroller output for a pulse input.

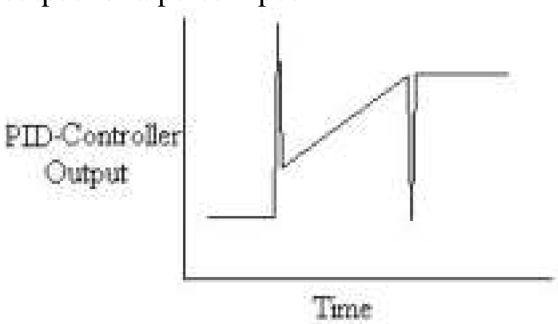


Figure (v) PID-controller output for pulse input

B.K.N GOVT POLYTECHNIC NARNAUL

DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: 5.4 PROCESS CONTROL

NAME OF FACULTY: Mrs. RAJNI

SEMESTER-5th

UNIT-3 Control Elements

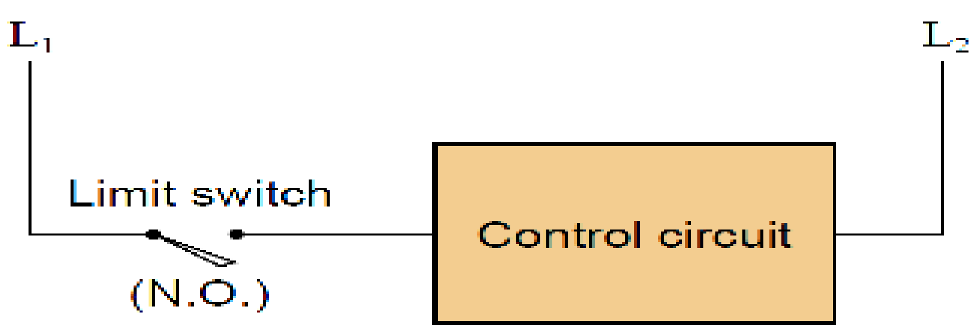
Construction, principle of operation and application of

3.1 Electrical control elements: limit switch, auto transformer, magnetic amplifier

3.1.1 Limit switches

Limit switch is a switch operated by the motion of a machine part or presence of an object. They are used for controlling machinery as part of a control system, as a safety interlocks, or to count objects passing a point. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch".



Figure(a)- Limit Switch

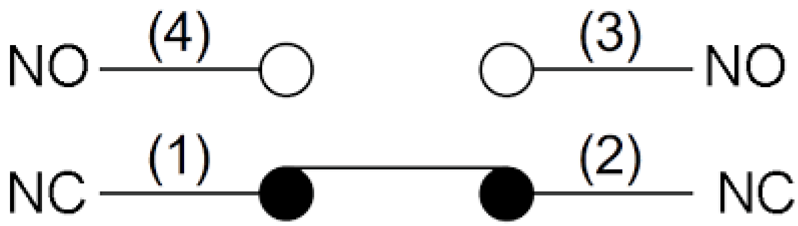


Figure (b) -Limit Switch

A limit switch brings out a change in the drive operation after a moving part reaches a given position. Function of a limit switch can be understood by the example of the ingot buggy control of a blooming mill. Function of the ingot buggy is to transport hot steel piece known as ingot from soaking pits to rolling stand. After the ingot is loaded on buggy at position A (Fig.), the buggy is accelerated to full speed by a drive mounted on it. From position B to C the buggy runs at a constant speed. When the buggy reaches position C, the operation of drive is shifted from motoring to braking, and buggy is brought to a stop. Since dynamics of the buggy is known, position C is so chosen that the buggy stops at position D which is just in front of rolling stand. The changeover of operation from motoring to braking at position C is done with the help of a limit switch. When position C is reached, contact of limit switch closes and initiates control logic of drive to change the operation from motoring to braking.

Figure(c) –Function of a Limit Switch

Limit switch can be of mechanical type or a photoswitch. In mechanical limit switch a projection on the buggy makes contact with the lever of limit switch mounted at position C. A photoswitch consists of a light sensor and a relay. A light source is mounted on buggy. When the buggy reaches position C the light from its light source strikes the sensor, the relay is energised, closing or opening one or more sets of relay contacts. The photoswitches are generally preferred because due to absence of moving parts, they hardly required any maintenance and have long life.

3.1.2 Auto Transformer

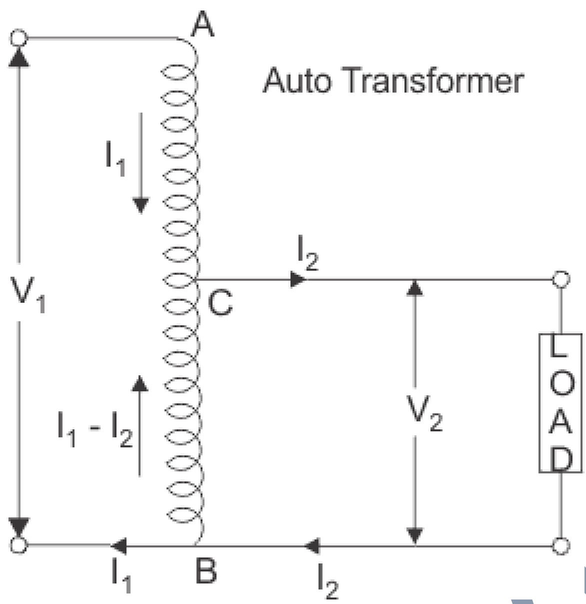
Autotransformer is an electrical transformer having only single winding which acts as both primary and secondary, so in input and output connected to shared single winding.

The autotransformer has a single winding on an iron core. One of the coil terminals is common to both input and output, and the other output terminal is movable so that it can make contact with any turn on the winding.

An auto transformer is similar to a two winding transformer but varies in the way the primary and secondary winding of the transformer are interrelated.

Autotransformer Theory

In an auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose. A circuit diagram of auto transformer is shown below.



The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point ′C′ and the portion BC is considered as secondary. Let's assume the number of turns in between points ′B′ and ′C′ is N_2.

If V_1 voltage is applied across the winding i.e. in between ′A′ and ′C′. $So\ voltage\ per\ turn\ in\ this\ winding\ is\ \frac{V_1}{N_1}$

Hence, the voltage across the portion BC of the winding, will be, $\frac{V_1}{N_1} X N_2\ and\ from\ the\ figure\ above,\ this\ voltage\ is\ V_2$

$$Hence,\ \frac{V_1}{N_1} X N_2 = V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = Constant = K$$

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant ′k′ is nothing but turns ratio or voltage ratio of that **auto transformer**. When load is connected between secondary terminals i.e.between ′B′ and ′C′, load current I_2 starts flowing. The current in the secondary winding or common winding is the difference of I_2 and I_1.

Copper Savings in Auto Transformer

Now we will discuss the savings of copper in auto transformer compared to conventional two winding transformer.

We know that weight of copper of any winding depends upon its length and cross-sectional area.

Again length of conductor in winding is proportional to its number of turns and cross-sectional area varies with rated current.
So weight of copper in winding is directly proportional to product of number of turns and rated current of the winding.

Therefore, weight of copper in the section AC proportional to,
$(N_1 - N_2)I_1$
and similarly, weight of copper in the section BC proportional to,
$N_2(I_2 - I_1)$
Hence, total weight of copper in the winding of auto transformer proportional to,
$(N_1 - N_2)I_1 + N_2(I_2 - I_1)$

$$\Rightarrow N_1I_1 - N_2I_1 + N_2I_2 - N_2I_1$$

$$\Rightarrow N_1I_1 + N_2I_2 - 2N_2I_1$$

$$\Rightarrow 2N_1I_1 - 2N_2I_1 (Since,\ N_1I_1 = N_2I_2)$$

$$\Rightarrow 2(N_1I_1 - N_2I_1)$$

In similar way it can be proved, the weight of copper in two winding transformer is proportional to,
$N_1I_1 - N_2I_2$

$$\Rightarrow 2N_1I_1 \qquad (Since,\ in\ a\ transformer\ N_1I_1 = N_2I_2)$$

$N_1I_1 + N_2I_2$
$\Rightarrow 2N_1I_1$ (Since, in a transformer $N_1I_1 = N_2I_2$)

Let's assume, W_a and W_{tw} are weight of copper in auto transformer and two winding transformer respectively,

$$Hence,\ \frac{W_a}{W_{tw}} = \frac{2(N_1 I_1 - N_2 I_1)}{2(N_1 I_1)}$$

$$= \frac{N_1 I_1 - N_2 I_1}{N_1 I_1} = 1 - \frac{N_2 I_1}{N_1 I_1}$$

$$= 1 - \frac{N_2}{N_1} = 1 - k$$

$$\therefore W_a = W_{tw}(1 - k)$$

$$\Rightarrow W_a = W_{tw} - kW_{tw}$$

∴ Saving of copper in auto transformer compared to two winding transformer, $\Rightarrow W_{tw} - W_a = kW_{tw}$

Auto transformer employs only single winding per phase as against two distinctly separate windings in a conventional transformer.

Advantages of an Autotransformer

Note that if the turn's ratio of the transformer is large, the power rating as an autotransformer will be much larger than the rating as a conventional transformer. In a conventional transformer, all of the power is transformed, whereas in an autotransformer, most of the power is conducted at an elevated potential. As a result, an autotransformer is much smaller than a conventional transformer of the same rating.

Other advantages of an autotransformer over a two winding transformer are:

1. Cheaper
2. More efficient, because losses stay the same while the rating goes up compared to a conventional transformer
3. Lower exciting current
4. Better voltage regulation

Disadvantages of an Autotransformer

Some of the disadvantages of an autotransformer are:

1. Larger short-circuit current
2. No isolation exists between the primary and secondary windings
3. Only useful for moderately smaller voltage changes
4.

Applications of Autotransformer

Practical applications of autotransformers include:

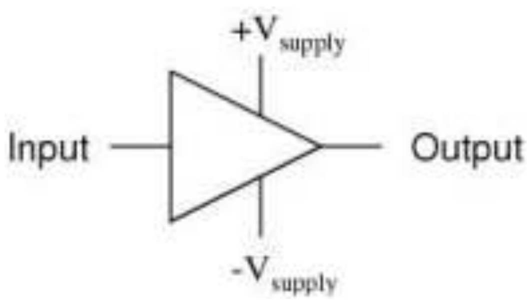
1. They are generally used to connect transmission lines of slightly different voltages (e.g., 115 kV and 138 kV or 138 kV and 161 kV)
2. They are employed to compensate for voltage drops on long feeder circuits where it is important that each load device receives the same voltage (e.g., on airfield lighting circuits to ensure uniform lamp intensity)

3. They offer variable voltage control in the laboratory setup: as we move the sliding contact, virtually all of the coil can become the series coil. Therefore, the entire coil must be sized for maximum current.
4. They are used to adjust the transformer output voltage in order to keep the system voltage constant with varying load.

3.1.3 Magnetic amplifier

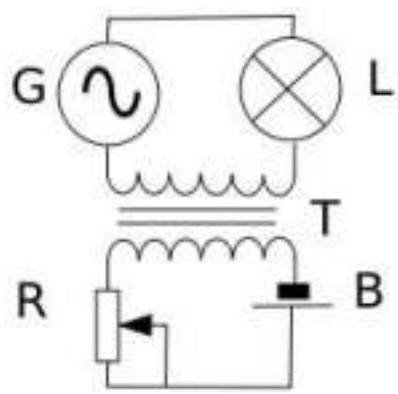
Amplifier

The amplitude of a signal waveform can be increased by using an electronic device called as an Amplifier.



Magnetic Amplifier

The electromagnetic device used for the amplification of electrical signals which utilizes the magnetic saturation of core principle and certain class of transformer's core non linear property is called as Magnetic amplifier. It is invented in early 1885 and is primarily used in theater lighting and it is designed with basic of design Saturable Reactor and hence can be used as saturable reactor in electrical machinery.



In above figure, amplifier consists of two cores with control winding and AC winding. By using small DC current fed to control winding the large amount of AC currents on AC windings can be controlled and it results in current amplification.

Two cores are connected in opposite phase for canceling the high flux generated AC current in control windings. The magnetic amplifier can be used to convert, multiply, phase shifting,

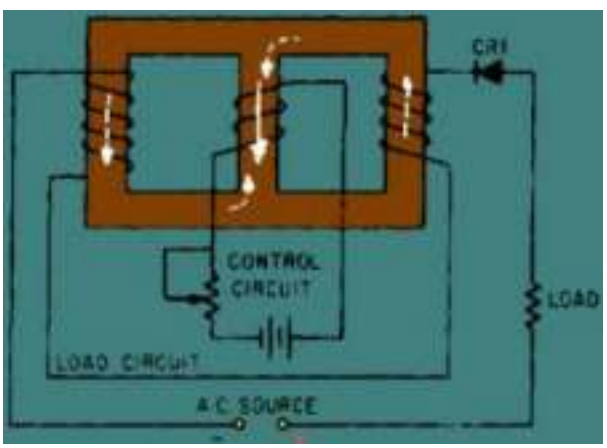
modulate, magnify, invert, pulse generation, etc. It can be simply called as one type of control valve using an inductive element as control switch.
Magnetic amplifiers, also called mag amps for short, provide an electro-magnetic method of amplification. Mag amps were quite common prior to the development of solid state transistors.

- highly reliable
- high isolation voltages
- two identical coils

Principles of Magnetic Amplifier Circuits

These are divided into two types as half wave and full wave magnetic amplifiers.

Half wave Magnetic Amplifier
Whenever DC supply is given to the control winding then the magnetic flux will be generated in the iron core. With the increase in this generated magnetic flux the impedance of the output winding will decreases, then the current flowing from the AC supply through the output winding and load will increases. Here it utilizes only half cycle of the AC supply; hence it is called as a half wave circuit.



At the core saturation point, at which the car is having a maximum flux it can hold, as the flux is maximum the impedance of the output winding will be very low making very high current to flow through the load.

Similarly, if the current through the control winding is zero, then the impedance of the output winding will be very high making no current to flow through the load or output winding.

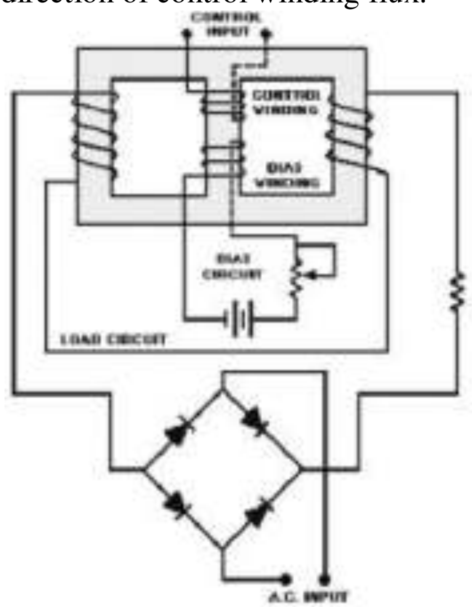
Hence, from above statements we can say that by controlling the current through control winding the impedance of the output winding can be controlled such that we can vary the current through the load continuously.

A diode is connected to the output winding as shown in the above figure which acts as a rectifier, used for reversing the polarity of the AC supply constantly from canceling out control winding flux.

To avoid the cancelation and the direction of current flow through the secondary can be varied to reinforce two fluxes each other created by control winding and the output winding.

Full wave Magnetic Amplifier

It is almost similar to the above half wave amplifier circuit, but it utilizes both half cycles of the AC supply, hence it is termed as a full wave circuit. Due to wound of the two halves of the output winding the direction of magnetic flux created by these two halves in center leg is same as direction of control winding flux.



Even though no, control voltage is supplied there will be some flux present in magnetic core, hence impedance of the output winding will never attain its maximum value and current through load never attain its minimum value. The operation of the amplifier can be controlled by using the bias winding. In case of vacuum tube amplifiers, certain part of its characteristic curve can be operated by the tube.

Many of the magnetic amplifiers will be having an additional control winding which is used to tap the output circuit current and give it as feedback control current. Hence this winding is used for giving feedback.

Applications of Magnetic Amplifier

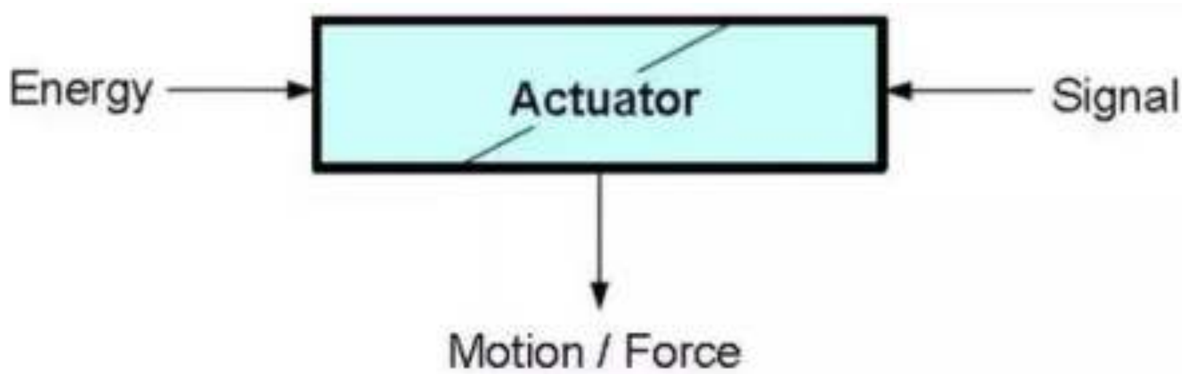
- These are typically used in radio communications for switching the circuits of high frequency alternators.
- It can be used for the speed regulation of Alexanderson alternators.
- Small amplifiers can be used for tuning indicators, controlling the speed of small motors, battery chargers.

- It is used as switching component in power supplies (in Switch Mode Power Supplies)
- Before Hall Effect current transducers, for the detection of wheel slip locomotives uses these amplifiers.
- These are in HVDC for the measurement of the high DC voltages without any direct connection to high voltages.
- Due to the advantage of these amplifiers, controlling high currents by using small currents, these are used for lighting circuits such as stage lighting.
- It can be used in arc welders.
- In mainframe computers during the 1950's it is used as a switching element.
- In 1960's these are typically used in electrical power generation systems.

3.2 Electrical Actuator

Electric actuator may provide the actuation force several ways. Electromechanical actuators may be used to power a motor that converts electrical energy into mechanical torque. Another approach is an electro hydraulic actuator, where the electric motor remains the prime mover, but provides torque to operate a hydraulic accumulator that is then used to transmit actuation force in much the same way that diesel engine/hydraulics are typically used in heavy equipment.

Electrical energy is used to actuate equipment such as multi-turn valves, or electric-powered construction and excavation equipment.



When used to control the flow of fluid through a valve, a brake is typically installed above the motor to prevent the fluid pressure from forcing open the valve. If no brake is installed, the actuator gets activated to reclose the valve, which is slowly forced open again. This sets up an oscillation (open, close, open ...) and the motor and actuator will eventually become damaged.

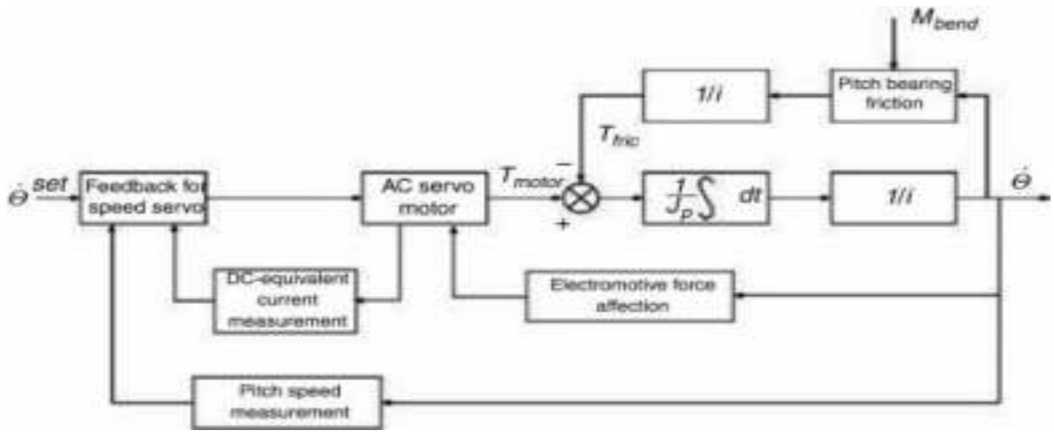
A key advantage of electric actuatorsis the requirement for multiple positions in an application. Other advantages are: higher axial force; high accuracy; low noise; flexibility through control characteristics; load stiffness and overall lower operating costs.

Based on functions and movement, mechanism actuators can be classified as follows:
Multi-turn actuator: Used for gate valves and damper applications.
Part turn actuators: Used for butterfly and ball valves and damper application. The torque delivery may be part revolution, e.g., 90°.

Linear actuators: These are mainly used for globe valves; however, because of low cost and simplicity of the pneumatic actuator, they enjoy an edge over their electrical counterpart.

Types of electric actuator

Electric actuators are available rod-style, or rodless, with or without motors and drives. Motors can be mounted axially behind the actuator body, or parallel to the actuator in four positions.



Typical applications of electric actuators

Electric actuators are found in a wide variety of industrial applications.

In the automotive industry for driverless transport vehicles, dispensing and a selection of jointing methods – gluing, welding and riveting.

In the food and beverage industry, for production of PET bottles, filling and labelling systems and robotic applications such as milking robots.

They are used in materials handling for operations such as servo presses and clamping and widely used in the packaging sector.

Their benefits in accuracy, flexibility and low operating costs lead to use in robotics, electronics and electronic assembly, machine tools and many other industrial sectors.

3.3 Pneumatic control elements: pneumatic pressure supply, pneumatic actuator, pneumatic relays, Flapper Nozzle system as a control element.

3.3.2 Pneumatic actuator

Actuator :

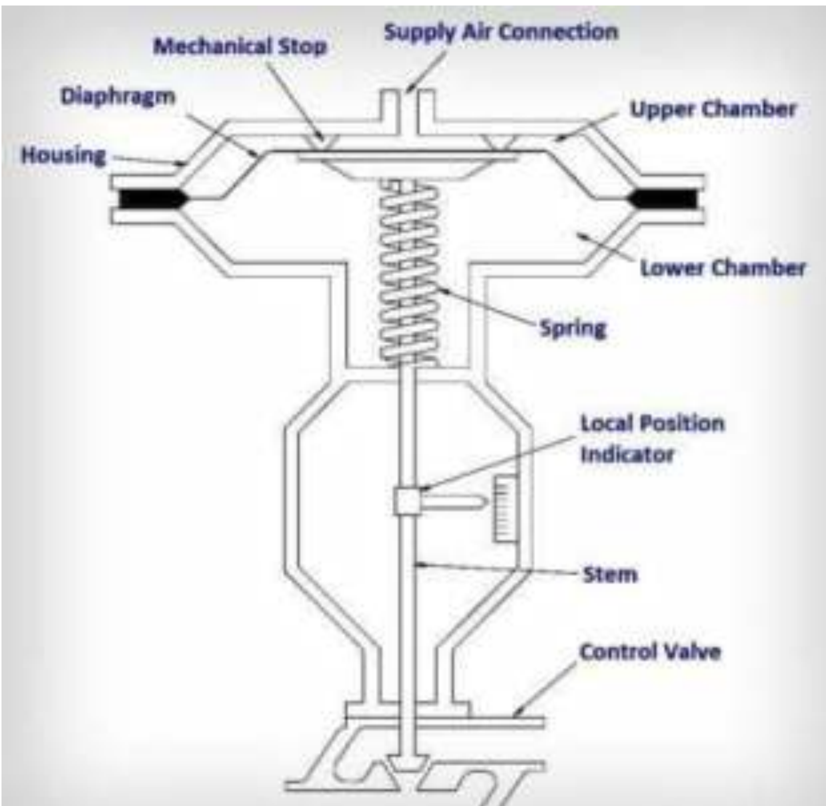
By themselves, valves cannot control a process. Manual valves require an operator to position them to control a process variable. Valves that must be operated remotely and automatically require special devices to move them. These devices are called actuators.

Actuators may be pneumatic, hydraulic, or electric solenoids or motors.

Pneumatic Actuators :

A simplified diagram of a pneumatic actuator is shown in Figure 1. It operates by a combination of force created by air and spring force. The actuator positions a control valve by transmitting its motion through the stem.

A rubber diaphragm separates the actuator housing into two air chambers. The upper chamber receives supply air through an opening in the top of the housing.



igure 1 : Pneumatic Actuator: Air-to-Close/Spring-to-Open

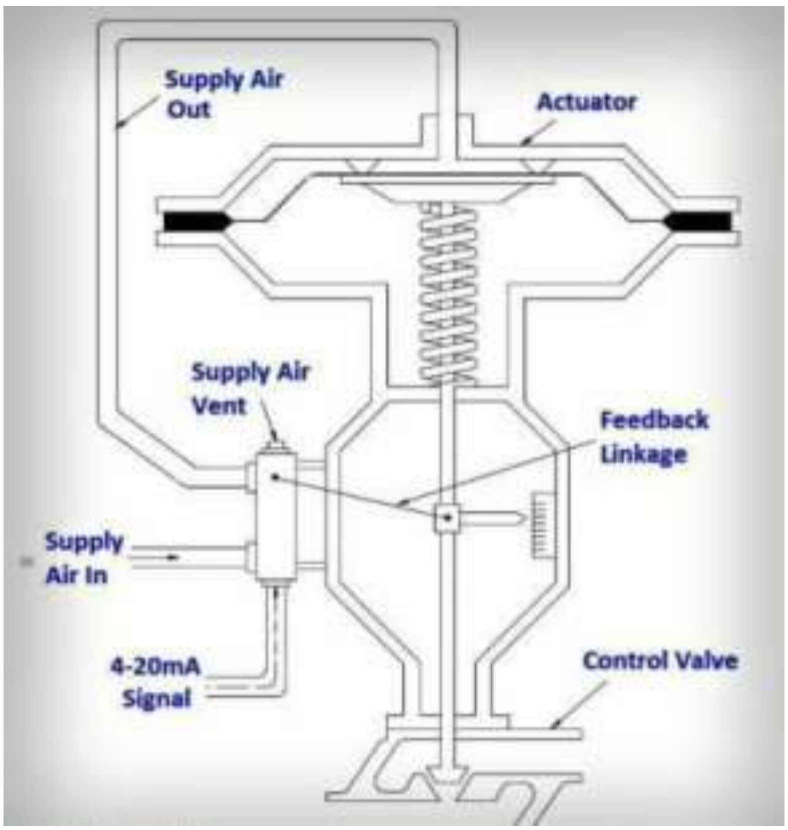
The bottom chamber contains a spring that forces the diaphragm against mechanical stops in the upper chamber. Finally, a local indicator is connected to the stem to indicate the position of the valve.

The position of the valve is controlled by varying supply air pressure in the upper chamber. This results in a varying force on the top of the diaphragm. Initially, with no supply air, the spring forces the diaphragm upward against the mechanical stops and holds the valve fully open.

As supply air pressure is increased from zero, its force on top of the diaphragm begins to overcome the opposing force of the spring. This causes the diaphragm to move downward and the control valve to close. With increasing supply air pressure, the diaphragm will continue to move downward and compress the spring until the control valve is fully closed.

Conversely, if supply air pressure is decreased, the spring will begin to force the diaphragm upward and open the control valve. Additionally, if supply pressure is held constant at some value between zero and maximum, the valve will position at an intermediate position. Therefore, the valve can be positioned anywhere between fully open and fully closed in response to changes in supply air pressure.

A **positioner** is a device that regulates the supply air pressure to a pneumatic actuator. It does this by comparing the actuator's demanded position with the control valve's actual position.
The demanded position is transmitted by a pneumatic or electrical control signal from a controller to the positioner. The pneumatic actuator in Figure 1 is shown in Figure 2 with a controller and positioner added.



The controller generates an output signal that represents the demanded position. This signal is sent to the positioner. Externally, the positioner consists of an input connection for the control signal (4-20mA), a instrument supply air input connection, a supply air output connection, a supply air vent connection, and a feedback linkage.

Internally, it contains an intricate network of electrical transducers, air lines, valves, linkages, and necessary adjustments. Other positioners may also provide controls for local valve positioning and gauges to indicate supply air pressure and control air pressure (for pneumatic controllers – old controlling methods).

Advantages of Pneumatic Actuators

The benefits of pneumatic actuators come from their simplicity.

Pneumatic actuators' typical applications involve areas where the conditions involve extreme temperatures, a typical temperature range is -40°F to 250°F.

In terms of safety and inspection, using air and pneumatic actuators avoids using hazardous materials. They also meet explosion protection and machine safety requirements because they create no magnetic interference due to the lack of motors.
Pneumatic actuators are also lightweight, require minimal maintenance, and have durable components that make pneumatics a cost effective method of power.

Disadvantages of Pneumatic Actuators

Pressure losses and compressibility of air make pneumatics less efficient than other methods. Compressor and air delivery limitations mean that operations at lower pressures will have lower forces and slower speeds.

To be truly efficient, pneumatic actuators must be sized for a specific job. Hence, they cannot be used for other applications.

Even though air is readily 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, along with the compressor and line maintenance costs.

Applications of Pneumatic Systems

Some of the important applications of the pneumatic systems as follow:

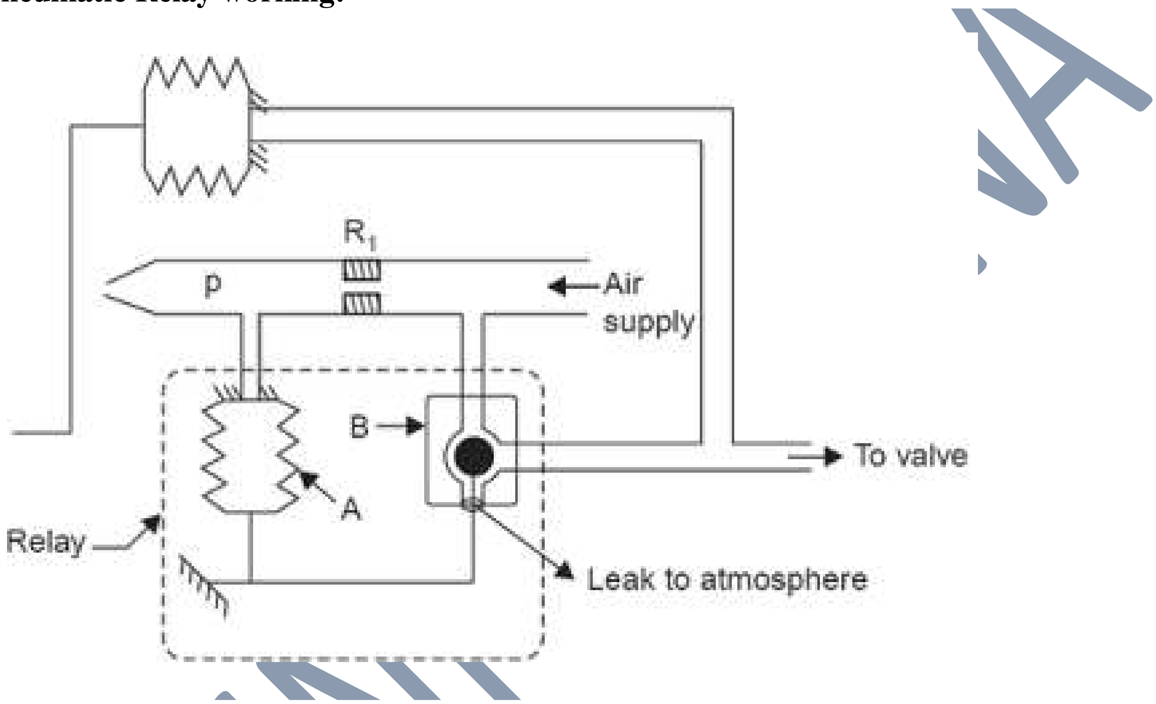
1. Using for packing.
2. Using for filling.
3. In drilling, hoisting, punching, clamping, assembling, riveting.
4. Opening and closing the doors.
5. Used in industrial robots.
6. For power hammers and nut runners.
7. Used in riveting hammers.
8. Using for breaking system in automobiles, railway coaches, wagons and printing presses.
9. Used in metal forming processes.
10. Used in material handling types of equipment and logic controlling operations.

3.3.3 Pneumatic relay

The relay is automatic switching device which can set ON/OFF large signal lines using comparatively small signals.

A pneumatic relay works in 3-15psi pneumatic signal which can control much higher signal that can control large devices large than 15 psi pressure.

Pneumatic Relay working:



A power amplifier is needed to act on a large control valve. A pneumatic relay is a power amplifier. The relay is composed of small volume A bellows and a specially designed valve. In the nozzle pressure is transmitted to bellows A and, as the pressure increases, the bellows expand the ball down the valve B cavity, decreasing the leakage to the atmosphere and increasing the pressure Pv.

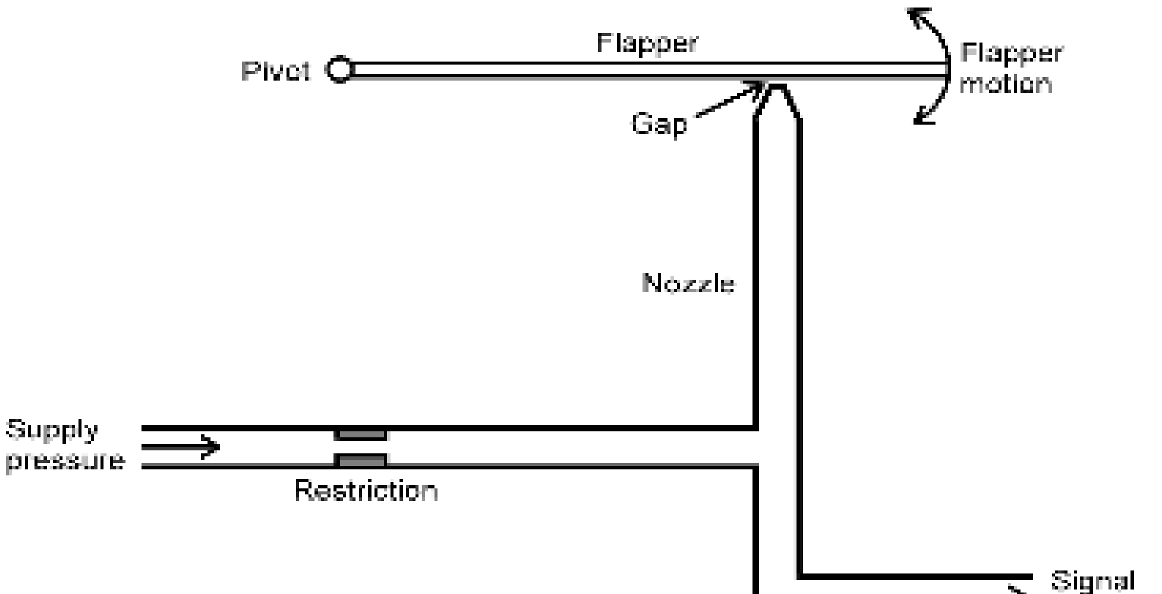
The relay is made in such a way that the output pressure Pv is proportional to the signal pressure p. The airflow of the relay will be much greater than the flow rate through the nozzle, since the resistance to the air supply may be too small compared to the resistance Rr in the nozzle. A relay valve can be designed as direct acting, in which case the outlet pressure is directly proportional to the inlet pressure, or it can be reverse acting, in which case the outlet pressure is inversely proportional to the inlet pressure.

3.3.4 Flapper Nozzle

A very important signal conversion is from pressure to mechanical motion and vice versa. This conversion can be provided by a **flapper nozzle system** (sometimes called as baffle/nozzle system).

Flapper Nozzle System

A diagram of this device is shown in Fig.I below.



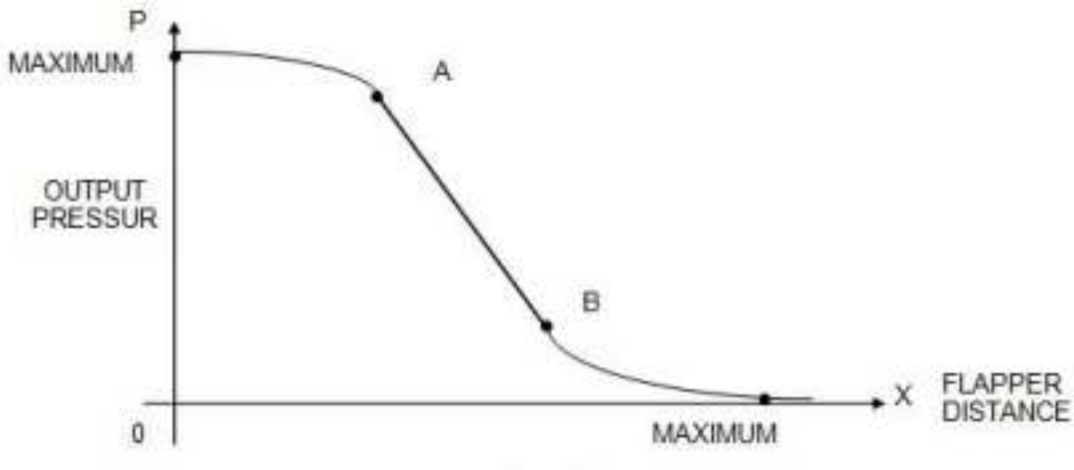
A regulated supply of pressure, usually 20 psig, provides a source of air through the restriction. The nozzle is open at the end where the gap exists between the nozzle and flapper, and air escapes in this region.

If the flapper moves down and closes off the nozzle opening so that no air leaks, the signal pressure will rise to the supply pressure.

As the flapper moves away, the signal pressure will drop because of leaking of the leaking air. Finally, when the flapper is far away, the pressure will stabilize at some value determined by the maximum leak through the nozzle.

Principle of Operation:

The air supply input (20 psi (1.4 bar)) passes through a restrictor (small hole). It then goes out of the nozzle or down the air signal output line. If the flapper is placed against the nozzle, no air can escape through it. So, the air signal output shows full pressure. If the flapper is pulled away from the nozzle, most of the air flows out of the nozzle, so the air signal output pressure is very small. The back pressure output signal depends on how near the flapper is to the nozzle. A simple graph of the output pressure (P) against flapper distance (X) is shown below.



Applications of Flow Nozzle

1. It is used to measure flow rates of the liquid discharged into the atmosphere.
2. It is usually used in situation where suspended solids have the property of settling.
3. Is widely used for high pressure and temperature steam flows.

Advantages of flow Nozzle

1. Installation is easy and is cheaper when compared to venturi meter
2. It is very compact
3. Has high coefficient of discharge.

Disadvantages of flow Nozzle

1. Pressure recovery is low
2. Maintenance is high
3. Installation is difficult when compared to orifice flow meter.

Hydraulic Actuator

Pneumatic actuators are normally used to control processes requiring quick and accurate response, as they do not require a large amount of motive force.

However, when a large amount of force is required to operate a valve (for example, the main stream system valves), hydraulic actuators are normally used.

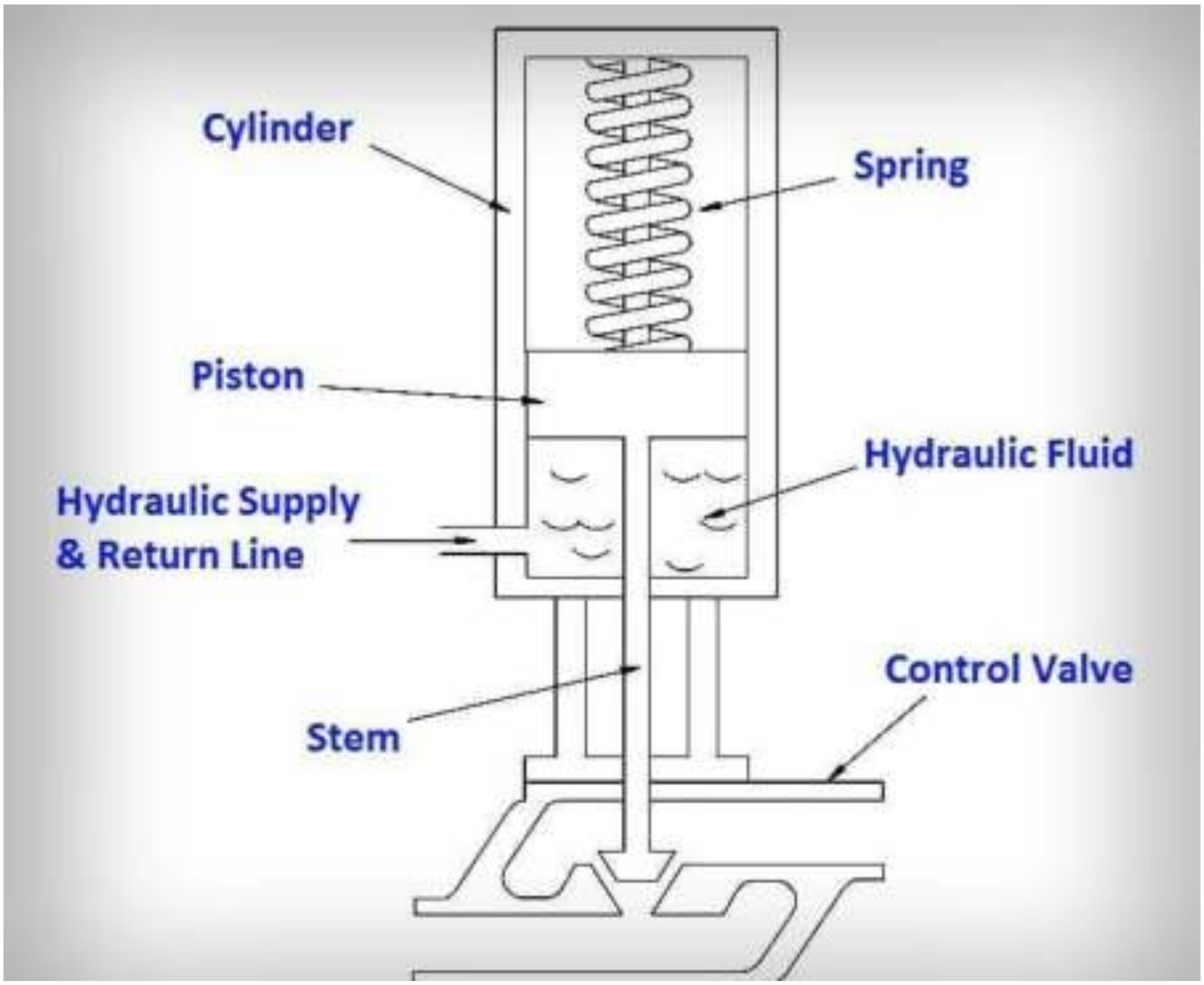
Although hydraulic actuators come in many designs, piston types are most common.

A typical piston-type hydraulic actuator is shown in Below Figure. It consists of a cylinder, piston, spring, hydraulic supply and return line, and stem.

The piston slides vertically inside the cylinder and separates the cylinder into two chambers. The upper chamber contains the spring and the lower chamber contains hydraulic oil.

3.4 Hydraulic control elements

3.4.1 Hydraulic Actuator



The hydraulic supply and return line is connected to the lower chamber and allows hydraulic fluid to flow to and from the lower chamber of the actuator. The stem transmits the motion of the piston to a valve.
Initially, with no hydraulic fluid pressure, the spring force holds the valve in the closed position. As fluid enters the lower chamber, pressure in the chamber increases.

This pressure results in a force on the bottom of the piston opposite to the force caused by the spring. When the hydraulic force is greater than the spring force, the piston begins to move upward, the spring compresses, and the valve begins to open.

As the hydraulic pressure increases, the valve continues to open. Conversely, as hydraulic oil is drained from the cylinder, the hydraulic force becomes less than the spring force, the piston moves downward, and the valve closes. By regulating amount of oil supplied or drained from the actuator, the valve can be positioned between fully open and fully closed.

The principles of operation of a hydraulic actuator are like those of the pneumatic actuator. Each uses some motive force to overcome spring force to move the valve. Also, hydraulic actuators can be designed to fail-open or fail-closed to provide a fail-safe feature.

Advantages of Hydraulic Actuators

1. 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.
2. A hydraulic actuator can hold force and torque constant without the pump supplying more fluid or pressure due to the incompressibility of fluids.
3. Hydraulic actuators can have their pumps and motors located a considerable distance away with minimal loss of power.

Disadvantages of Hydraulic Actuators

Hydraulics will leak fluid. Like pneumatic actuators, loss of fluid leads to less efficiency and cleanliness problems resulting in potential damage to surrounding components and areas.

Hydraulic actuators require many complementary parts, including a fluid reservoir, motor, pump, release valves, and heat exchangers, along with noise reduction equipment.

3.6 Comparison between Pneumatic and Hydraulic control systems

THE DIFFERENCE BETWEEN HYDRAULIC AND PNEUMATICS

HYDRAULIC	PNEUMATIC
Hydraulics uses liquids like water or oil	Pneumatics uses compressed gas like air
Liquids are incompressible, high specific mass and have a free surface.	Gases are readily compressible, have a very low specific mass and do not have free surface.
Hydraulic systems are used for high force and where stiffness in position is necessary. They move relatively slowly but can handle higher loads.	Pneumatic systems are used for relatively lower forces, faster motion, and where stiffness isn't required.
The installation is complex and maintenance cost is high.	Installation of this system is less complicated and have less maintenance cost
The tank is used to store oil from which the system can draw oil in case of deficit.	In a pneumatic, the system can just draw air from the atmosphere and just a filter would be required to purify it.
Liquids are not very compressible, there is no delay in the movement.	Because gases can be compressed. there is a delay in the movement, the force
EX. Vehicle Breaks, Jacks, Forklift, Crans, Jaws of lift, Hydraulic lift etc.	EX. Pneumatic air breaks, Nailgun, Cylinders, Actuators, Jackhammer, Air gun etc.

B.K.N GOVT POLYTECHNIC NARNAUL

DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: 5.4 PROCESS CONTROL

NAME OF FACULTY: Mrs. RAJNI

SEMESTER-5th

UNIT-4 Control Valves

Principle of operation, constructional details and applications of

4.1 Diaphragm operated valve

Diaphragm valves (or membrane valves) consists of a valve body with two or more ports, an elastomeric diaphragm, and a "weir or saddle" or seat upon which the diaphragm closes the valve. The valve body may be constructed from plastic, metal, wood or other materials depending on the intended use.

There are two main categories of diaphragm valves:

- One type seals over a "weir" (saddle)
- The other (sometimes called a "full bore or straight-through" valve) seals over a seat

In general, straight-through diaphragm valves are used in on-off applications and weir-type diaphragm valves are used for control or throttling applications. While diaphragm valves usually come in two-port forms (2/2-way diaphragm valve), they can also come with three ports (3/2-way diaphragm valves also called T-valves) and more (so called block-valves). When more than three ports are included, they generally require more than one diaphragm seat; however, special dual actuators can handle more ports with one membrane.

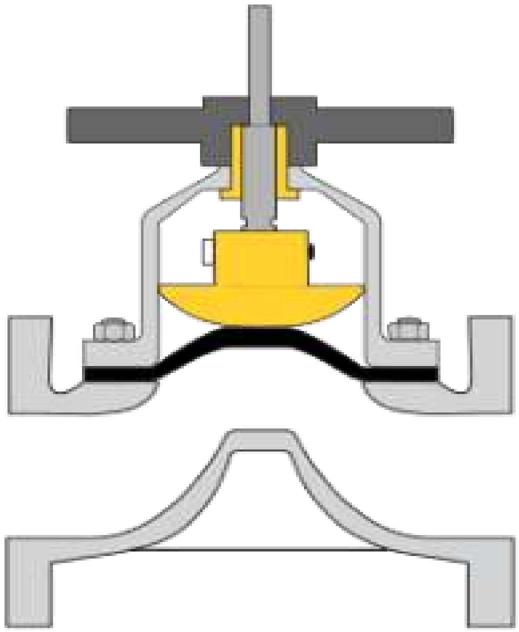


Figure Diaphragm Valve

For high purity applications, the design of the basic weir-style diaphragm valve seal presents a number of issues for process engineers working in the biotechnology and pharmaceutical industry. In typical configurations, a weir in the valve body rises in a fluid path and when the valve is closed, the diaphragm meets the weir to shut off the flow. While the technology is intended to reduce turbulence and shear, weir-style valves present a number of issues, for example in upstream processing applications they can be difficult to install, prone to leaks, and increase the potential of product contamination.

Diaphragm valves can be manual or automated. Automated diaphragm valves may use pneumatic, hydraulic or electric actuators along with accessories such as solenoid valves, limit switches and positioners.

In addition to the well known, two way shut off or throttling diaphragm valve, other types include: Three way zero deadleg valve, sterile access port, block and bleed, valbow and tank bottom valve.

4.2 Globe valve

A globe valve is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body. The valve can have a stem or a cage, similar to ball valves, that moves the plug into and out of the globe. The fluid's flow characteristics can be controlled by the design of the plug being used in the valve. A seal is used to stop leakage through the valve. Globe valves are designed to be easily maintained. They usually have a top that can be easily removed, exposing the plug and seal. Globe valves are good for on, off, and accurate throttling purposes but especially for situations when noise and caviatation are factors. A common example would be the valves that control the hot and cold water for a kitchen or bathroom sink.

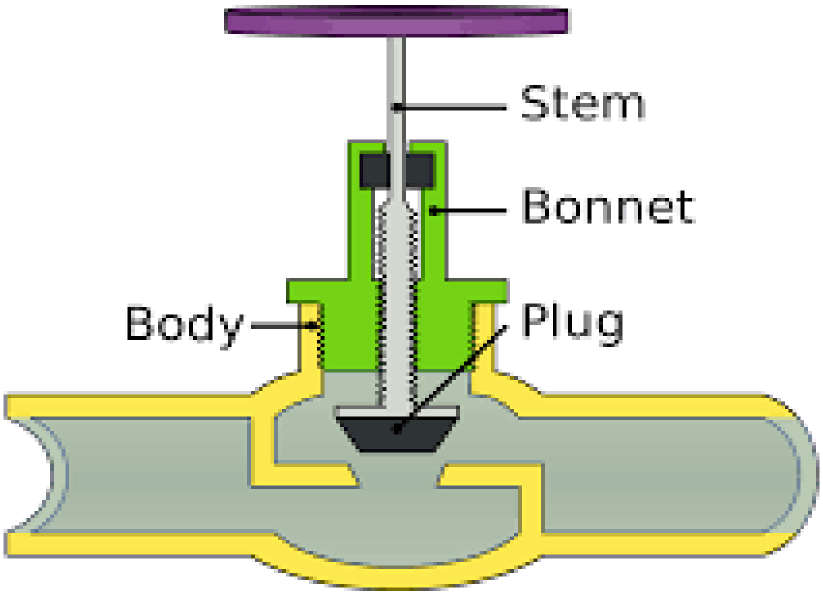
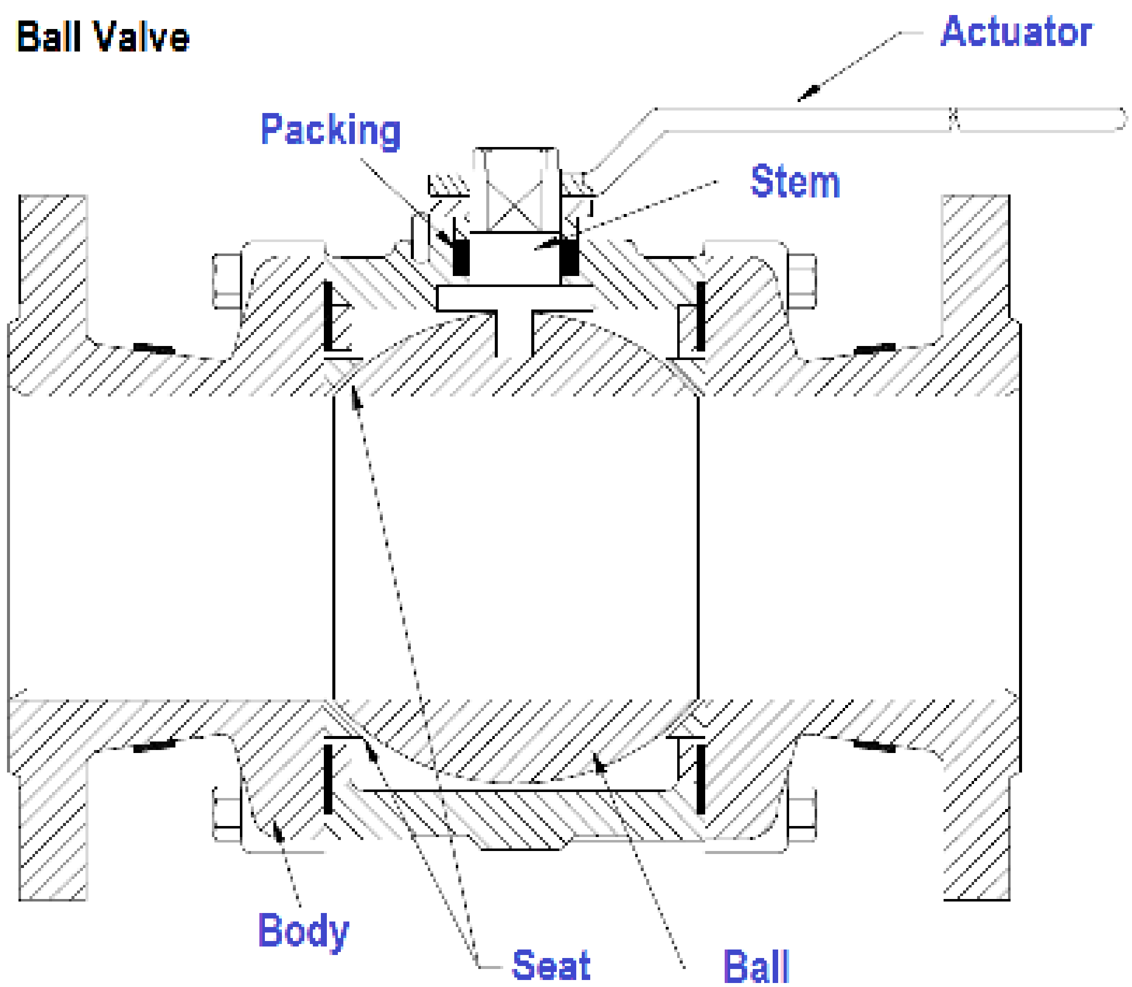


Diagram – Globe valve

4.3 Ball valve

A ball valve is a valve with a spherical disc, the part of the valve which controls the flow through it. The sphere has a hole, or port, through the middle so that when the port is in line with both ends of the valve, flow will occur. When the valve is closed, the hole is perpendicular to the ends of the valve, and flow is blocked. There are four types of ball valves.

1. A **full port ball valve** has an over sized ball so that the hole in the ball is the same size as the pipeline resulting in lower friction loss. Flow is unrestricted, but the valve is larger. This is not required for general industrial applications as all types of valves used in industry like gate valves, plug valves, butterfly valves, etc have restrictions across the flow and does not permit full flow. This leads to excessive costs for full bore ball valves and is generally an unnecessary cost.
2. In **reduced port ball valves**, flow through the valve is one pipe size smaller than the valve's pipe size resulting in flow area becoming lesser than pipe. But the flow discharge remains constant as it is a multiplier factor of flow discharge (Q) is equal to area of flow (A) into velocity (V). A1V1 = A2V2; the velocity increases with reduced area of flow and decreases with increased area of flow.
3. A **V port ball valve** has either a 'v' shaped ball or a 'v' shaped seat. This allows the orifice to be opened and closed in a more controlled manner with a closer to linear flow characteristic. When the valve is in the closed position and opening is commenced the small end of the 'v' is opened first allowing stable flow control during this stage. This type of design requires a generally more robust construction due to higher velocities of the fluids, which would quickly damage a standard valve.
4. A **trunnion ball valve** has a mechanical means of anchoring the ball at the top and the bottom, this design is usually applied on larger and higher pressure valves (say, above 10 cm and 40 bars).



Ball valves are good for on/off situations. A common use for a ball valve is the emergency shut off for a sink.

4.4 Butterfly valves

Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation. The characteristics of the flow can be controlled by changing the design of the disk being used. For example, there are designs that can be used in order to reduce the noise caused by a fluid as it flows through. Butterfly valves are good for situations with straight flow and where a small pressure drop is desired. There are also high performance butterfly valves. They have the added benefit of reduced torque issues, tight shutoff, and excellent throttling. It is necessary to consider the torque that will act on the valve. It will have water moving on both sides and when being used to throttle the flow through the valve it becomes a big factor. These valves are good in situations with high desired pressure drops. They are desirable due to their small size, which makes them a low cost control instrument. Some kind of seal is necessary in order for the valve to provide a leak free seal. A common example would be the air intake on older model automobiles.

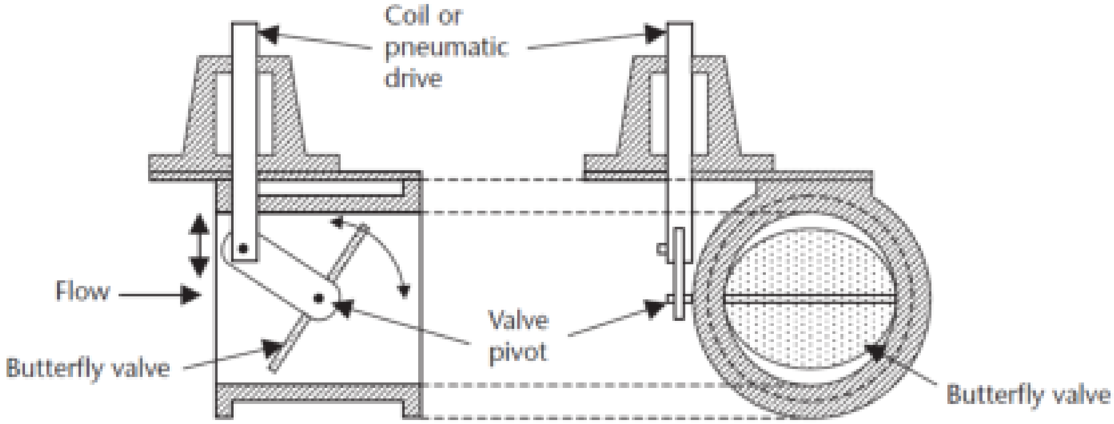
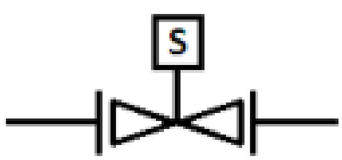


Figure Butterfly valves

4.5 Solenoid Valves

Another electrically operated device that is commonly encountered in process control is the solenoid valve. The solenoid valve is a combination of two basic functional units: an electromagnetic solenoid with its core and a valve body that contains one or more orifices. The flow through an orifice can be allowed or prevented by the action of the core when the solenoid is energized or deenergized, respectively. Solenoid valves normally have a solenoid that is mounted directly on the valve body. The core is enclosed and free to move in a sealed tube called a core tube, which thus gives it a compact assembly. The two different electrical schematic symbols that are used to represent solenoid valves on electrical and control drawings are given in Figure (a) and (b)



Solenoid Valve Symbol

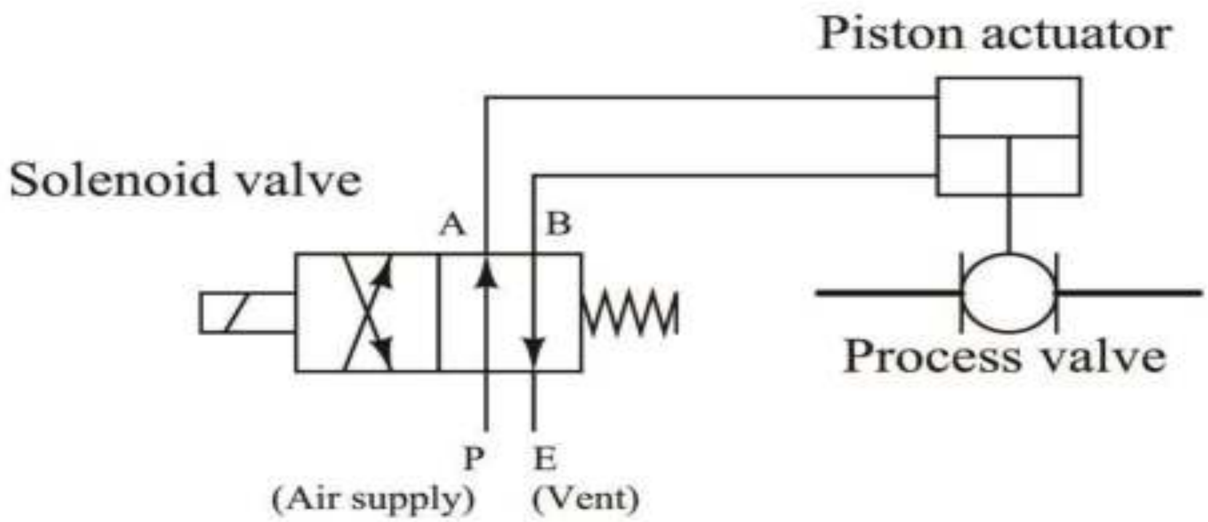


Figure (b) – Solenoid Valve

The three most common types of solenoid valves are direct acting, internal pilot operated, and manual reset. In direct-acting valves, the solenoid core directly opens or closes the orifice, depending on whether the solenoid is energized or de- energized, respectively. The valve will operate from 0 psi inlet pressure to its maximum rated inlet pressure. The force that is required to open a solenoid valve is proportional to the orifice size and the pressure drop across the valve. As the orifice size increases, the force needed to operate the valve increases. To keep the solenoid coil small and open large orifices at the same time, some plants use internal pilot-operated solenoid valves. Internal pilot-operated solenoid valves have a pilot and bleed orifice and use the line pressure to operate. When the solenoid is energized, the core opens the outlet side of the valve. The imbalance of pressure causes the line pressure to lift the piston or diaphragm off the main valve orifice, thus opening the valve. When the solenoid is deenergized, the pilot orifice is closed, and to close the valve the full line pressure is applied to the top of the piston or diaphragm through the bleed orifice. In some applications, a small manual valve replaces the bleed orifice so the plant personnel can control the speed that is required to open and close the valve. The manual reset type of solenoid valve must be manually positioned (latched). It will return to its original position when the solenoid is energized or deenergized, depending on the valve design. Three configurations of solenoid valves are normally available for process control applications: two, three, and four way. Figure shows the process diagram symbols that are used to represent two-, three-, and four-way solenoid valves. Two-way valves have one inlet and one outlet process. They are available in either normally open or normally closed configurations. Three-way solenoid valves have three process piping connections and two orifices (one orifice is always open and the other is always closed). These valves are normally used in process control to alternately apply air pressure to and exhaust air from diaphragm-operated control valves or single-acting cylinders. Four-way solenoid valves have four pipe connections: one for supplying air pressure, two for process control, and one for air exhaust. These valves are normally used to control double-acting actuators on control valves.

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DEPARTMENT- INSTRUMENTATION AND CONTROL ENGINEERING

SUBJECT: 5.4 PROCESS CONTROL

NAME OF FACULTY: Mrs. RAJNI

SEMESTER-5th

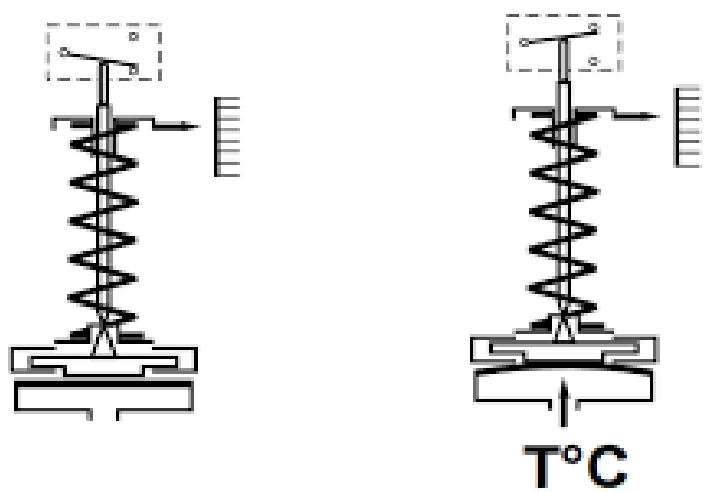
UNIT-5 Switches

5.1 Temperature switches

Temperature switches are used in a variety of industrial and technical processes. If a preset temperature is reached, then the temperature switch opens or closes a corresponding switch contact. Depending on the requirements, mechanical or electronic switches can be used.

Temperature Switch has a vapour filled flexible sensing element actuates a micro switch by means of a piston when temperature reaches the set point. The set point is adjusted by means of a compressible spring or a adjustable screw installed in the switch.

Basics of Temperature Switch



The temperature switch consists of a pressure switch that has a sealed temperature sensing bulb attached directly to the pressure port. (An optional remote temperature sensing bulb can be connected to the pressure port with an armor-clad capillary.) The temperature sensing system is partially filled with a fluid.

Process temperature changes cause proportional vapor pressure changes in
the temperature sensing bulb that act on the diaphragm/piston assembly to actuate and de-actuate a snap-action electrical switching element at discrete process temperatures. The change in electrical contact indicates the required temperature value.

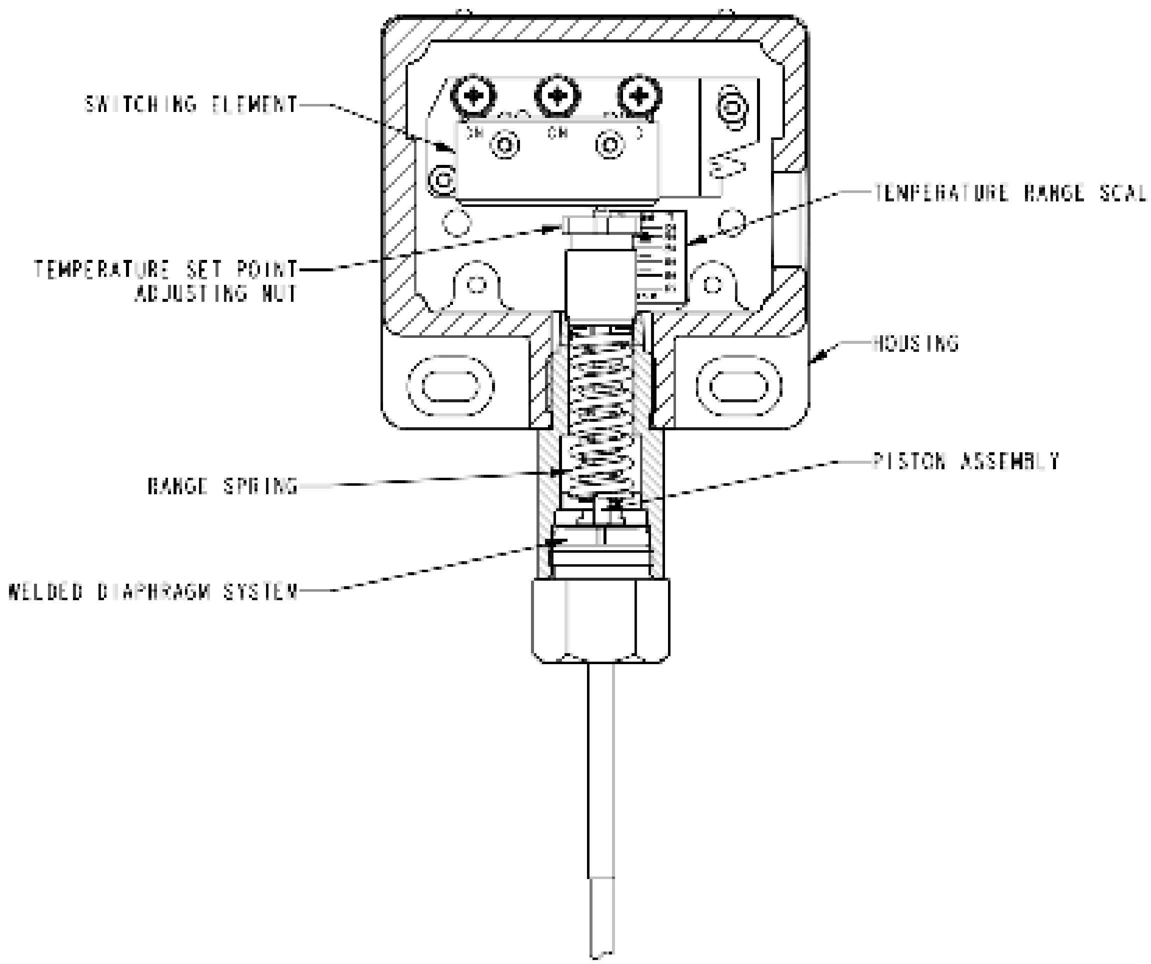


Diagram- Temperature switch

Temperature switch symbols

Normally-open (NO)

Normally-closed (NC)

Temperature Switch

A bi-stable electromechanical device that actuates/ deactuates one or more electrical switching element(s) at a predetermined discrete temperature (set point) upon rising or falling temperature.

Adjustable Range

The span of temperature between upper and lower limits within which the temperature switch can be adjusted to actuate/deactuate. It is expressed for increasing temperature

Set Point

That discrete temperature at which the temperature switch is adjusted to actuate/deactuate on rising or falling temperature. It must fall within the adjustable range and be called out as increasing or decreasing temperature.

Dead Band

The difference in temperature between the increasing set point and decreasing set point. It is expressed as "typical," which is an average with the increasing set point at mid-adjustable range with the standard K switch element. It is normally fixed (not adjustable).

Hermetically Sealed

A welded steel capsule with glass-to-metal, factory sealed electrical leads that isolates the electrical switching element(s) from the environment.

Over-range

Over-range temperature is that temperature to which the sensing bulb can be continuously exposed without causing permanent change of set point or distortion sufficient to cause leakage or significant degradation of the fill fluid. Temperatures greater than over-range could cause permanent damage and render the device inoperative.

Maximum Process Pressure

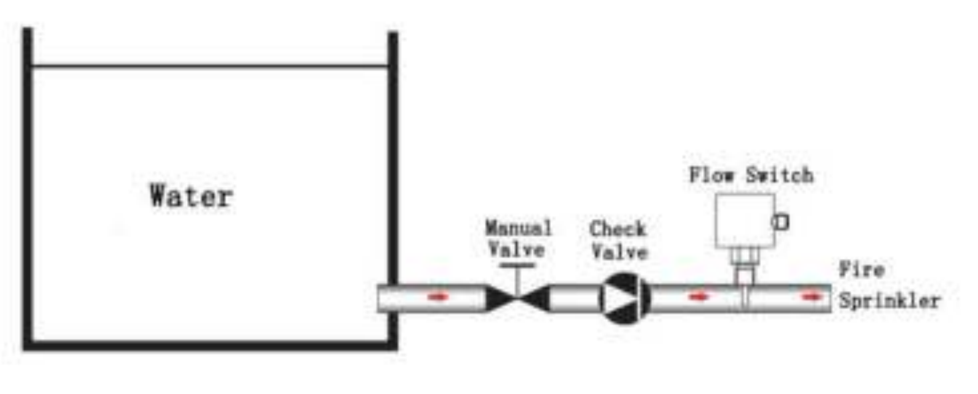
The maximum process pressure to which the temperature sensing bulb should be exposed without being protected by a thermo well.

Repeatability

The ability of a temperature switch to successively operate at a set point that is approached from a starting point in the same direction and returns to the starting point over consecutive cycles to establish a temperature profile. The closeness of the measured set point values is normally expressed as percentage of full scale (maximum adjustable range temperature.)

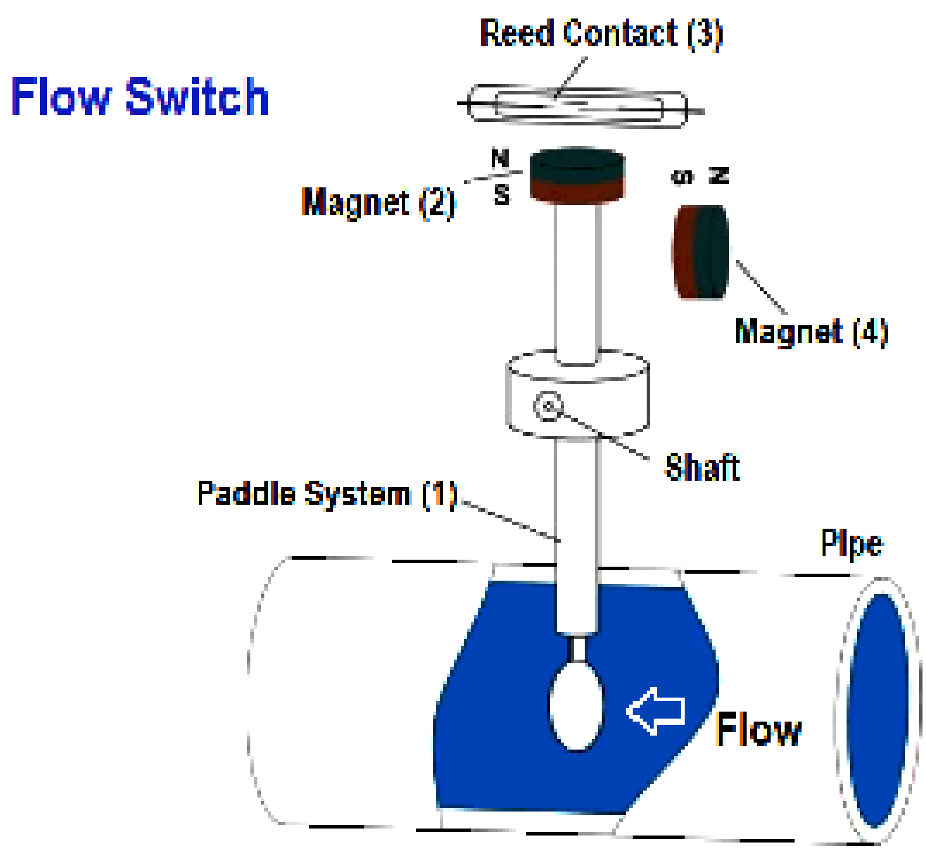
5.2 Flow switches

Flow means the physical movement (velocity) of liquid, gas or steam in a pipe that causes a switch to actuate. No-flow means a decrease in velocity or, sometimes, completes stoppage, allowing the switch to revert to the original position.



Flow Switch is a mechanical switch that is switched on or off in response to the flow or non-flow of a fluid such as air or water. The switch typically operates through the use of a paddle which gets displaced due to the force of fluid moving past it. Flow switch is a special electric device with a very simple design and of a small size. But despite of its simplicity, flow switch plays important role in the variety of different applications.

These electric devices are used with the purpose to protect a pump and when the flow of air, gas or liquid through the specific line is needed to be monitored. Also the alarms can be triggered with the help of them when it is necessary. Switches may be specific to a type of system. For example, a water line will need the switch specifically for liquids as some manufacturers indicating water and liquids on their technical specifications.



Applications

These switches find application in the detection of fluid flow and measurement of fan speeds. A flow switch might be used to protect a central heating system electric heating element from being energized before the air flow from the blower is established. Flow switches might also be used to alarm if a ventilation fan in a hazardous location fails and air flow has stopped.

- Pump protection
- Safety spray nozzle monitoring
- Cooling water or heat exchangers
- Oil well system testing
- Drain line flow
- Relief valve monitoring

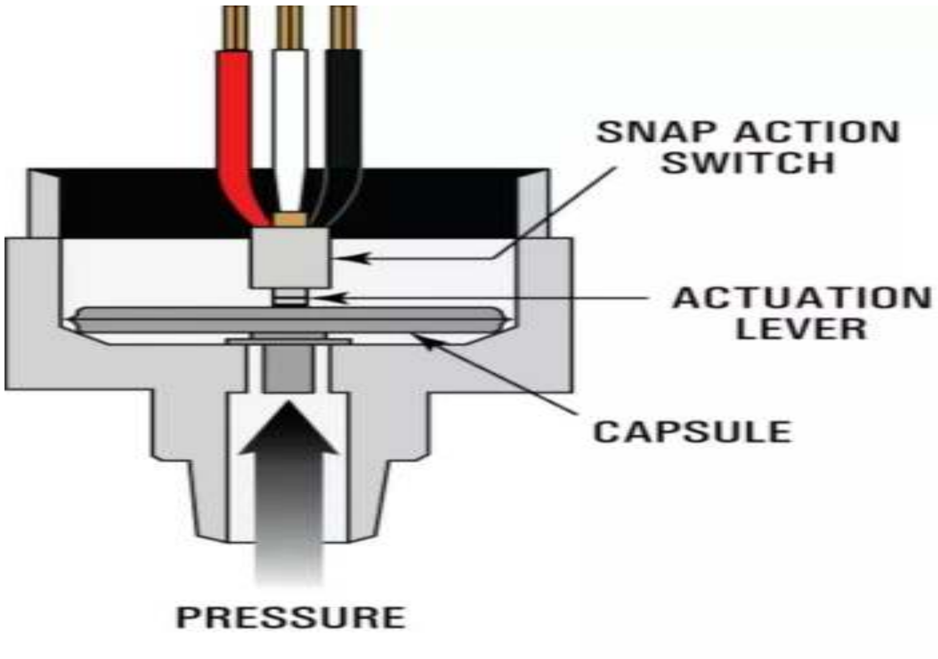
5.3 Pressure switches

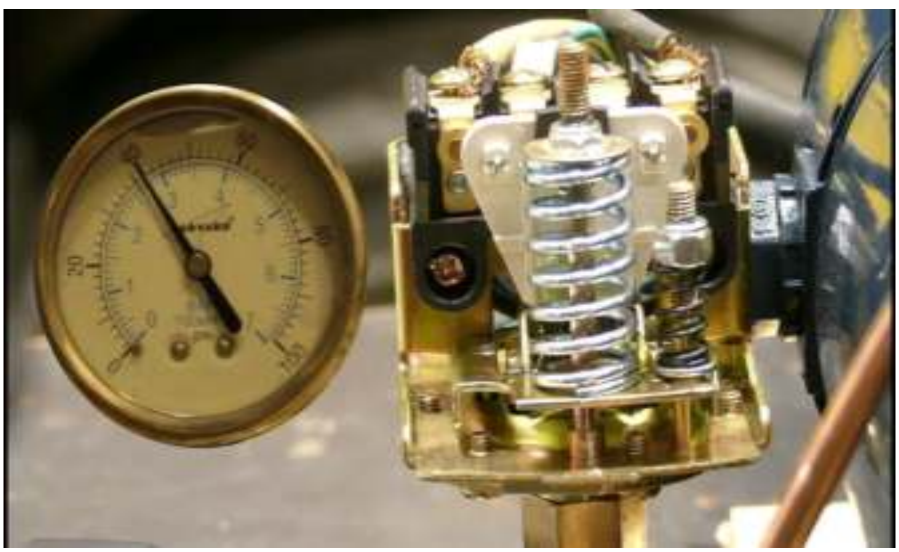
Pressure switches are used to make or break (open or close) electrical circuits at selected pressures to operate solenoid-operated valves or other devices used in the system.

A pressure switch is used to detect the presence of fluid pressure. Most pressure switches of a diaphragm or bellows as a detection element. The movement of this sensor element is used to activate one or more switch contacts to indicate an alarm or to indicate or initiate a control alarm.

Operating principle of Pressure switches:

The operating principle of a pressure switch is shown below





This design contains two separate electrical switches. Each one is operated by a push rod that bears against a piston whose position is controlled by hydraulic and spring forces. The pressure at which the switches operate is selected by turning the adjusting screw to increase or decrease the spring force.

It should be noted that in this design the switches are actuated by the springs when the unit is assembled. Thus the normally open contacts are closed and vice versa. When the preset pressure is reached the plunger will compress the spring and allow the push rods to move down causing the snap action switches to revert to their normal condition. By using both switches in conjunction with an electrical relay, system pressures may be maintained within widely variable high and low ranges.

Uses of pressure switches

- Uses in limiting pressure
- It is used to operate as a safety valve, which vents out pressure when the pressure exceeds the upper limit
- Pressure switches are used in: Boilers, Gas compressor, Automobiles, pumps, steam turbine, Steam power plant.

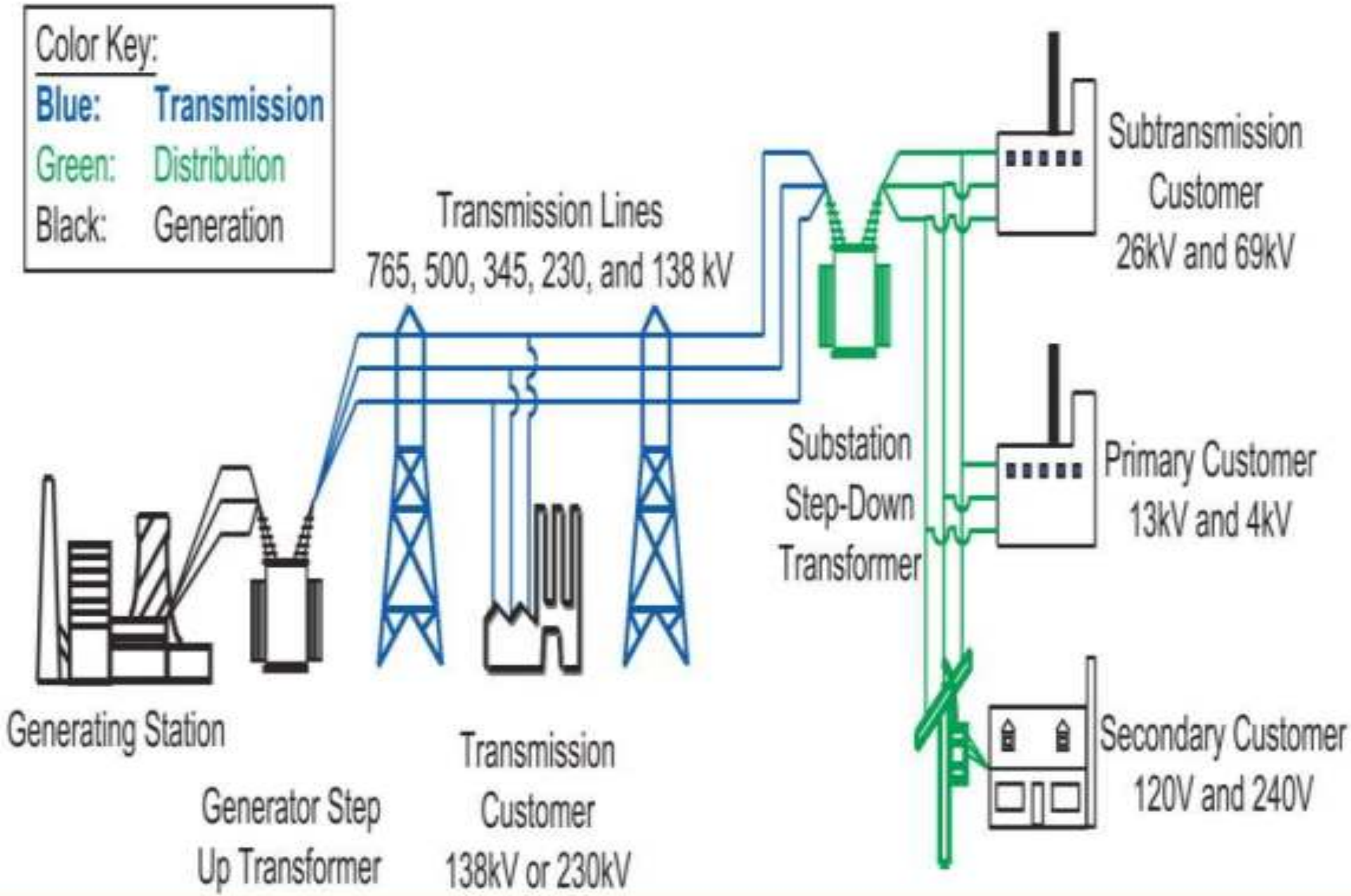
INTRODUCTION

POWER ELECTRONICS

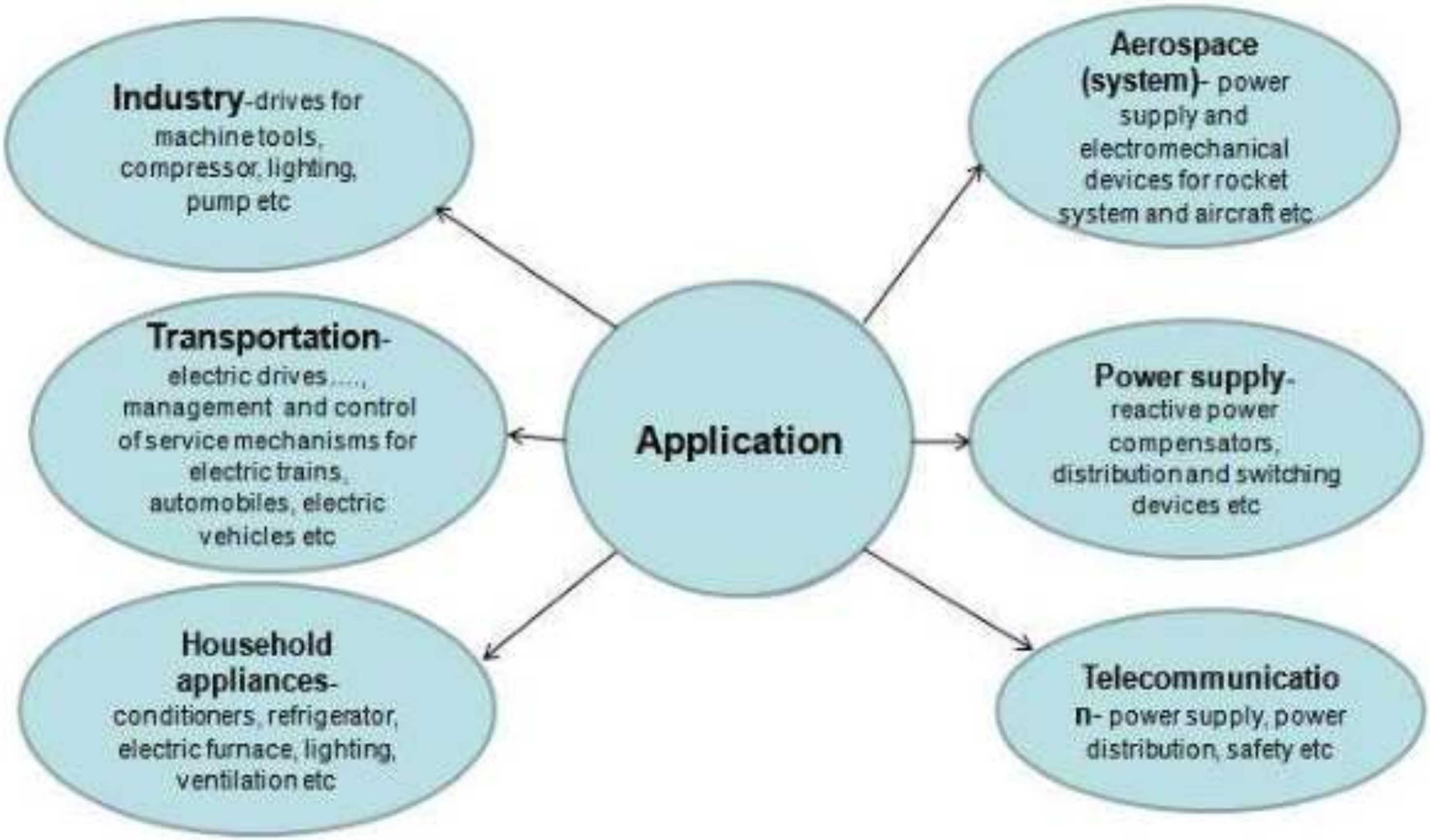
Power Electronics deal with how to control and convert power (electrical energy)into one form to another and how to utilization of power at high efficiency

BY-RAJNI

Transmission & Distribution of power



Applications of Power Electronics



Power electronic converters(5-types)

- Rectifiers-convert fixed AC to variable DC
- Inverter-convert DC to AC having variable amplitude and variable frequency
- Choppers-convert fixed DC to variable DC
- Cycloconverters - convert fixed AC to AC with variable frequency
- AC Voltage Controllers-convert fixed AC to variable AC at same input frequency

Power electronic Devices

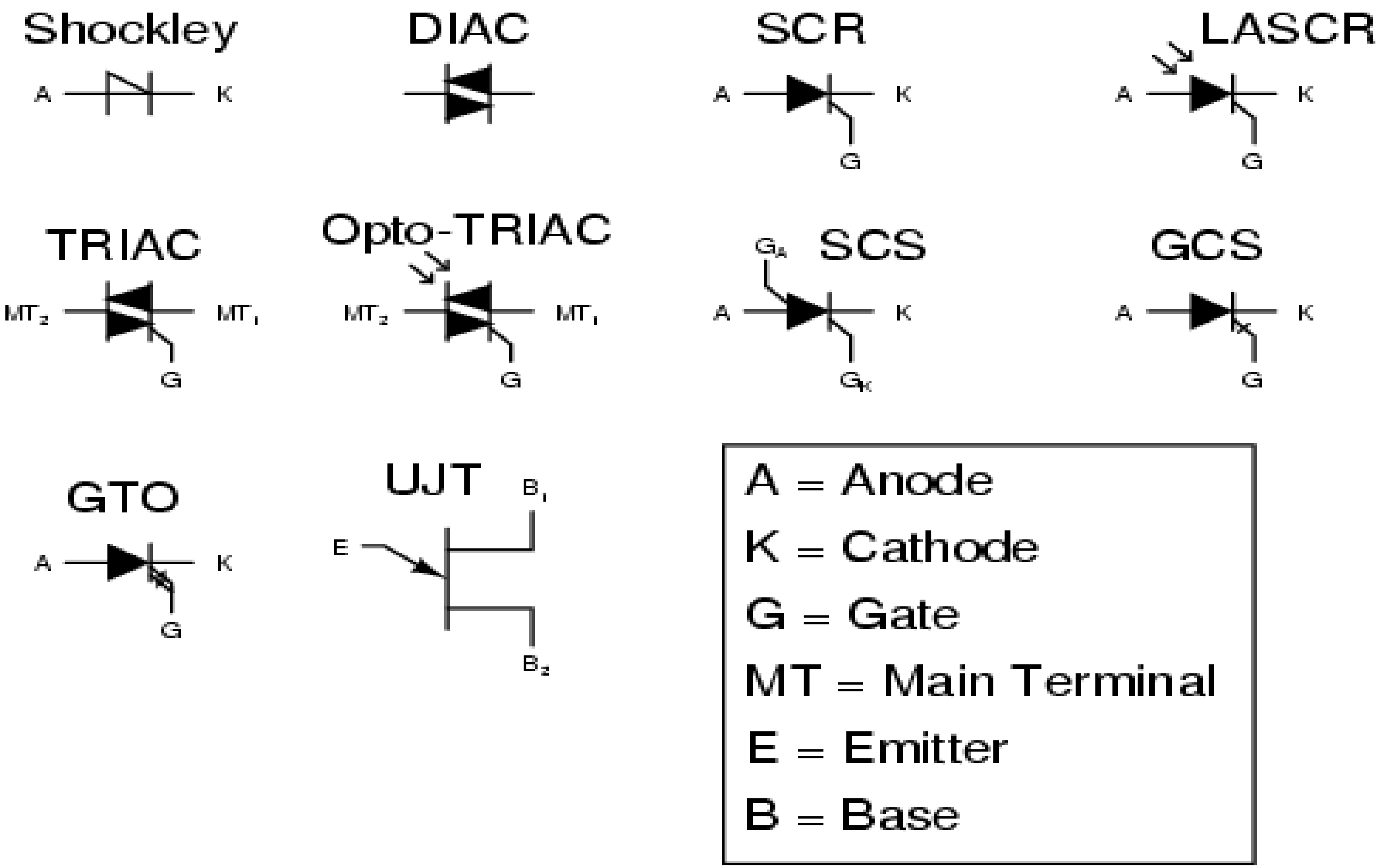
- POWER DIODES
- POWER TRANSISTOR
- POWER MOSFET
- THYRISTOR
- IGBT

THYRISTOR

Thyristor is a power semiconductor switch which is used to control output power of an electrical circuit.

Thyristor designed to handle large current and voltage, because it has high voltage, current and power rating.

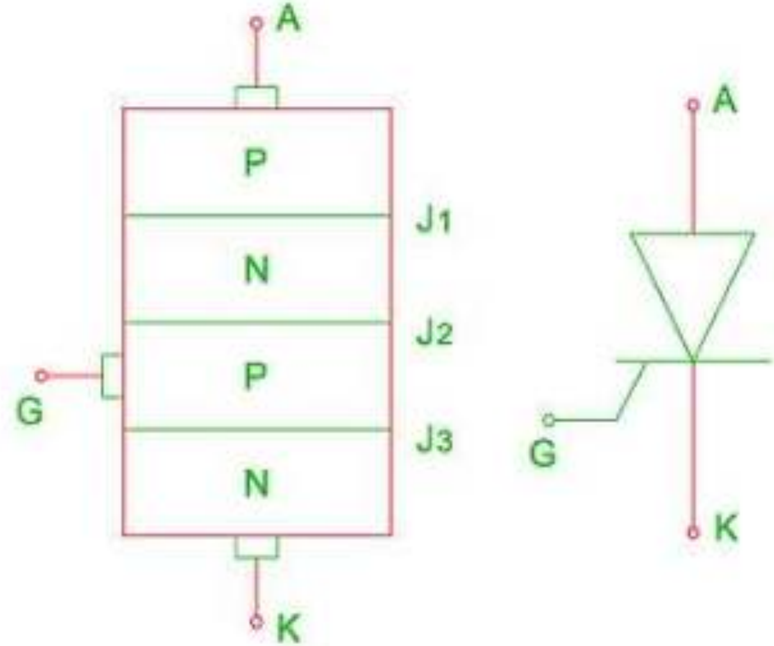
TYPES OF THYRISTORS



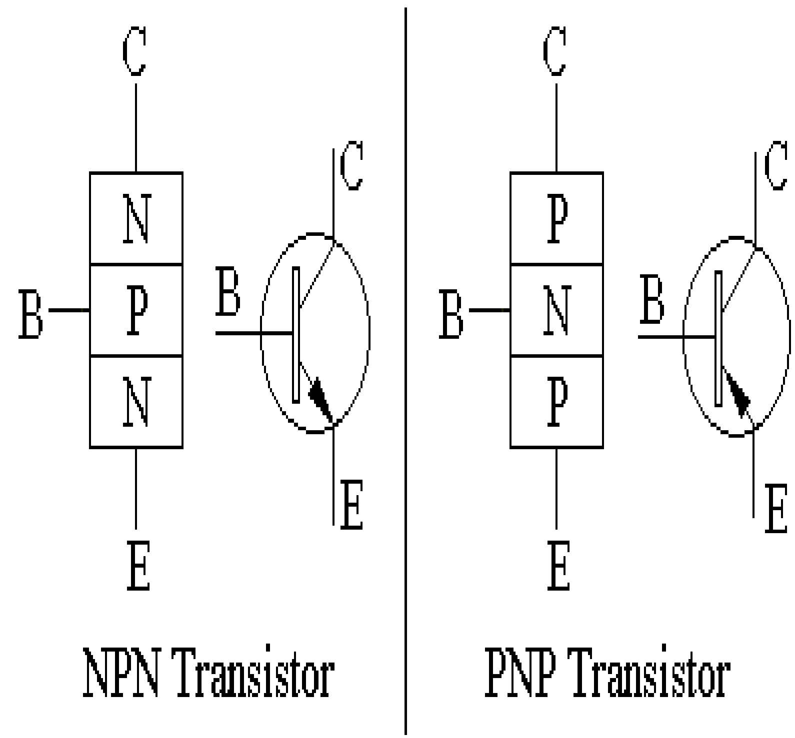
SILICON CONTROL RECTIFIER(SCR)

- SCR is 4- layers, 3-terminal, 3-junction device.
- SCR is unidirectional device
- Bipolar device can block both +ve & -ve voltage.
- SCR is a semi control device.
- **Construction of Silicon Controlled Rectifier**
- The SCR is a four layer and three terminal device. The four layers made of P and N layers, are arranged alternately such that they form three junctions J1, J2 and J3.
- The outer layers (P and N-layers) are heavily doped whereas middle P and N-layers are lightly doped. The gate terminal is taken at the middle P-layer, anode is from outer P- layer and cathode is from N- layer terminals. The SCR is made of silicon because compared to germanium leakage current in silicon is very small.
- This construction is mainly used for high power Silicon Controlled Rectifiers.

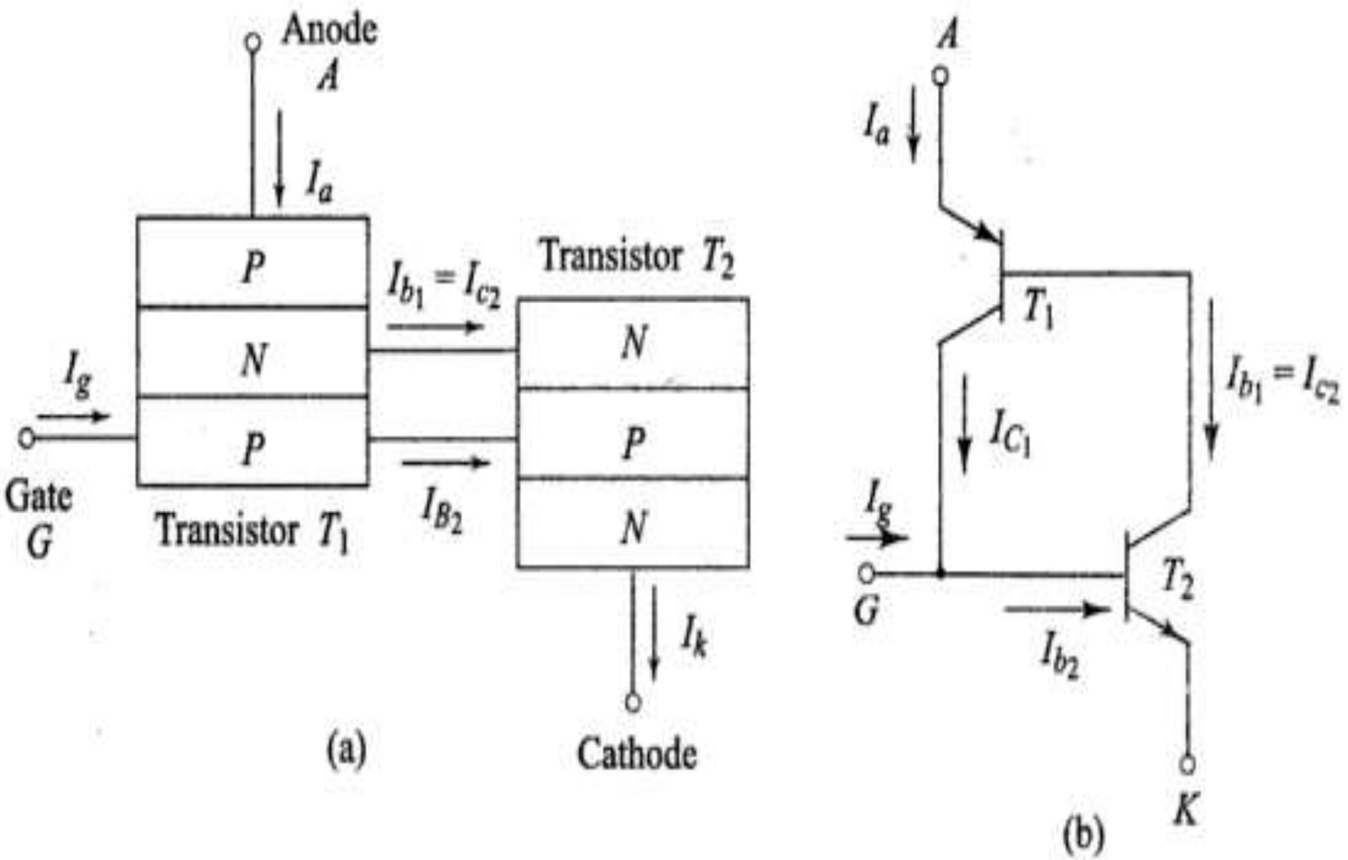
Figure -SCR



(A) Structure (B) Symbol



TWO TRANSISTOR ANALOGY OF SCR



(a)

(b)

TWO TRANSISTOR MODEL THEORY

- The two transistor analogy or two transistor model as shown in figure. The collector of each transistor is connected to the base of the other transistor.
- Assume that load resistance is connected between the anode and cathode terminals and a small voltage is applied at the gate and cathode terminals. When there is no gate voltage, the transistor 2 is in cut-off mode due to zero base current. Therefore, no current flows through the collector and hence the base of transistor T1. Hence, both transistors are open circuited and thereby no current flows through the load.
- When a particular voltage is applied between the gate and cathode, a small base current flows through the base of the transistor 2 and thereby collector current will increase. And hence the base current at the transistor T1 drives the transistor into saturation mode and thus load current will flow from anode to cathode.

Working or Modes of Operation of SCR

SCR is divided into three modes. They are

1) Forward blocking mode (**off** state)

2) Forward **conduction** mode (on state)

3) Reverse blocking mode (**off** state)

1. **Forward Blocking Mode**

In this mode of operation, the positive voltage is applied to the anode and the negative voltage applied to the cathode, there will not be any pulse applied to the gate, it will be kept in the open state. Once the voltage is applied, the junctions J1 and J3 will be forward biased and the junction J2 will be reverse biased. Since J2 is reverse biased the width of the depletion region increases and it acts as an obstacle for conduction, so only a small amount of current will be flowing from J1 to J3.

When the voltage applied to the SCR is increased and if it reaches the **breakdown voltage of the SCR**, the junction J2 gets depleted due to avalanche breakdown. Once the **Avalanche breakdown** occurs the current will start flowing through the SCR. In this mode of operation, the SCR is forward biased, but, there will not be any current flow.

2. Forward Conduction Mode

The Forward Conduction Mode is the only mode at which the SCR will be in the ON state and will be conducting. We can make the SCR conduct in two different ways, one we can increase the applied **forward bias voltage beyond the breakdown voltage** or else we can apply a positive voltage to the gate terminal.

3. reverse blocking mode

The positive voltage is applied to the Cathode (-) and the Negative voltage is given to the Anode (+), There will not be any pulse given to the gate, it will be kept as an open circuit. During this mode of operation the Junctions J1 and J3 will be **reverse biased** and the junction J2 will be forward biased. Since the junctions J1 and J3 are reverse biased there will not be any current flowing through the SCR. Although there will be a small leakage current flowing due to the drift charge carriers in the forward-biased Junction J2, it is not enough to turn on the SCR.

VI Characteristics of SCR

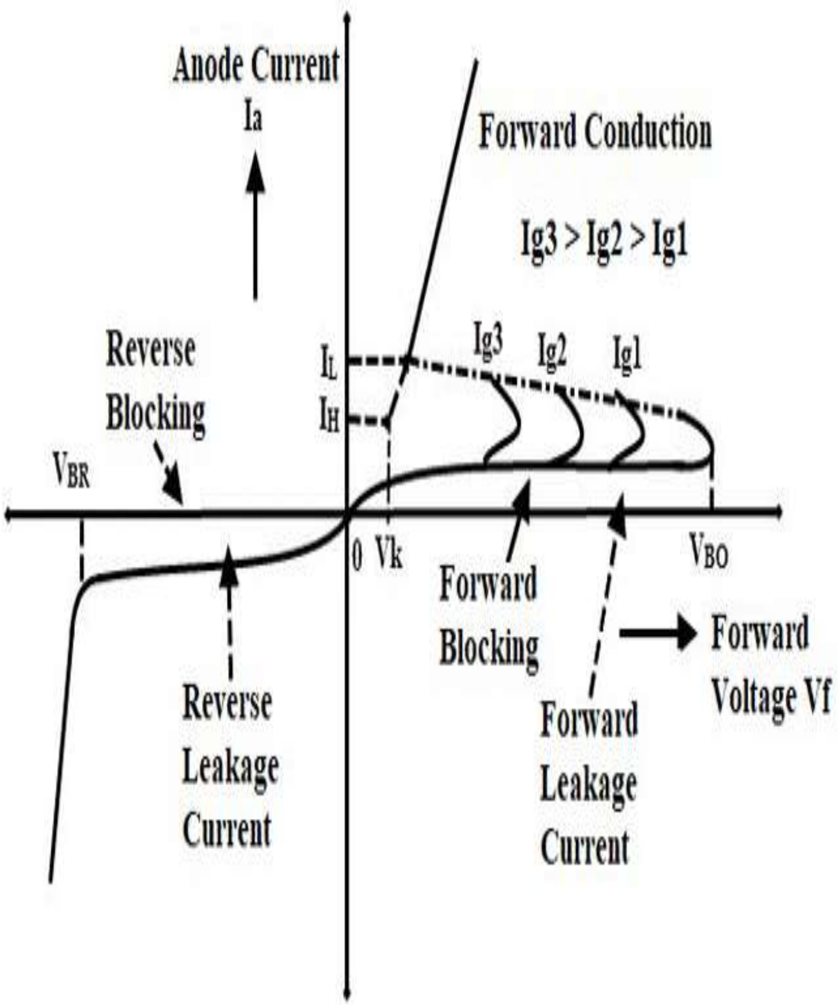
The **VI characteristics of the SCR** as show in figure are obtained by operating the SCR in three different regions, namely forward blocking region, forward conduction region and reverse blocking region

reverse blocking mode, there will be small leakage current flowing in the reverse direction of the SCR which is mentioned as the reverse leakage current in the graph, the reverse leakage current will be located at the negative quadrants of the graph.

forward blocking mode and a small leakage current will be flowing through the SCR in the positive direction, hence the curve starts rising to a certain level in the positive quadrants of the graph which is mentioned as the forward leakage current.

conduction mode and a high amount of current starts flowing through the SCR. The current flow is represented as the forward conduction in the **VI curve**.

The gate current applied are mentioned as Ig1, Ig2 and Ig3, higher the applied gate current faster the SCR goes to the conduction state as Ig3 > Ig2 > Ig1.



B.K.N GOVT POLYTECHNIC NARNAUL

DEPARTMENT INSTRUMENTATION AND CONTROL ENGG.

SUBJECT: 5.1 POWER ELECTRONICS

NAME OF FACULTY: Mrs . RAJNI

UNIT-1

1.1 Construction, working principle of SCR, two transistor analogy of SCR,V-I characteristics of SCR

The Silicon Controlled Rectifier (SCR) is the most important and mostly used member of the thyristor family. SCR can be used for different applications like rectification, regulation of power and inversion, etc. Like a diode, SCR is a unidirectional device that allows the current in one direction and opposes in another direction.

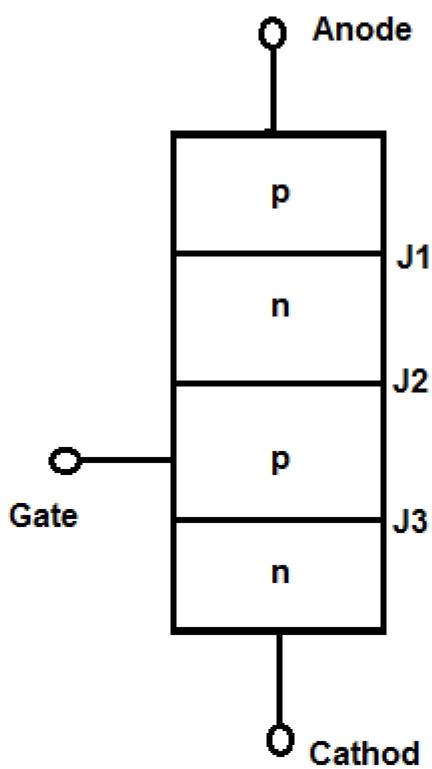


Figure-1

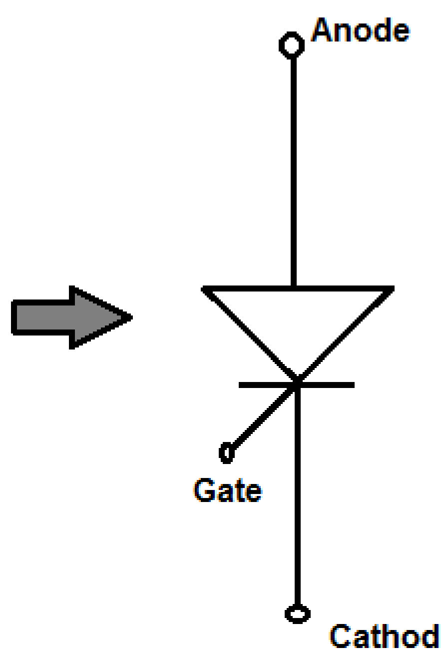
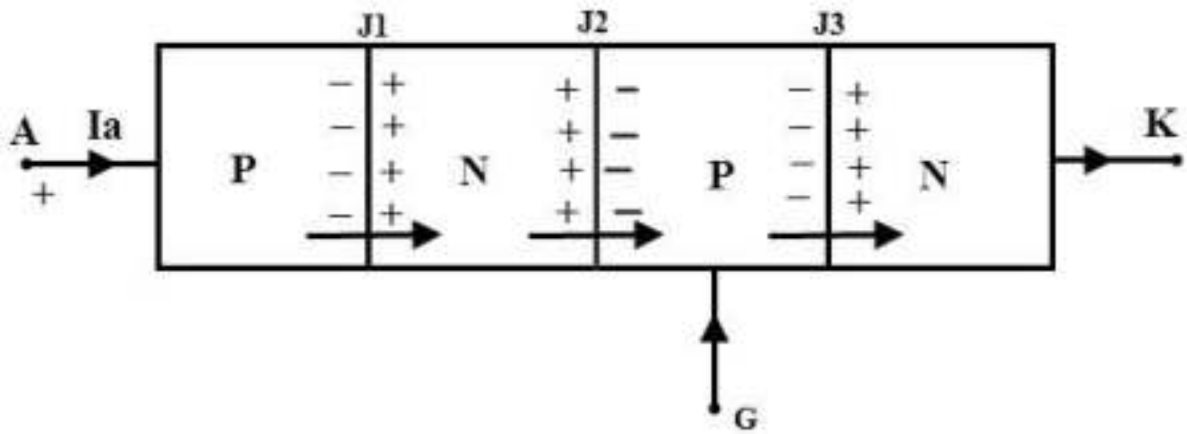


Figure-2

Construction of Silicon Controlled Rectifier

The SCR is a four layer and three terminal devices. The four layers made of P and N layers, are arranged alternately such that they form three junctions J1, J2 and J3. These junctions are either alloyed or diffused based on the type of construction.

The outer layers (P and N-layers) are heavily doped whereas middle P and N-layers are lightly doped. The gate terminal is taken at the middle P-layer, anode is from outer P- layer and cathode is from N- layer terminals. The SCR is made of silicon because compared to germanium leakage current in silicon is very small.



To manufacture the SCR, three types of constructions are used, namely the planar type, Mesa type and Press pack type. For low power SCRs, planar construction is used where all the junctions in an SCR are diffused. In mesa type construction, junction J2 is formed by diffusion method and thereby outer layers are alloyed to it.

This construction is mainly used for high power Silicon Controlled Rectifiers. To provide high mechanical strength, the SCR is braced with plates made up of either molybdenum or tungsten. And one of these plates is soldered to a copper stud which is further threaded to connect the heat sink.

V-I characteristics of SCR

A typical V-I characteristics of a SCR is show below in figure. The V-I characteristics of SCR can be explained with the help of three mode of operation.

Working or Modes of Operation of SCR

Depending on the biasing given to the SCR, the operation of SCR is divided into three modes. They are

1. Forward blocking Mode
2. Forward Conduction Mode and

3. Reverse Blocking Mode

Forward Blocking Mode

In this mode of operation, the Silicon Controlled Rectifier is connected such that the anode terminal is made positive with respect to cathode while the gate terminal kept open. In this state junctions J1 and J3 are forward biased and the junction J2 reverse biased.

Due to this, a small leakage current flows through the SCR. Until the voltage applied across the SCR is more than the break over voltage of it, SCR offers a very high resistance to the current flow. Therefore, the SCR acts as a open switch in this mode by blocking forward current flowing through the SCR as shown in the VI characteristics curve of the SCR.

Forward Conduction Mode

In this mode, SCR or thyristor comes into the conduction mode from blocking mode. It can be done in two ways as either by applying positive pulse to gate terminal or by increasing the forward voltage (or voltage across the anode and cathode) beyond the break over voltage of the SCR.

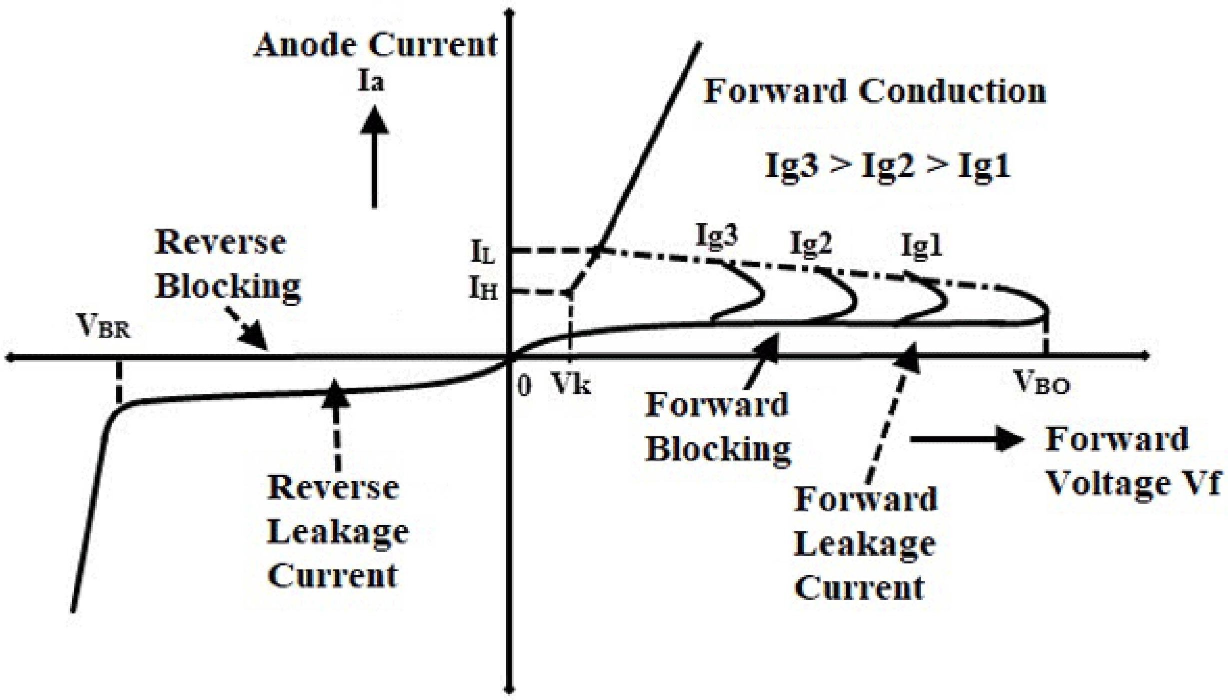
Once any one of these methods is applied, the avalanche breakdown occurs at junction J2. Therefore the SCR turns into conduction mode and acts as a closed switch thereby current starts flowing through it.

Note that in the VI characteristic figure, if the gate current value is high, the minimum will be the time to come in conduction mode as Ig3 > Ig2 > Ig1. In this mode, maximum current flows through the SCR and its value depends on the load resistance or impedance.

It is also noted that if gate current is increasing, the voltage required to turn ON the SCR is less if gate biasing is preferred. The current at which the SCR turns into conduction mode from blocking mode is called as latching current (IL).

And also when the forward current reaches to level at which the SCR returns to blocking state is called as holding current (IH). At this holding current level, depletion region starts to develop around junction J2. Hence the holding current is slightly less than the latching current.

V-I characteristics of SCR



Reverse Blocking Mode

In this mode of operation, cathode is made positive with respect to anode. Then the junctions J1 and J3 are reverse biased and J2 is forward biased. This reverse voltage drives the SCR into reverse blocking region results to flow a small leakage current through it and acts as an open switch as shown in figure.

So, the device offers a high impedance in this mode until the voltage applied is less than the reverse breakdown voltage VBR of the SCR. If the reverse applied voltage is increased beyond the VBR, then avalanche breakdown occurs at junctions J1 and J3 which results to increase reverse current flow through the SCR.

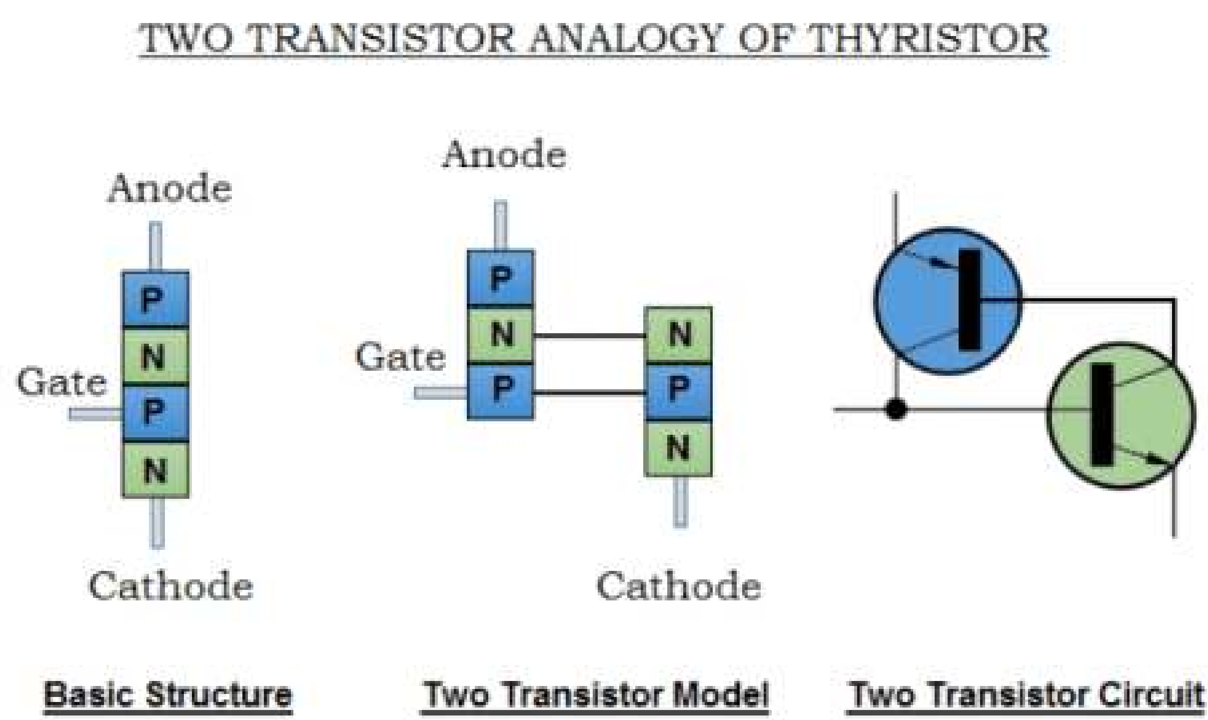
This reverse current causes more losses in the SCR and even to increase the heat of it. So there will be a considerable damage to the SCR when the reverse voltage applied more than VBR.

Two Transistor Analogy of SCR

The two transistor analogy or two transistor model of SCR expresses the easiest way to understand the working of SCR by visualizing it as a combination of two transistors as shown in figure. The collector of each transistor is connected to the base of the other transistor.

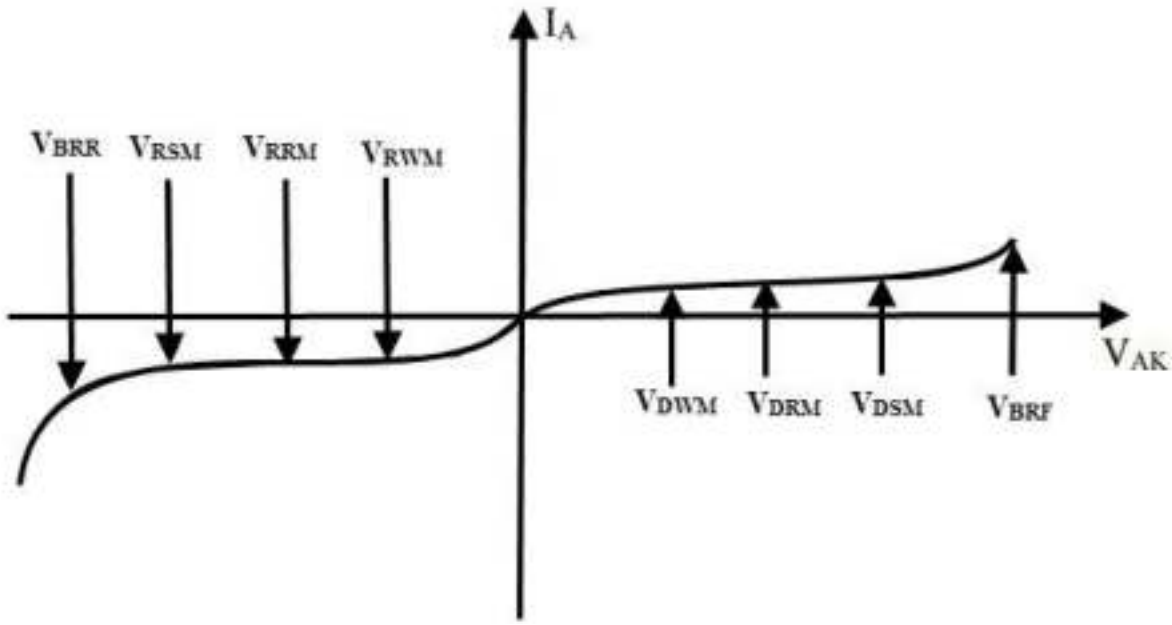
Assume that load resistance is connected between the anode and cathode terminals and a small voltage is applied at the gate and cathode terminals. When there is no gate voltage, the transistor 2 is in cut-off mode due to zero base current. Therefore, no current flows through the collector and hence the base of transistor T1. Hence, both transistors are open circuited and thereby no current flows through the load.

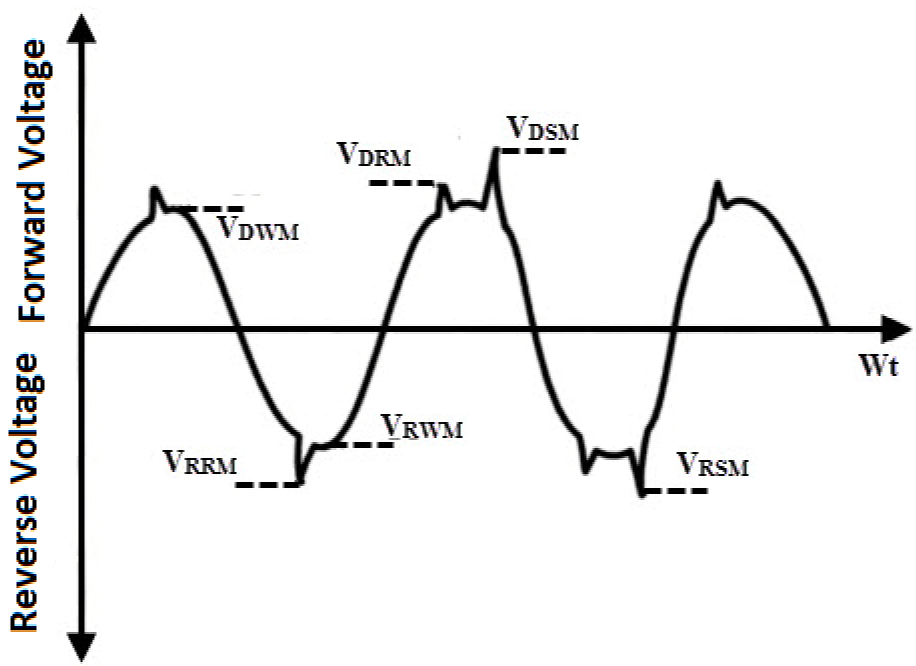
When a particular voltage is applied between the gate and cathode, a small base current flows through the base of the transistor 2 and thereby collector current will increase. And hence the base current at the transistor T1 drives the transistor into saturation mode and thus load current will flow from anode to cathode.



1.2 SCR specification and ratings

The main specifications of the SCR are its voltage rating and current rating. In this post, let us see various ratings of thyristor.





Voltage Rating:

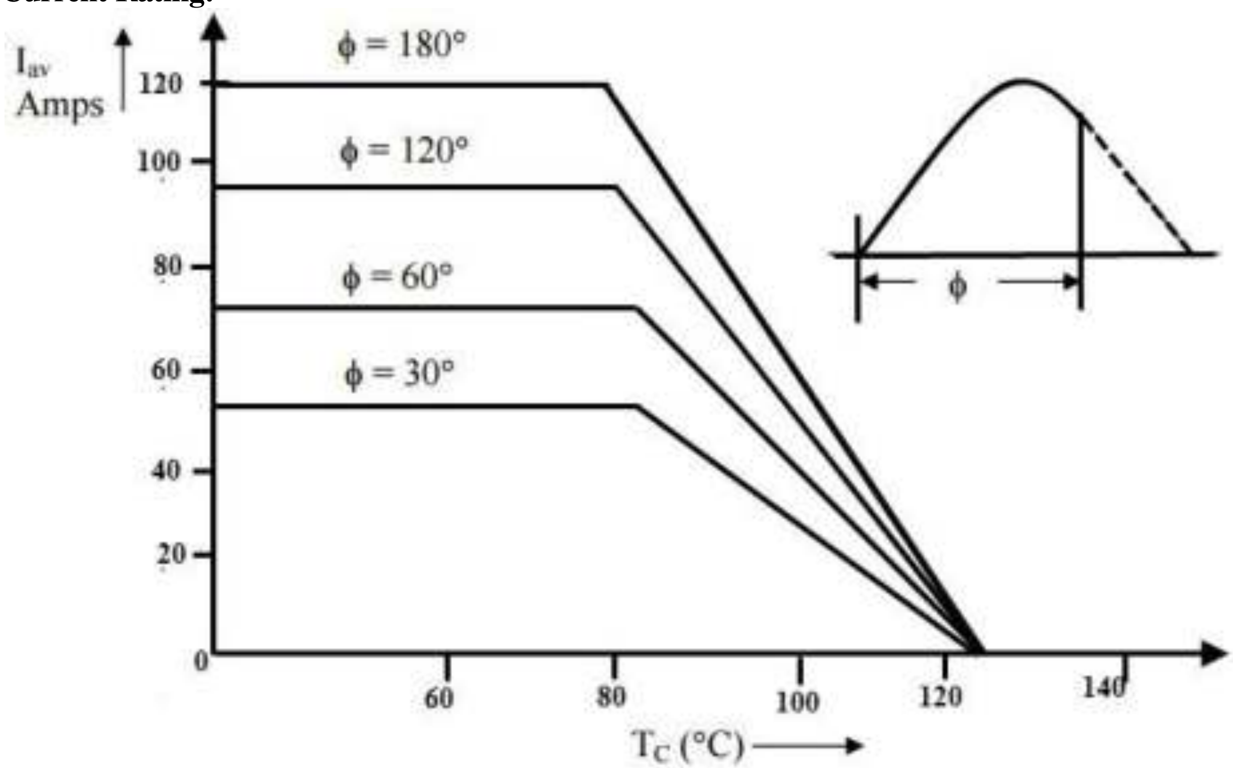
Peak Invese Voltage (V_{PIV})

The peak inverse voltage is defined as the maximum voltage which SCR can safely withstand in its OFF state. The applied voltage should never be exceeded under any circumstances.

On State Voltage:

The voltage which appears across the SCR during its ON state is known as its ON state Voltage. The maximum value of voltage which can appear across the SCR during its conducting state is called its maximum on state voltage. Usually it will be 1V to 4V.

Finger Voltage:
The minimum voltage, which is required between the anode and cathode of an SCR to trigger it to conduction mode, is called its finger voltage.
Rate of Rise of Voltage (dV/dt)
The rate at which the voltage across the device rises (for forward condition) without triggering the device, is known as its rate of rise of voltage.
Voltage Safety Factor:
The normal operating voltage of the SCR is kept well below its peak inverse voltage(V_{PIV}) to avoid puncture of SCR due to uncertain conditions. The operating voltage and peak inverse voltage are related by voltage safety factor V_f
V_f = Peak inverse voltage / (2 x RMS value of input voltage)
Normally V_f value lies between 2 and 2.5
Current Rating:



The **current** carrying capacity of the device is known as its **current rating**..
Maximum average ON state current (I_{mac}):
This is the average value of maximum continuous sinusoidal ON state current with conduction angle 180deg, at frequency 40 to 60Hz, which should not be exceeded even with intensive cooling.
Maximum rms ON-state current: (I_{mrc})
It is the rms value of the maximum continuous sinusoidal ON state current at the frequency 40 to 60 Hz and conduction angle 180deg, which should not be exceeded even with intensive cooling.
Maximum surge – ON state Current (I_{msc})
It is the maximum admissible peak value of a sinusoidal half cycle of tem milliseconds duration at a frequency of 50Hz.
Latching Current (I_l)

It is the minimum current, which is required to latch the device from its OFF state to its ON state. In other words, it is the minimum current required to trigger the device.

Holding Current (I_H)

It is the minimum current required to hold the SCR conducting. In other words, It is the minimum current, below which the device stops conducting and returns to its OFF state.

Gate Current:

The current which is applied to the gate of the device for control purposes is known as gate current.

Minimum Gate Current:

The minimum current required at the gate for triggering the device.

Maximum Gate Current:

The maximum current which can be applied to device safely. Current higher than this will damage the gate terminal.

Gate Power Loss:

The mean power loss, which occurs due to flow of gate current between the gate and the main terminals.

Turn ON time:

The time taken by the device before getting latched from its OFF state to ON state. In other words, it is the time for which the device waits before achieving its full conduction. Usually it will be 150 to 200µsec.

Turn OFF time:

After applying reverse voltage, the device takes a finite time to get switched OFF. This time is called as turn-OFF time of the device. Usually it will be 200µsec.

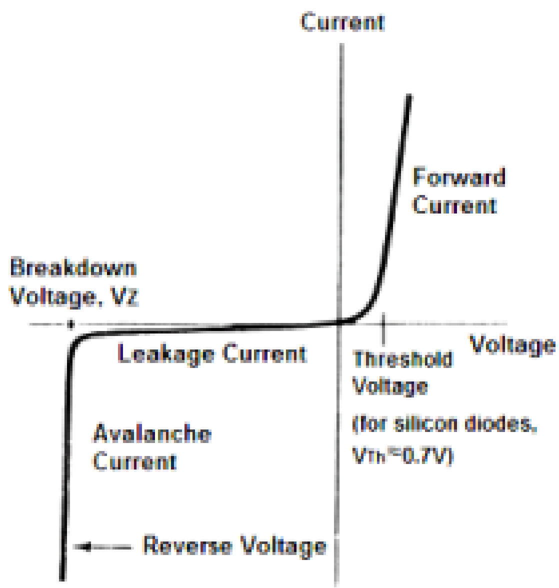
Rate of rise of current (di/dt)

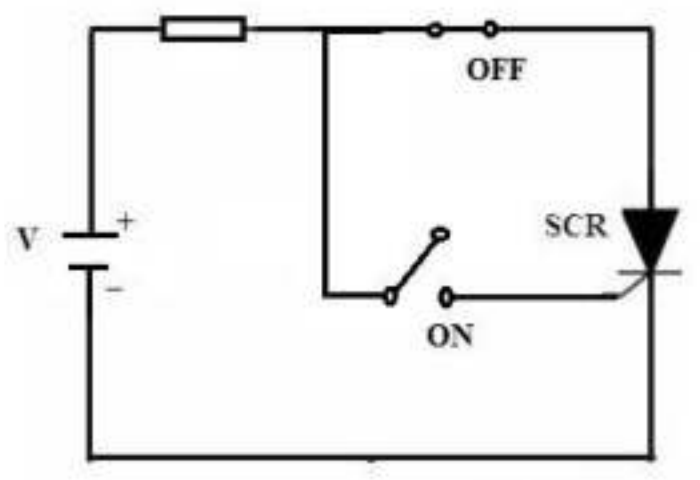
The rate at which the current flowing in the device rises is known as its rate of rise (dI/dt) of current.

1.3 Different method of SCR triggering (Turn On)

We know that the SCR has two stable states as forward blocking and forward conduction state. Switching the SCR from forward blocking state (OFF- state) to forward conduction state (ON-State) is known as turning ON process of SCR. It is also called as SCR **triggering (Turn On) Method**

As show in figure (a) & (b)



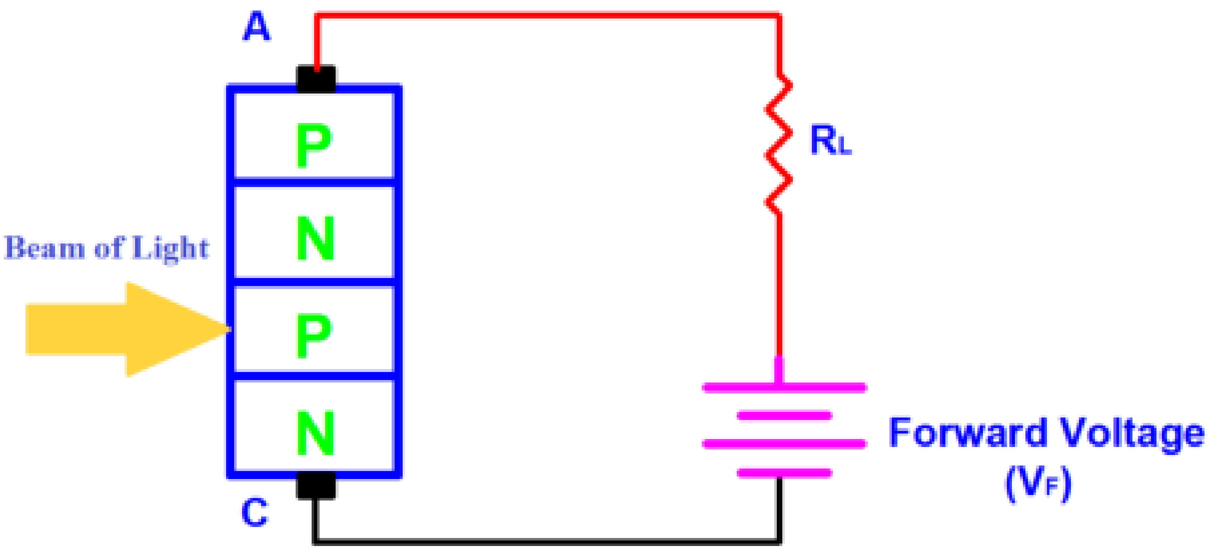


The various SCR triggering methods are
- Forward Voltage Triggering
- Thermal or Temperature Triggering
- Radiation or Light triggering
- dv/dt Triggering
- Gate Triggering

(a) Forward Voltage Triggering:-
- In this mode, an additional forward voltage is applied between anode and cathode.
- When the anode terminal is positive with respect to cathode(V_{AK}) , Junction J1 and J3 is forward biased and junction J2 is reverse biased.
- No current flows due to depletion region in J2 is reverse biased (except leakage current).
- As V_{AK} is further increased, at a voltage V_{BO} (Forward Break Over Voltage) the junction J2 undergoes avalanche breakdown and so a current flows and the device tends to turn ON(even when gate is open)

(b) Thermal (or) Temperature Triggering:-
- The width of depletion layer of SCR decreases with increase in junction temperature.
- Therefore in SCR when V_{AR} is very near its breakdown voltage, the device is triggered by increasing the junction temperature.
- By increasing the junction temperature the reverse biased junction collapses thus the device starts to conduct.

(c) Radiation Triggering (or) Light Triggering:-
- For light triggered SCRs a special terminal niche is made inside the inner P layer instead of gate terminal.
- When light is allowed to strike this terminal, free charge carriers are generated.
- When intensity of light becomes more than a normal value, the thyristor starts conducting.
- This type of SCRs are called as LASCR



Radiation or Light Triggering of SCR

(d) dv/dt Triggering:-

- When the device is forward biased, J1 and J3 are forward biased, J2 is reverse biased.
- Junction J2 behaves as a capacitor, due to the charges existing across the junction.
- Therefore when the rate of change of voltage across the device becomes large, the device may turn ON, even if the voltage across the device is small.

(e) Gate Triggering:-

- This is most widely used SCR triggering method.
- Applying a positive voltage between gate and cathode can Turn ON a forward biased thyristor.
- When a positive voltage is applied at the gate terminal, charge carriers are injected in the inner P-layer, thereby reducing the depletion layer thickness.
- As the applied voltage increases, the carrier injection increases, therefore the voltage at which forward break-over occurs decreases.
- Three types of signals are used for gate triggering.

1.4 Different commutation circuit for SCR

The turn OFF process of an SCR is called **commutation**. The term commutation means the transfer of currents from one path to another. So the commutation circuit does this job by reducing the forward current to zero so as to turn OFF the SCR or Thyristor.

To turn OFF the conducting SCR the below conditions must be satisfied.

- The anode or forward current of SCR must be reduced to zero or below the level of holding current and then,
- A sufficient reverse voltage must be applied across the SCR to regain its forward blocking state.

SCR Turn OFF Methods

The reverse voltage which causes to commutate the SCR is called commutation voltage. Depending on the commutation voltage located, the commutation methods are classified into two major types.

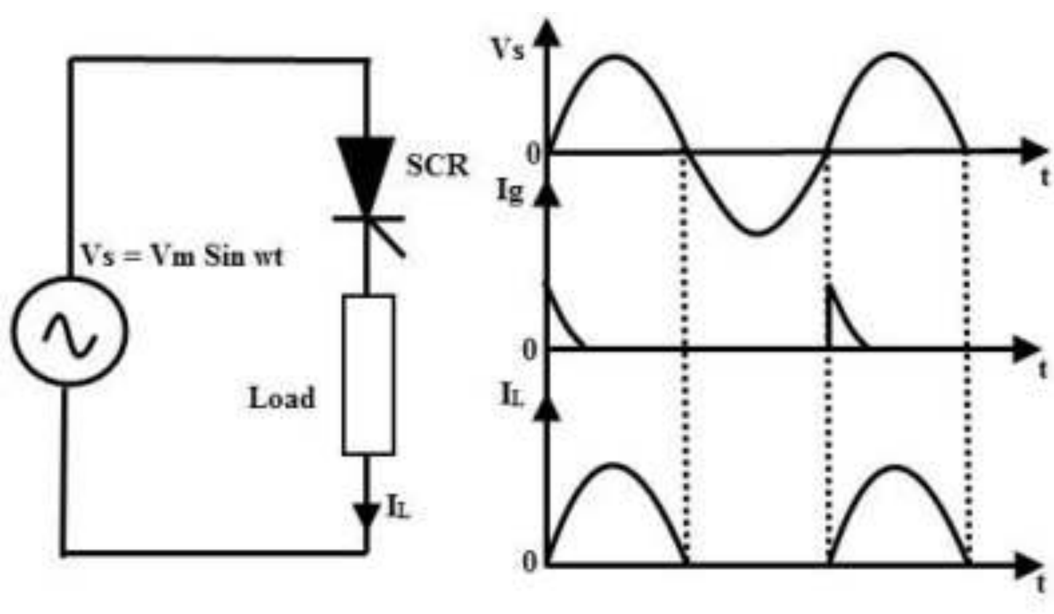
(1) Forced commutation

(2) Natural commutation.

Let us discuss in brief about these methods.

Natural Commutation

Generally, if we consider AC supply, the current will flow through the zero crossing line while going from positive peak to negative peak. Thus, a reverse voltage will appear across the device simultaneously, which will turn off the thyristor immediately. This process is called as natural commutation as thyristor is turned off naturally without using any external components or circuit or supply for commutation purpose.



Natural commutation (Class F commutation) can be observed in AC voltage controllers, phase controlled rectifiers.

Forced commutation

It can be observed while using DC supply; hence it is also called as DC commutation. The external circuit used for forced commutation process is called as commutation circuit and the elements used in this circuit are called as commutating elements.

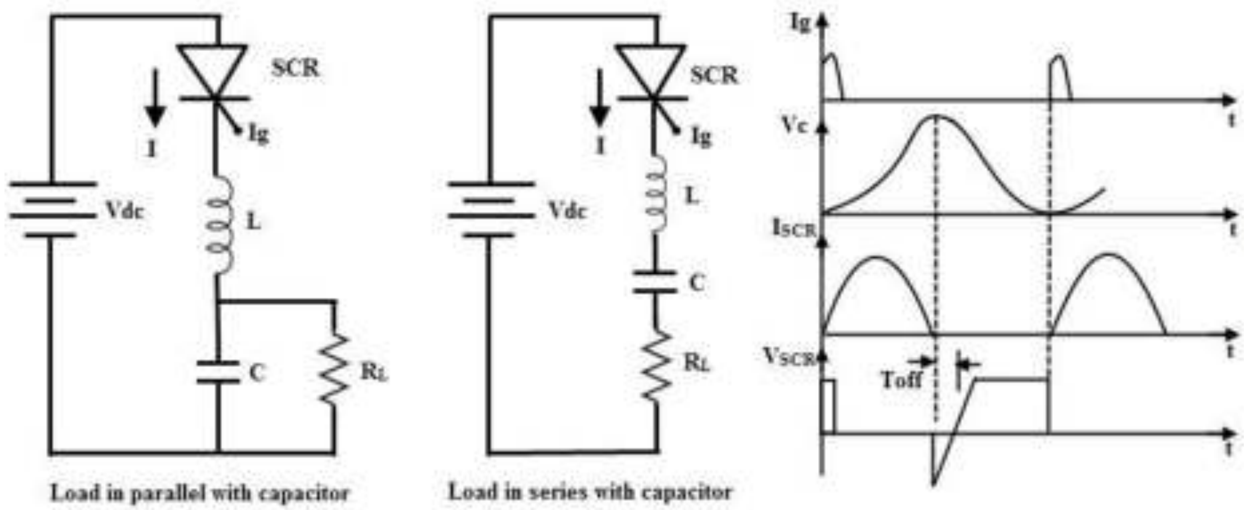
Classification of Forced Commutation Methods

The forced commutation can be classified into different methods as follows:

- Class A: Self commutated by a resonating load
- Class B: Self commutated by an LC circuit
- Class C: Additional or complementary SCR
- Class D: Auxiliary SCR
- Class E: External pulse source for commutation
- Class F: AC line commutation

Class A: Self Commutated by a Resonating Load

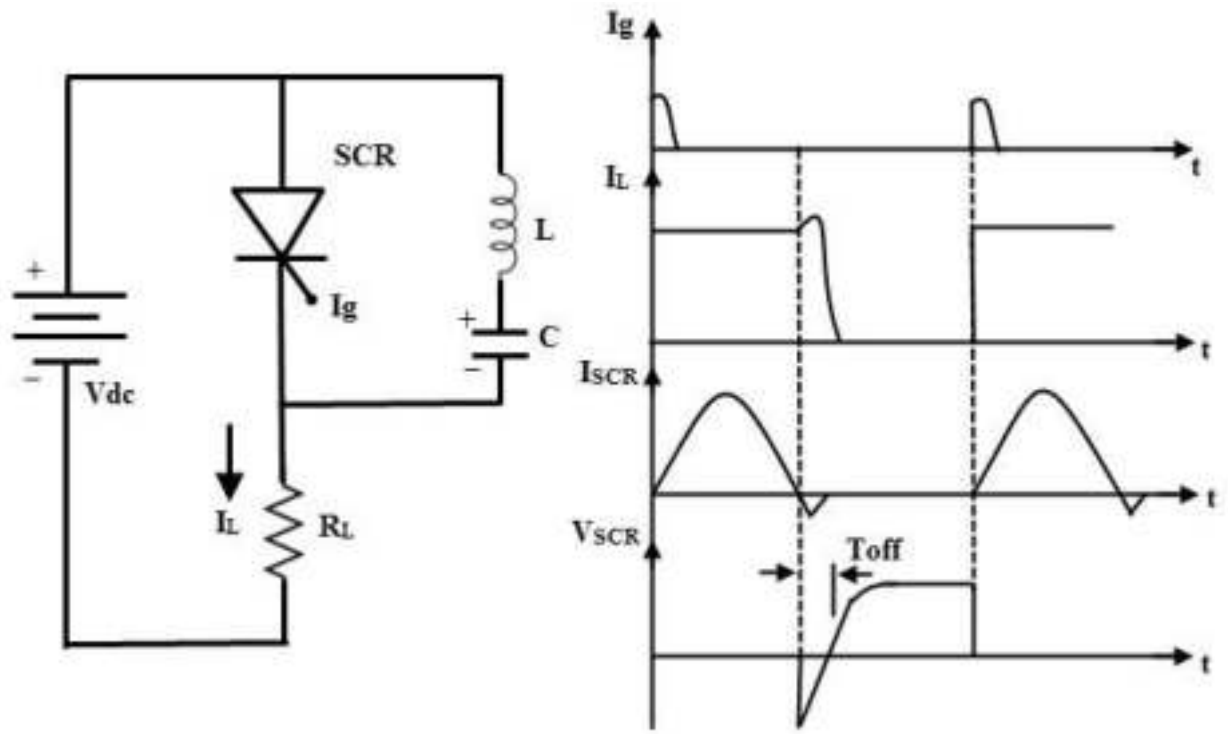
Class A is one of frequently used thyristor commutation techniques. If thyristor is triggered or turned on, then anode current will flow by charging capacitor C with dot as positive. The second order under-damped circuit is formed by the inductor or AC resistor, capacitor and resistor. If the current builds up through SCR and completes the half cycle, then the inductor current will flow through the SCR in the reverse direction which will turn off thyristor.



After the thyristor commutation or turning off the thyristor, the capacitor will start discharging from its peak value through the resistor is an exponential manner. The thyristor will be in reverse bias condition until the capacitor voltage returns to the supply voltage level.

Class B: Self Commutated by an L-C Circuit

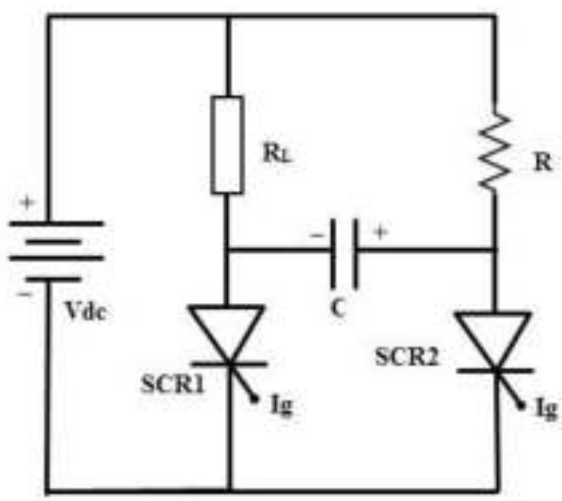
The major difference between the class A and class B thyristor commutation techniques is that the LC is connected in series with thyristor in class A, whereas in parallel with thyristor in class B. Before triggering on the SCR, the capacitor is charged up (dot indicates positive). If the SCR is triggered or given triggering pulse, then the resulting current has two components. The constant load current flowing through the R-L load is ensured by the large reactance connected in series with the load which is clamped with freewheeling diode. If sinusoidal current flows through the resonant L-C circuit, then the capacitor C is charged up with dot as negative at the end of the half cycle.

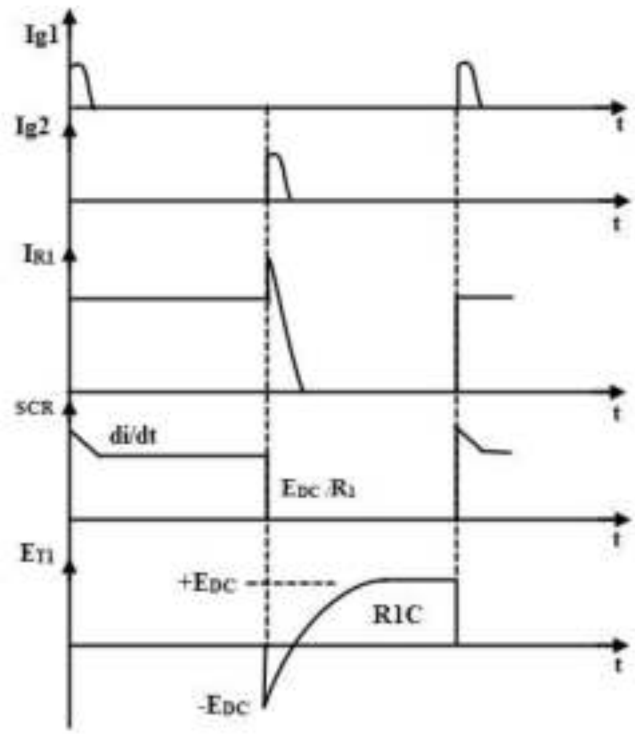


The total current flowing through the SCR becomes zero with the reverse current flowing through the SCR opposing the load current for a small a small fraction of the negative swing. If the resonant circuit current or reverse current becomes just greater than the load current, then the SCR will be turned OFF.

Class C: Additional or complementary SCR

In the above thyristor commutation techniques we observed only one SCR but in these class C commutation techniques of thyristor there will be two SCRs. One SCR is considered as main thyristor and the other as auxiliary thyristor. In this classification both may act as main SCRs carrying load current and they can be designed with four SCRs with load across the capacitor by using a current source for supplying an integral converter.

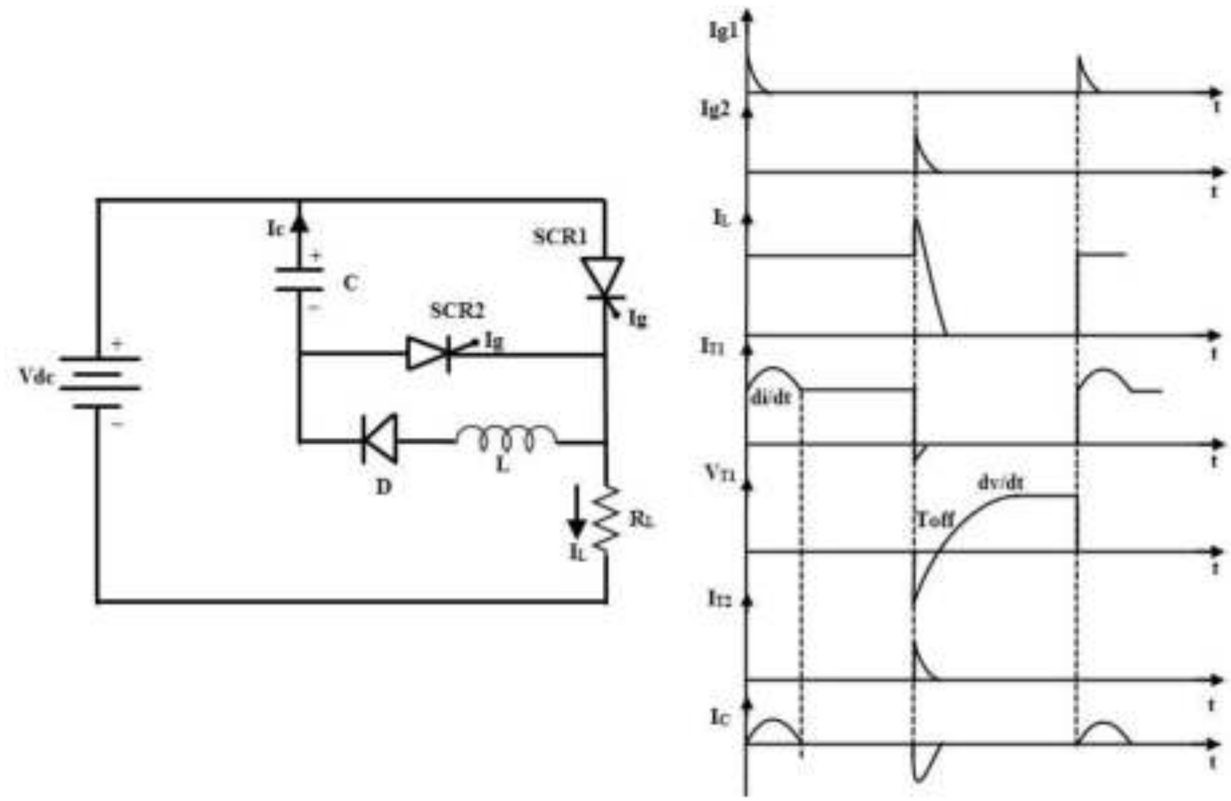




If the SCR_2 is triggered, then the capacitor will be charged up. If the SCR_1 is triggered, then the capacitor will discharge and this discharge current of C will oppose the flow of load current in SCR_2 as the capacitor is switched across SCR_2 via SCR_1

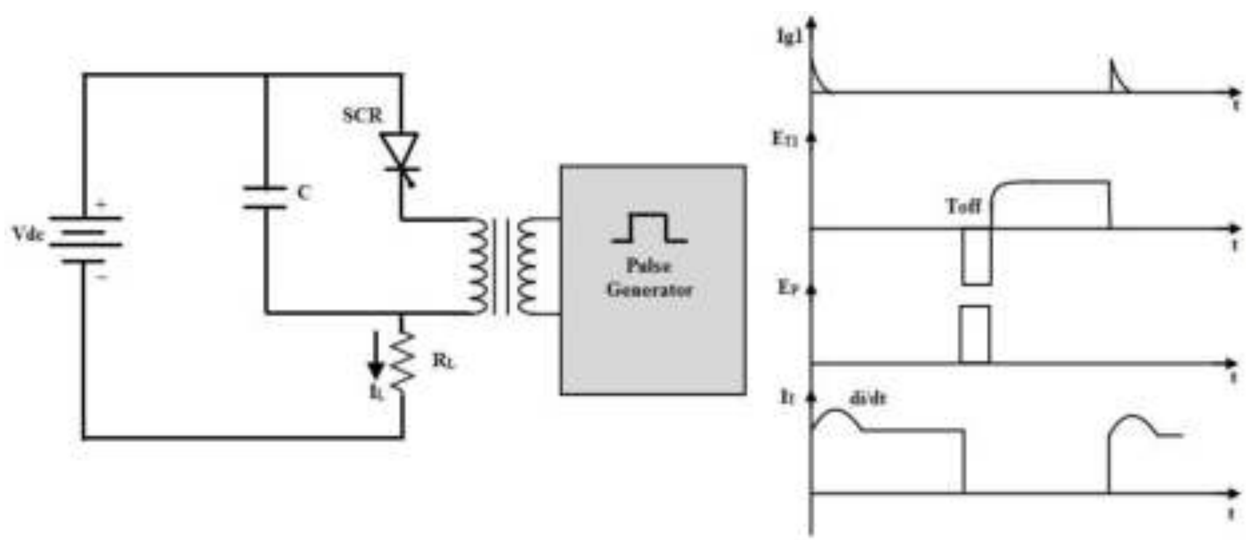
Class D: Auxiliary SCR

The class C and class D thyristor commutation techniques can be differentiated with the load current in class D: only one of the SCR's will carry the load current while the other acts as an auxiliary thyristor whereas in class C both SCRs will carry load current. The auxiliary thyristor consists of resistor in its anode which is having resistance of approximately ten times the load resistance.



Class E: External Pulse Source for Commutation

For the class E thyristor commutation techniques, a transformer which cannot saturate (as it is having a sufficient iron and air gap) and capable to carry the load current with small voltage drop compared with the supply voltage. If the thyristor T is triggered, then the current will flow through the load and pulse transformer.



An external pulse generator is used to generate a positive pulse which is supplied to the cathode of the thyristor through pulse transformer. The capacitor C is charged to around 1v and it is considered to have zero impedance for the turn off pulse duration. The voltage across the thyristor is reversed by the pulse from the electrical transformer which supplies the reverse recovery current, and for the required turn off time it holds the negative voltage.

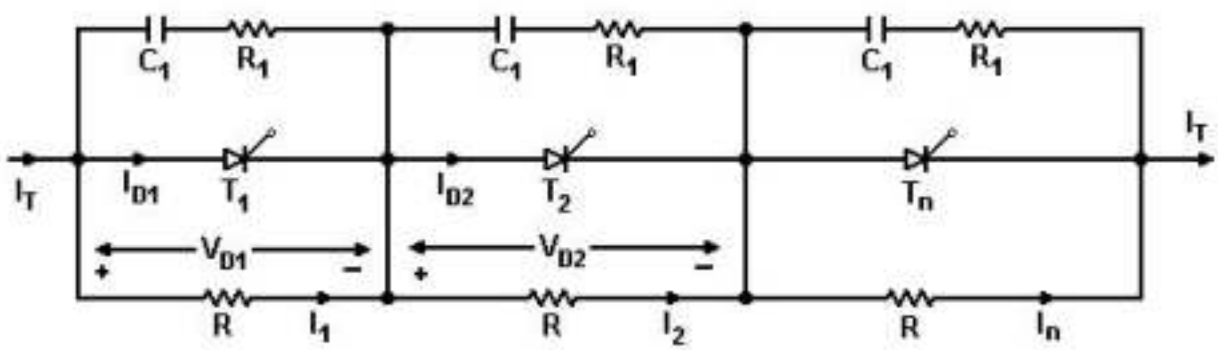
1.5 Series and parallel operation of SCR

Series operation of thyristors

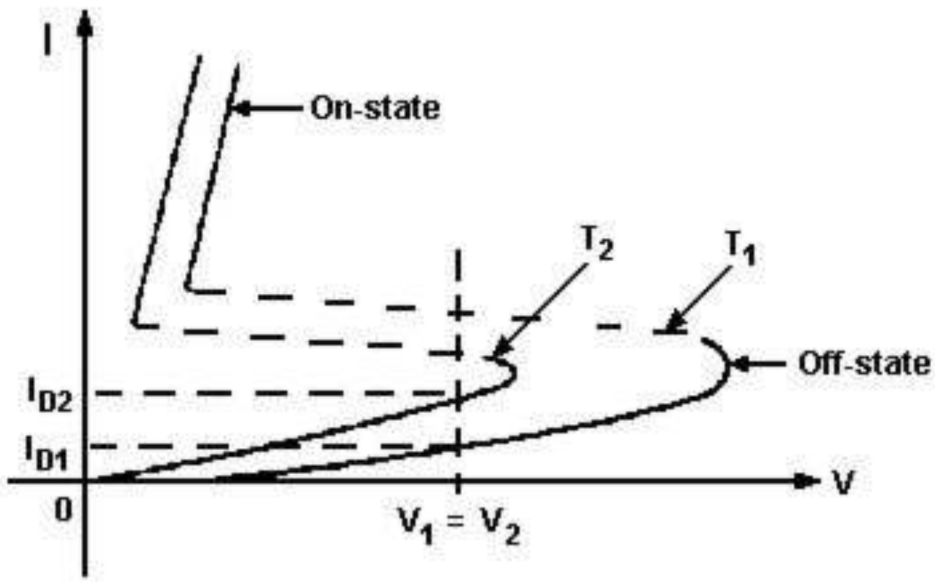
As we know series configuration increases the voltage ratings while the current ratings remain the same. Thyristors of same type do not have same I-V and off state characteristics.

So the voltage drop across the thyristors would be unequal. To solve this issue following parameters are set by default.

- Resistors are connected across each thyristor to avoid the unequal voltage sharing.
- The values of the resistors should be selected, so the equivalent resistance of thyristor and resistor would be same.



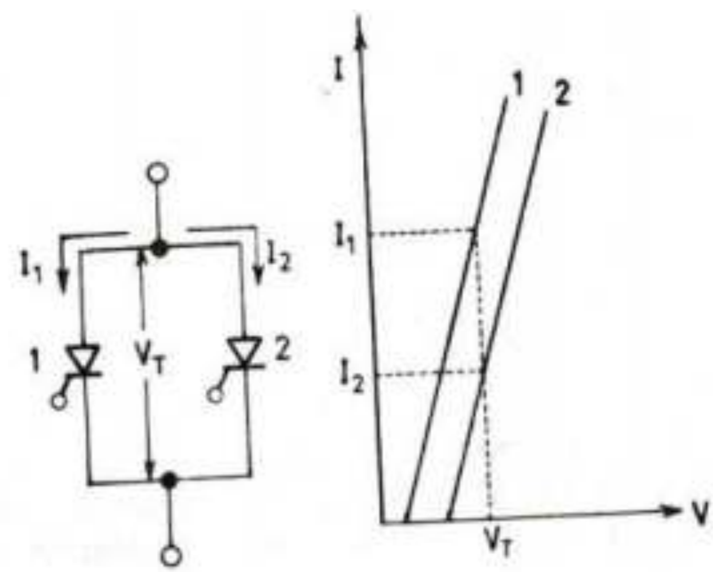
Now, the off state currents would be as shown in the figure:



High and steep trigger pulses must be used in order to make the firing of thyristors simultaneously.

Parallel operation of thyristors

Parallel operation of SCR is also known as high current operation as this connection is used to meet high current demand. If the load current increases from the current rating of a single thyristor, then the parallel configuration is used. The same problem arises here as well. Current is not shared equally among the thyristors as the V-I characteristics are not similar.

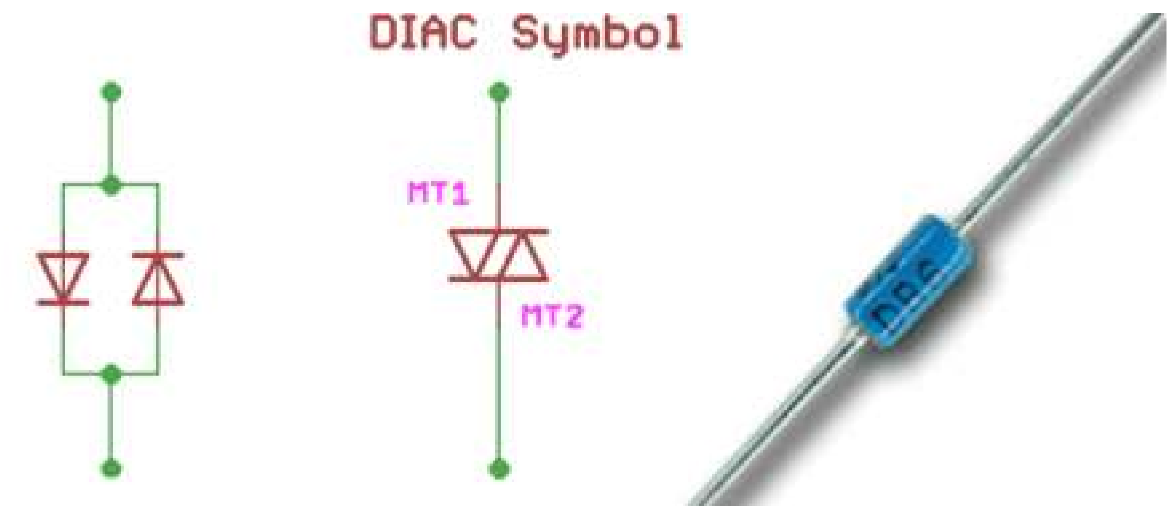


Parallel operation to parallel devices in order to achieve higher current ratings or lower conducting voltages than are attainable with a single device. Although devices in parallel complicate layout and interconnections, better cooling distribution is obtained. Also, built-in redundancy can give improved equipment reliability. A cost saving may arise with smaller, cheaper, high production volume, devices. The main design consideration for parallel device operation is that all devices share both the steady-state and transient currents. Any bipolar device carrying a disproportionately high current will heat up and conduct more current, eventually leading to thermal runaway as considered in section. The problem of current sharing is less severe with diodes because diode characteristics are more uniform (because of their simpler structure and manufacturing) than those of thyristors and transistors

1.6 Construction and working principle of DIAC, TRIAC and their V-I characteristics

DIAC

The term DIAC stands for the Diode for **A**lternating **C**urrent (DIAC), it is a **bidirectional semiconductor switch** that can be turned ON in both forward and reverse direction. The device is a member of the Thyristor family and it is mostly used in triggering TRIAC and other Thyristor based circuits. The DIAC starts conducting electric current if the applied voltage goes beyond its break-over voltage.

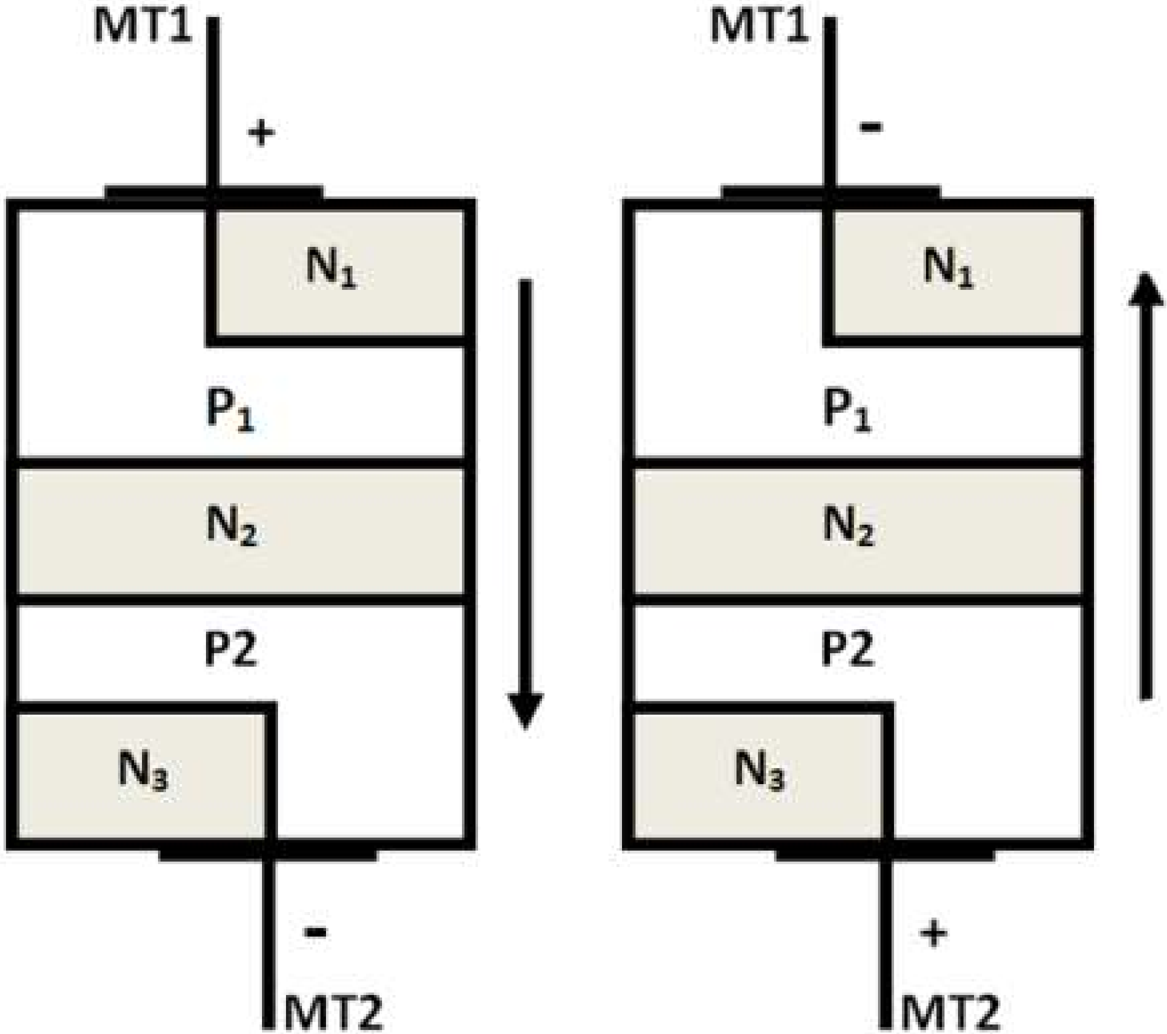


DIAC - Symbol

DIAC is given by the symbol of two Diodes connected in parallel and opposite to one another and has two terminals. Since the DIAC is bidirectional, we can’t name those terminals as anode and cathode, the **terminals of DIAC** are simply called A1 and A2 or MT1 and MT2 where MT stands for Main terminals. Hence the **pinouts of DIAC** are reversible just like a resistor or ceramic capacitor.

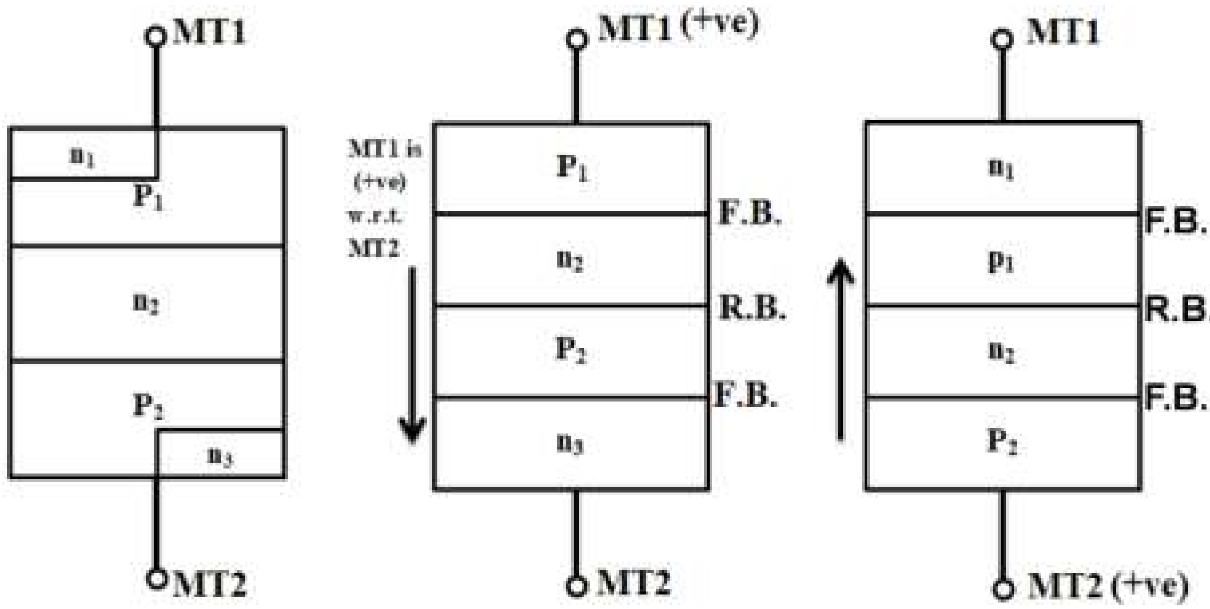
1.6.1. DIAC Construction

The construction of DIAC will be quite similar to the structure of the transistor, but they have some differences like the DIAC does not have any base terminal, all the three layers have the same amount of doping and it delivers symmetrical switching properties in both the polarities of the applied voltage.



The above diagram shows the typical **construction of the DIAC**. As mentioned earlier the DIAC has two terminals namely MT1 and MT2 and it can **deliver current flow in both directions**. The DIAC is made of a five-layered structure; the layers closer to the terminals are the combination of both positive and negative layers. When the voltage is passed to the terminals the layer with respective polarity to the voltage gets activated, this combination of both the polarities helps in operating the DIAC in both the directions.

DIAC Working Principle

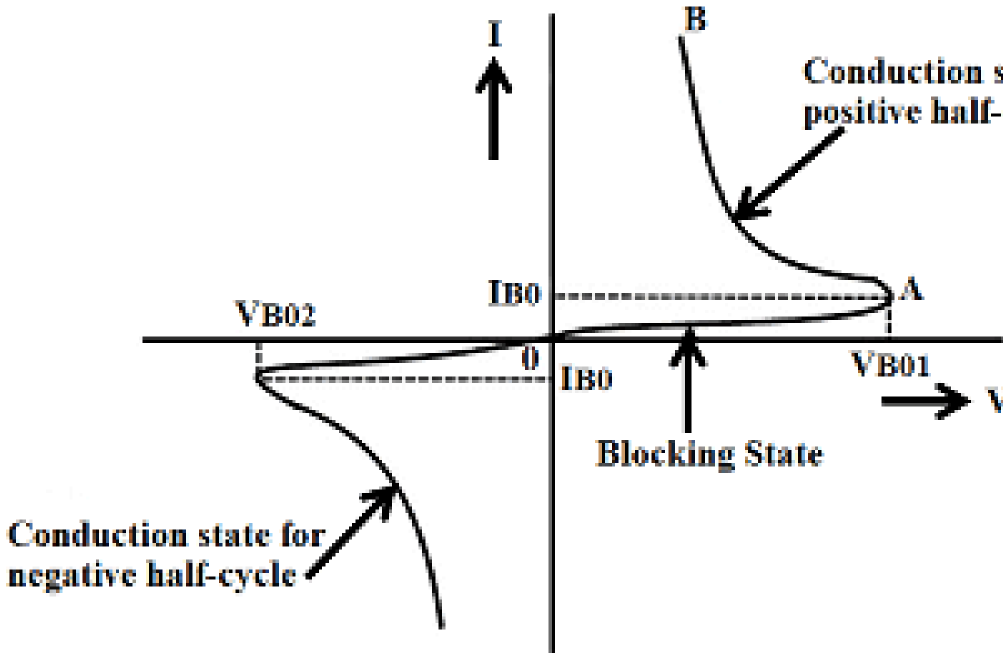


The above image shows the clear operation of the DIAC with respe!ctive to the polarities. Consider the MT1 terminal to be positive, then the P1 layer near MT1 will be activated, so the conduction will be taking place in the order of P1-N2-P2-N3. When the current is flowing from MT1 to MT2 the junction between P1-N2 and P2-N3 are Forward Biased and the junction between N2-P2 is reverse biased.

Similarly, if we consider MT2 terminal to be positive, then the P2 layer near MT2 will be activated and the conduction will be taking place in the order of P2-N2-P1-N1. The current will be flowing from MT2 to MT1 and the junctions between P2-N2 and P1-N1 are forward biased and the junction Between N2- P1 is reverse biased. Hence the conduction will be possible in both the directions.

VI Characteristics of DIAC

The **V-I characteristic curve of the DIAC** will be in the shape of a Z and the curve will be lying on the first and third quadrants because they conduct in both the positive and negative polarity. The First quadrant represents the positive half cycle where the current will be flowing from MT1 to MT2 and the second quadrant represents the negative half cycle where the current will be flowing from MT2 to MT1.



Initially, the resistance of the DIAC will be higher because of the Reverse Bias junction between the layers so there will be **small leakage current** flowing through the DIAC, it is mentioned as the **blocking state** in the curve. Once the applied voltage reaches the breakdown voltage the resistance of the DIAC drops abruptly and then it starts conducting which leads to a sharp decrease in voltage and the current starts increasing, which is mentioned as a **conduction state** in the curve. Most of the DIACs will be having the breakdown voltage around 30 Volts, the exact breakdown voltage will be based on the type of the device. The DIAC will be in the **conducting state** until the current reaches the particular value called the **holding current**, where holding current is the minimum current that required for a device to keep it in the ON state.

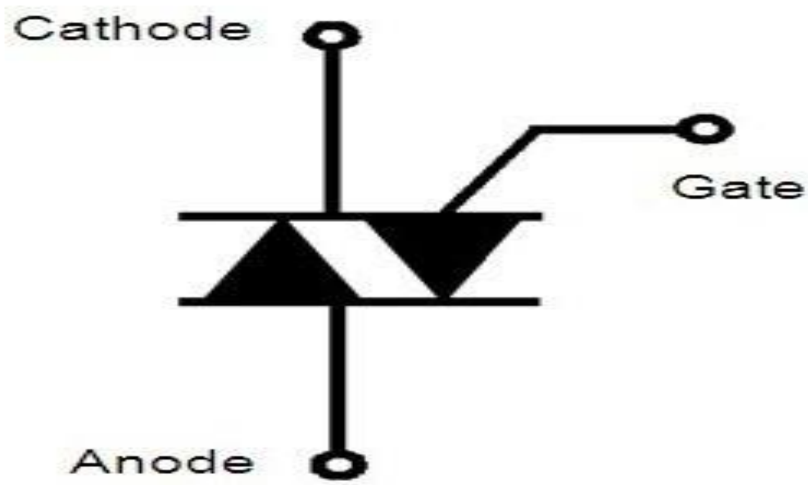
1.6.2. TRIAC

TRIAC can be expanded as a **TRI**ode for **A**lternating **C**urrent. While other power electronic switches like MOSFET, IGBT, etc are used for switching/controlling DC power, the TRIAC is used to control AC power because once turned on TRIAC can conduct in both the direction allowing AC voltage to passes completely in both the positive and negative cycle.

The TRIAC is a three-terminal semiconductor switching device that is used for controlling current flow in a circuit. It is one of the most important members of the thyristor family; it is a **bidirectional device** that can pass the current in both forward and reverse direction, which means that they can conduct in both the conditions of the **gate signal**, positive and negative.

TRIAC Symbol

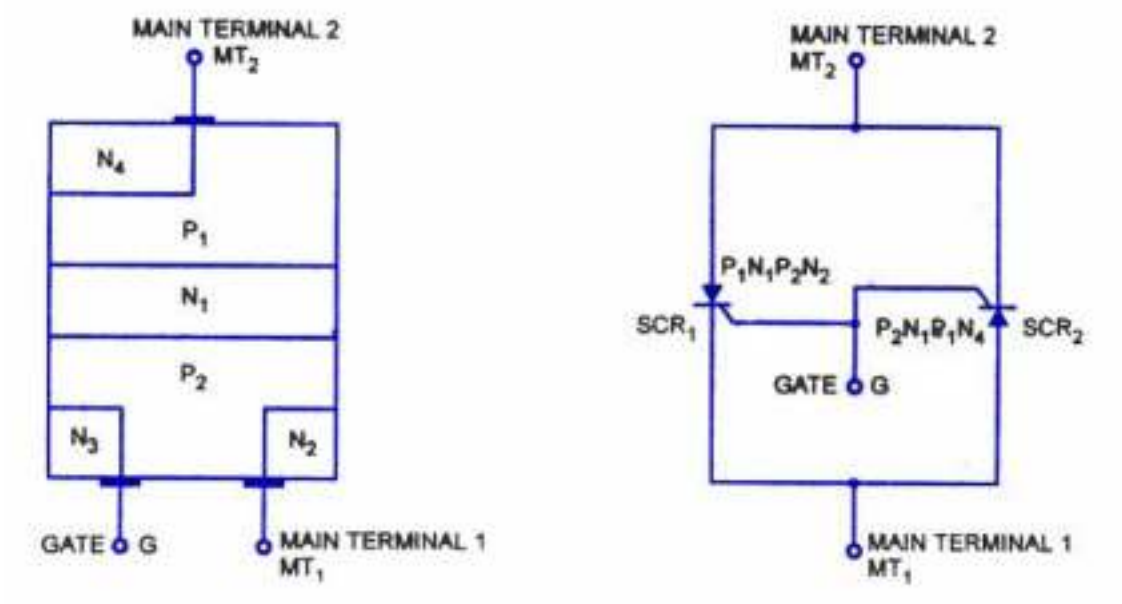
A TRIACs can be formed by connecting two equivalent SCRs in inverse parallel to one another and the gates of the two SCR are connected together to form a single gate. If you are new to DIACs as well then you can read the **DIAC Introduction Article** to know more about it. The **Symbol of the TRIAC** will be like the image below, it has three terminals Main Terminal 1 (MT1), Main Terminal 2 (MT2) and Gate (G).



The MT1 and MT 2 are also called as Anode 1 and Anode 2. The TRIAC can be included in a circuit in a way that the current is flowing from either MT1 to MT2 or MT2 to MT1, there will not be any current until we inject a gate current pulse at G.

TRIAC Construction

The below shows the **structure of the TRIAC**, it is a four-layer device that consists of six doping regions. The gate terminal is designed in a way to have ohmic contact with both N and P regions, which helps the device to get triggered with both positive and negative polarities.



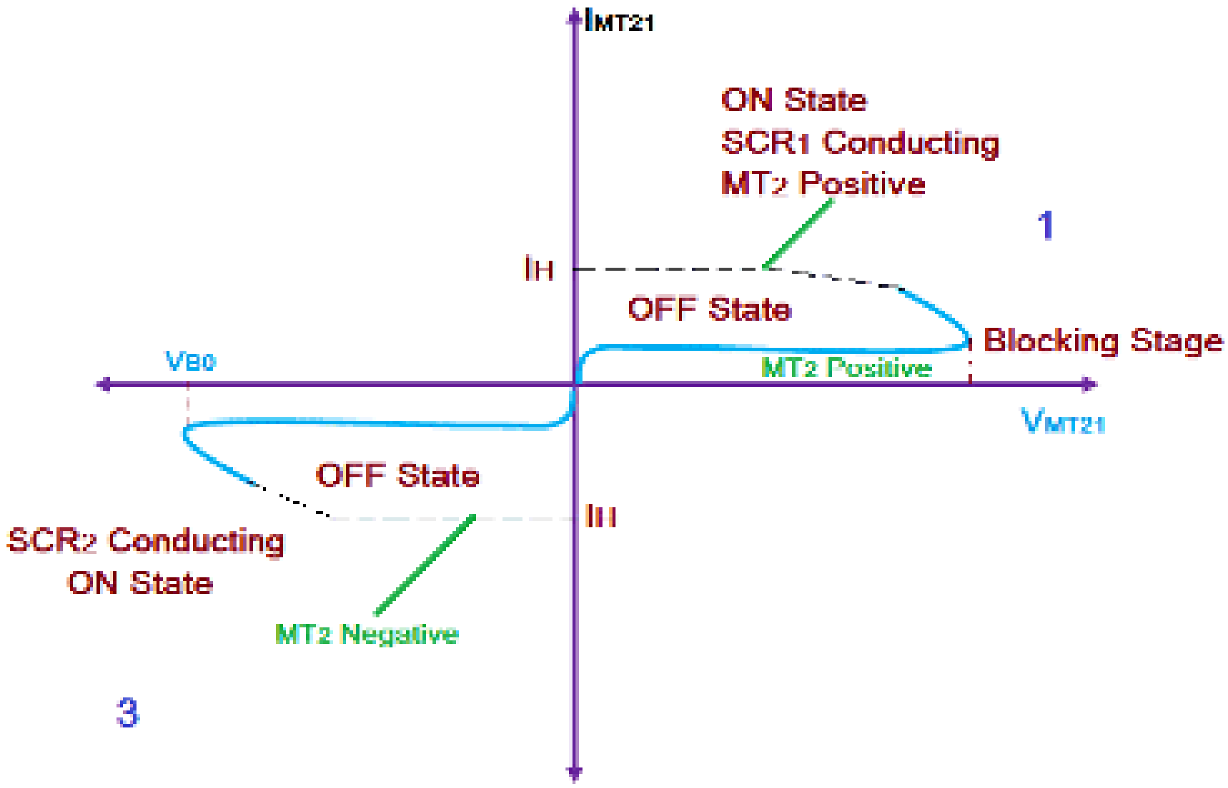
Basic Structure *Electrical Equivalent Circuit*

Although TRIAC is a bidirectional device, everyone prefers to specify voltage and current using MT1 as the reference in order to reduce confusion.

VI characteristics of TRIAC

Since the TRIAC is a bidirectional device it's the **VI characteristics curve of TRIAC** will be on the first and third quadrant of the graph, which is similar to the **VI characteristics of a Thyristor**. If you are completely news to Thyristors like SCR you can check the Introduction to SCR article. When the terminal MT2 is set to be positive with respect to the terminal MT1 the TRIAC will be operating in the forward blocking mode.

During the initial stage due to the resistance of the TRIAC, there will be a small leakage current flowing through the device as the applied voltage is less than the breakdown voltage. When the voltage is increased and it reaches the **breakdown voltage** the TRIAC is turned on and high current starts flowing through the device.



V-I Characteristics of a TRIAC

Apart from increasing the voltage of the device the TRIAC can be turned ON by applying the gate pulse, even if the applied voltage is less than the breakdown voltage. The same operation can be carried out in the negative direction of the TRIAC which can leave us with a mirror image of the same curve on the negative quadrant. The supply voltage at which the TRIAC starts conduction will depend on the gate current applied to the TRIAC. If the gate current is higher, then the voltage required to turn ON the TRIAC can be less. The characteristic curve that is given above shows the operation of TRIAC in mode 1 on the first quadrant and mode 3 on the third quadrant.

1.7 Construction, working principle of UJT, V-I characteristics of UJT. UJT as relaxtion oscillator.

B.K.N. GOVT POLYTECHNIC NARNAUL

DEPTT: - INSTRUMENTATION AND CONTROL ENGG.

SUBJECT: - PROCESS INSTRUMENTATION (5^{th} Semester)

UNIT:-1 INTRODUCTION

1. Introduction

Define following process variables along with their importance and measuring units.

1.1 Temperature

1.2 Pressure

1.3 Level

1.4 Flow

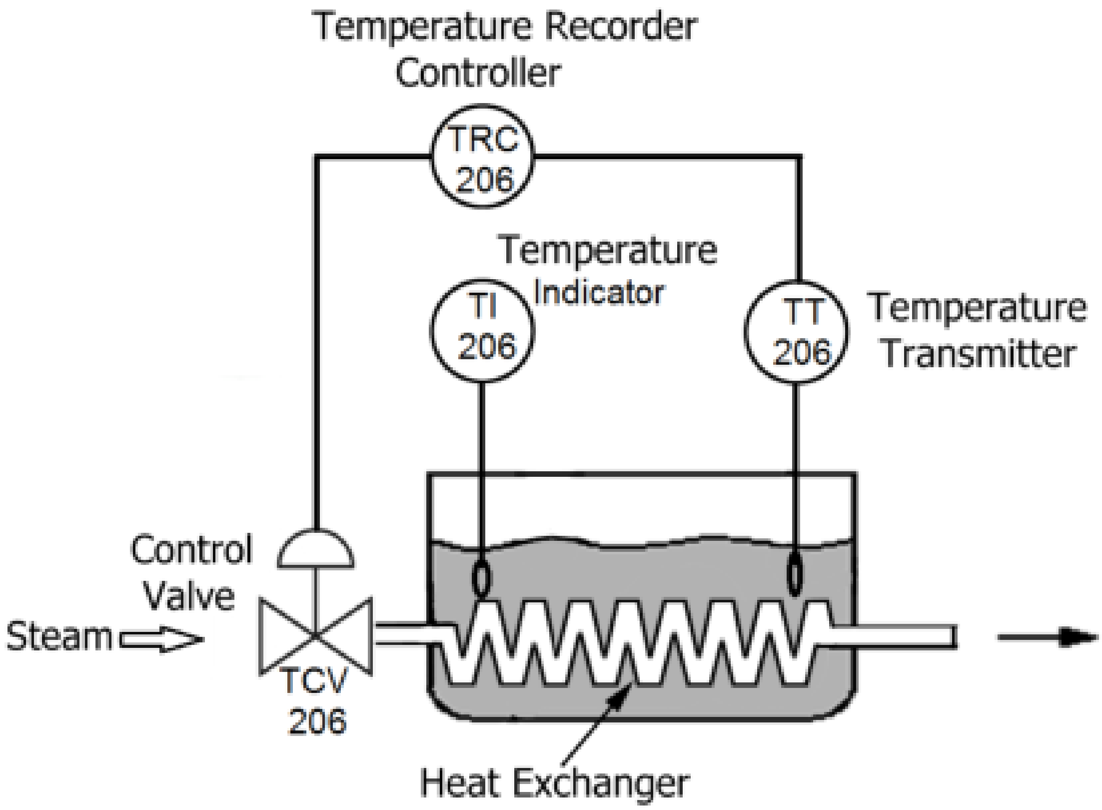
A process variable, process value or process parameter is the current measured value of a particular part of a process which is being monitored or controlled.

Instruments are used to monitor and control a process to keep the process within a correct limit. The parameters or quantities that we wish to control at the correct limit are called Process Variables. A variable is something that can vary or change. Because process variables can and do change, instrumentation systems measure the variable then control the variable to keep the variable within the given limits.

Pressure, Temperature, Flow are the main three process variables in industries. The level is another process variable in industries.

Temperature variable:

Temperature is a measurement of how hot or how cold an object is. Below figure shows a temperature control unit.



Water in the vessel is heated by the heat exchanger. Measuring the temperature the steam flow to the exchanger is controlled. Temperature changes when the amount of steam is changed. The process variable is called Temperature.

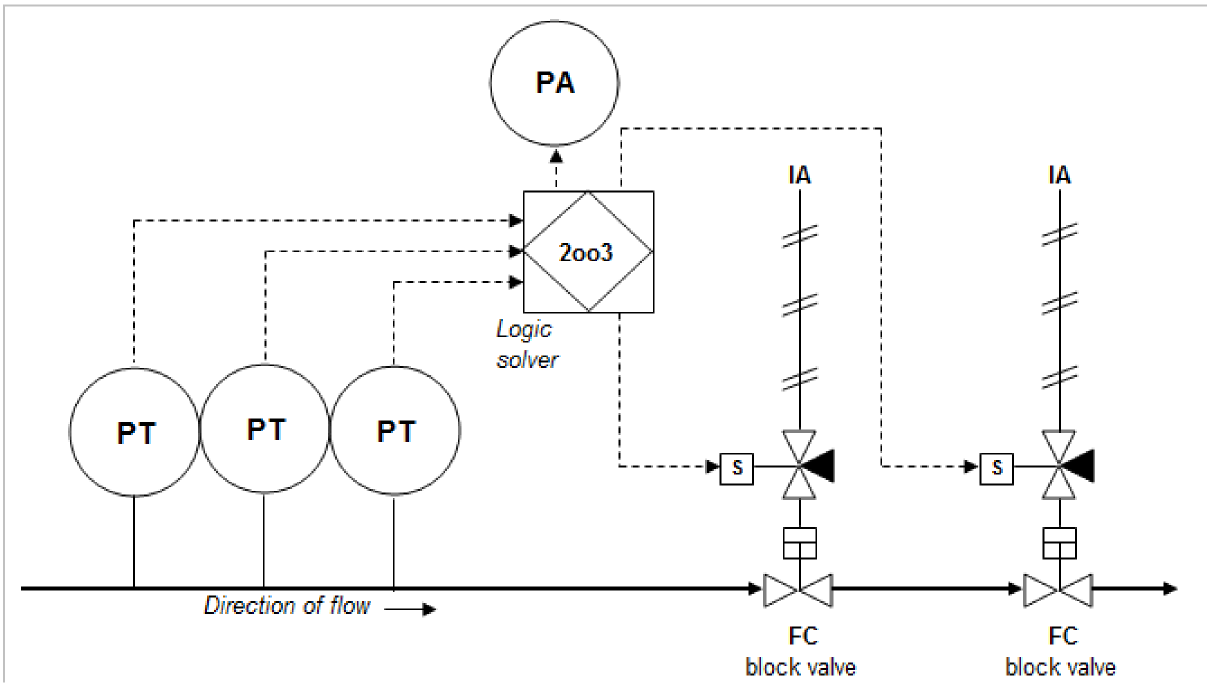
Measuring Units:-

The basic unit of temperature in (SI) is the Kelvin. It has the symbol K.

For everyday applications, it is often convenient to use the Celsius scale, in which 0 °C corresponds very closely to the freezing point of water and 100 °C is its boiling point at sea level. Because liquid droplets commonly exist in clouds at sub-zero temperatures, 0 °C is better defined as the melting point of ice. In this scale a temperature difference of 1 degree Celsius is the same as a 1kelvin increment, but the scale is offset by the temperature at which ice melts (273.15 K).

Pressure variable:

Pressure is a term used to describe the amount of force applied to a specific unit area. Below shows a flow channel of fluid from a compressor.



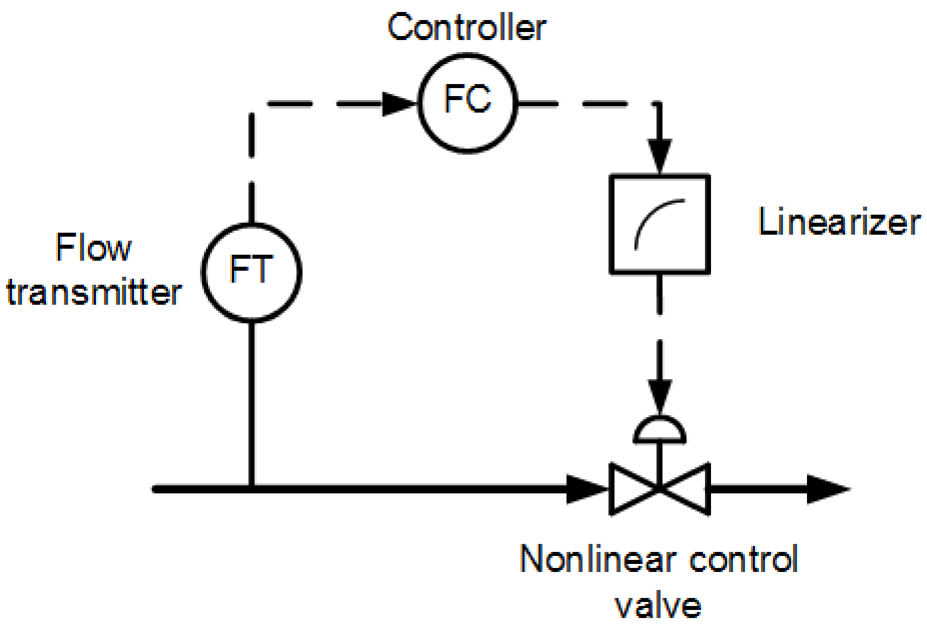
If you open the block valve, air is released to the atmosphere, so the pressure inside the receiver decreases. If you close the control valve, you keep the air inside the receiver and the pressure increases. The process variable that we are controlling is called PRESSURE.

Measuring Units:-

For pressure, the SI system's basic unit is Pascal (Pa), which is N/m² (Newton per square meter, while Newton is kegs/s²).

Flow variable:

Flow is the movement of fluid inside a pipe in a given direction. Figure below shows the flow control loop.



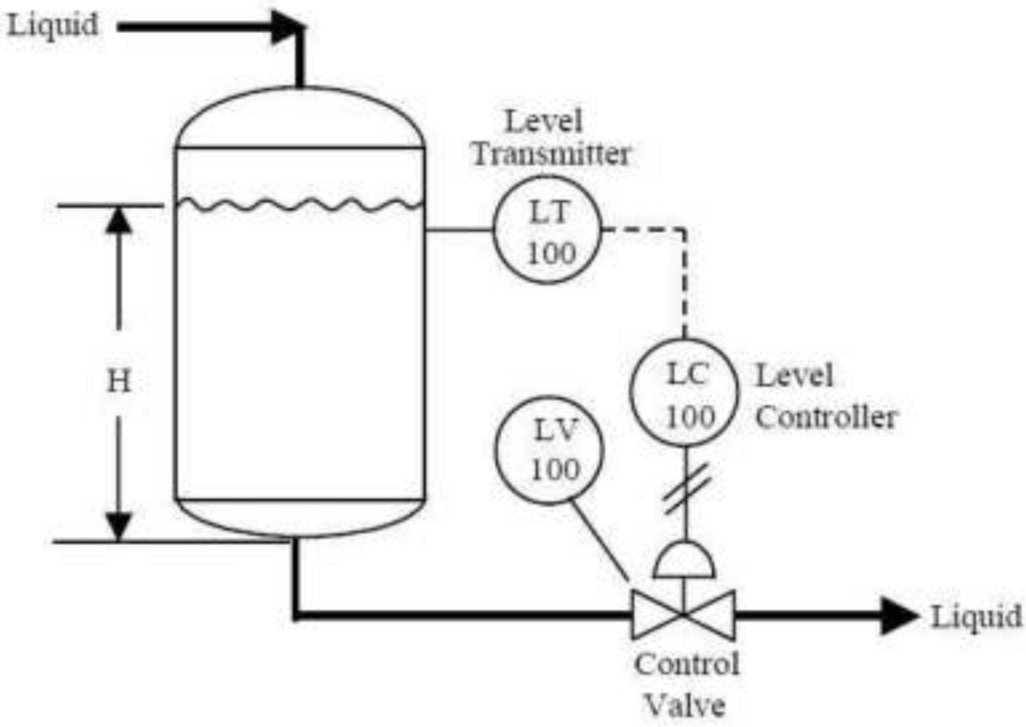
A valve in the flow channel controls the flow through the pipeline. The greater the valve opening the greater the water flow inside the pipe. Here we are controlling the flow the fluid passing through the pipeline, so the process variable is flow.

Measuring Units:-

Kg/hr, Litre/min. , M^3/Sec.

Level variable:

The level in the tank change up and down depending up the fluid in the tank. A control valve is installed in the output line to control the level of the tank.



The process variable is level. You can change the level by closing or opening the control valve. If you close the valve, the level increases. If you open the valve, the level decreases.

Measuring Units:-

Metre,Centimeter

TEMPERATURE MEASUREMENT – CHAP.-2 (PI)

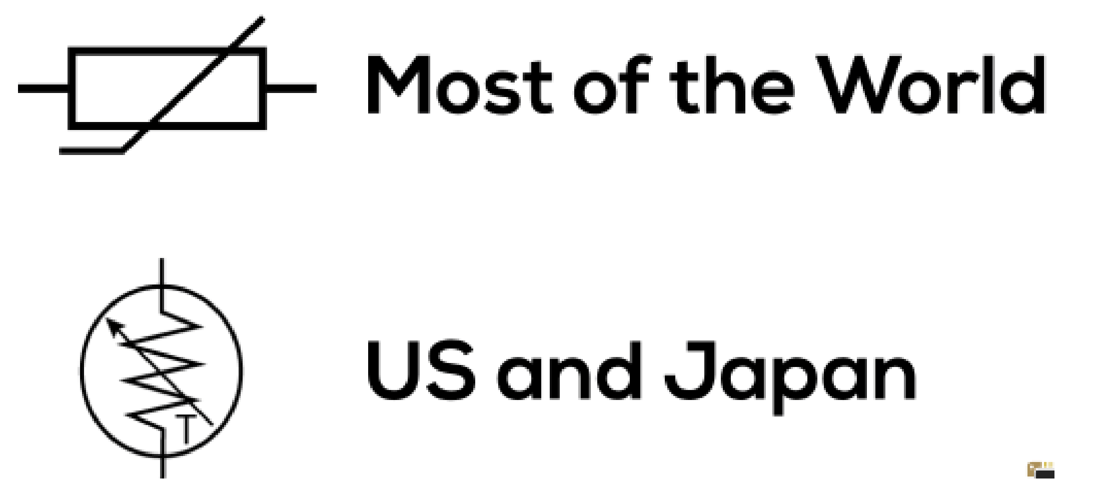
MADE BY: ANJANI KUMAR (LECT. I&C)

THERMISTOR:

A thermistor (or thermal resistor) is defined as a type of resistor whose electrical resistance varies with changes in temperature. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.

Thermistors act as a passive component in a circuit. They are an accurate, cheap, and robust way to measure temperature. While they do not work well in extremely hot or cold temperatures, they are the sensor of choice for many different applications. They are ideal when a precise temperature reading is required. The circuit symbol for a thermistor is shown below:

THERMISTOR SYMBOL:



THERMISTOR TYPES:

There are two types of thermistors:

- Negative Temperature Coefficient (NTC) Thermistor
- Positive Temperature Coefficient (PTC) Thermistor

NTC Thermistor:

In an NTC thermistor, when the temperature increases, resistance decreases. And when temperature decreases, resistance increases. Hence in an NTC thermistor temperature and resistance are inversely proportional. These are the most common type of themistor.

THERMISTOR TYPES:

PTC Thermistor:

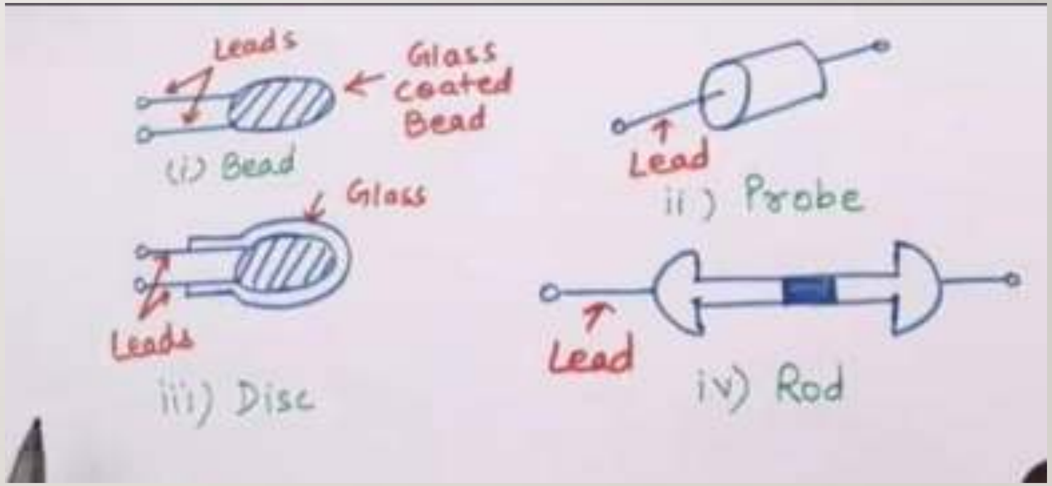
- A PTC thermistor has the reverse relationship between temperature and resistance. When temperature increases, the resistance increases. And when temperature decreases, resistance decreases. Hence in a PTC thermistor temperature and resistance are inversely proportional.
- Although PTC thermistors are not as common as NTC thermistors, they are frequently used as a form of circuit protection. Similar to the function of fuses, PTC thermistors can act as current-limiting device.
- When current passes through a device it will cause a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings then the device heats up. In a PTC thermistor, this heating up will also cause its resistance will increase. This creates a self-reinforcing effect that drives the resistance upwards, therefore limiting the current. In this way, it acts as a current limiting device – protecting the circuit.

THERMISTOR CONSTRUCTION:

To make a thermistor, two or more semiconductor powders made of metallic oxides are mixed with a binder to form a slurry. Small drops of this slurry are formed over the lead wires. For drying purpose, we have to put it into a sintering furnace. During this process, that slurry will shrink onto the lead wires to make an electrical connection. This processed metallic oxide is sealed by putting a glass coating on it. This glass coating gives a waterproof property to the thermistors – helping to improve their stability.

THERMISTOR CONSTRUCTION:

There are different shapes and sizes of thermistors available in the market. Smaller thermistors are in the form of beads of diameter from 0.15 millimeters to 1.5 millimeters.Thermistors may also be in the form of disks and washers made by pressing the thermistor material under high pressure into flat cylindrical shapes with diameter from 3 millimeters to 25 millimeters.



THERMISTOR CONSTRUCTION:

The typical size of a thermistor is 0.125mm to 1.5 mm. Commercially available thermistors have nominal values of 1K, 2K, 10K, 20K, 100K, etc. This value indicates the resistance value at a temperature of 25oC.

Thermistors are available in different models: bead type, rod type, disc type, etc. The major advantages of thermistors are their small size and relatively low cost.

This size advantage means that the time constant of thermistors operated in sheaths is small, although the size reduction also decreases its heat dissipation capability and so makes the self-heating effect greater. This effect can permanently damage the thermistor.

To prevent this, thermistors have to be operated at low levels of electric current compared to resistance thermometer – resulting in lower measurement sensitivity.

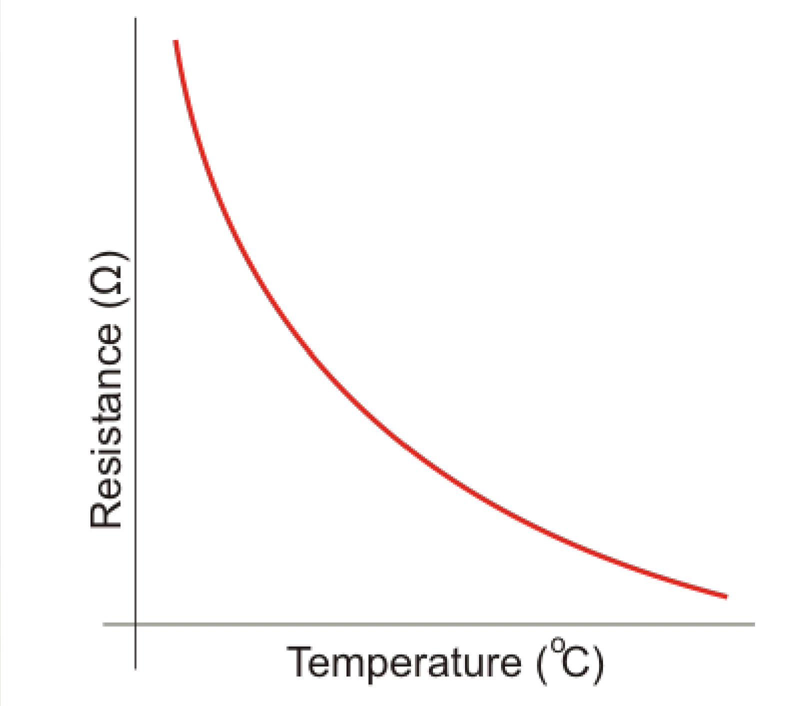
THERMISTOR WORKING PRINCIPLE:

The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter. If we know the exact relationship between how changes in the temperature will affect the resistance of the thermistor – then by measuring the thermistor's resistance we can derive its temperature.

How much the resistance changes depends on the type of material used in the thermistor. The relationship between a thermistor's temperature and resistance is non-linear. A typical thermistor graph is shown below:

THERMISTOR WORKING PRINCIPLE:

If we had a thermistor with the above temperature graph, we could simply line up the resistance measured by the ohmmeter with the temperature indicated on the graph. By drawing a horizontal line across from the resistance on the y-axis, and drawing a vertical line down from where this horizontal line intersects with the graph, we can hence derive the temperature of the thermistor.



USES OF THERMISTORS:

Thermistors have a variety of applications. They are widely used as a way to measure temperature as a thermistor thermometer in many different liquid and ambient air environments. Some of the most common uses of thermistors include:

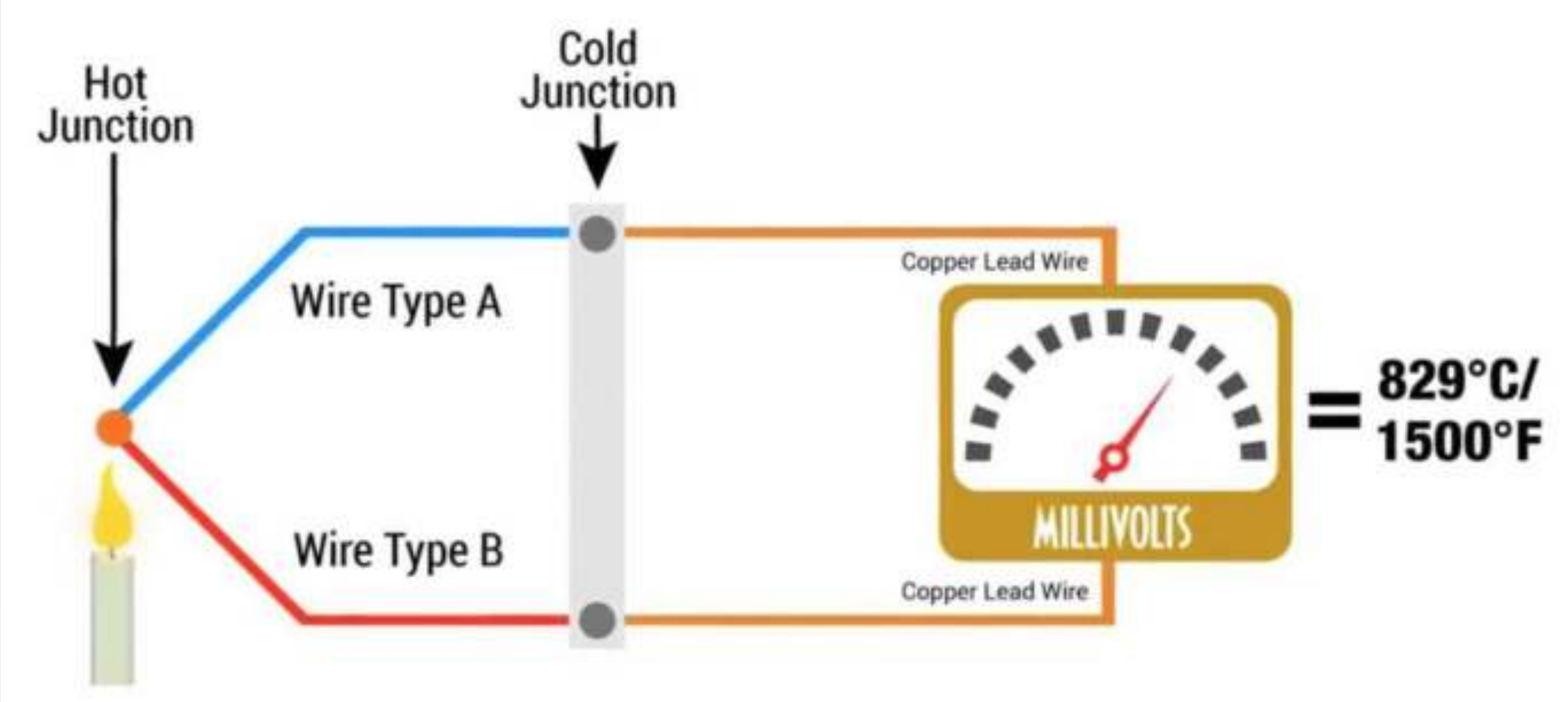
- Digital thermometers (thermostats)
- Automotive applications (to measure oil and coolant temperatures in cars & trucks)
- Household appliances (like microwaves, fridges, and ovens)
- Circuit protection (i.e. surge protection)
- Rechargeable batteries (ensure the correct battery temperature is maintained)
- To measure the thermal conductivity of electrical materials
- Useful in many basic electronic circuits (e.g. as part of a beginner Arduino starter kit)
- Temperature compensation (i.e. maintain resistance to compensate for effects caused by changes in temperature in another part of the circuit)
- Used in wheatstone bridge circuits

THERMOCOUPLE:

A Thermocouple is a sensor used to measure temperature. Thermocouples consist of two wire legs made from different metals. The wires legs are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.

There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility. Type J, K, T, & E are "Base Metal" thermocouples, the most common types of thermocouples. Type R, S, and B thermocouples are "Noble Metal" thermocouples, which are used in high temperature applications (see thermocouple temperature ranges for details).

THERMOCOUPLE:



CONSTRUCTION OF THERMOCOUPLE:

The construction of the thermocouple is shown below. It comprises of two different metal wires and that are connected together at the junction end. The junction thinks as the measuring end. The end of the junction is classified into three type's namely ungrounded, grounded and exposed junction.

Ungrounded-Junction:

In this type of junction, the conductors are totally separated from the protecting cover. The applications of this junction mainly include high-pressure application works. The main benefit of using this function is to decrease the stray magnetic field effect.

CONSTRUCTION OF THERMOCOUPLE:

Grounded-Junction:

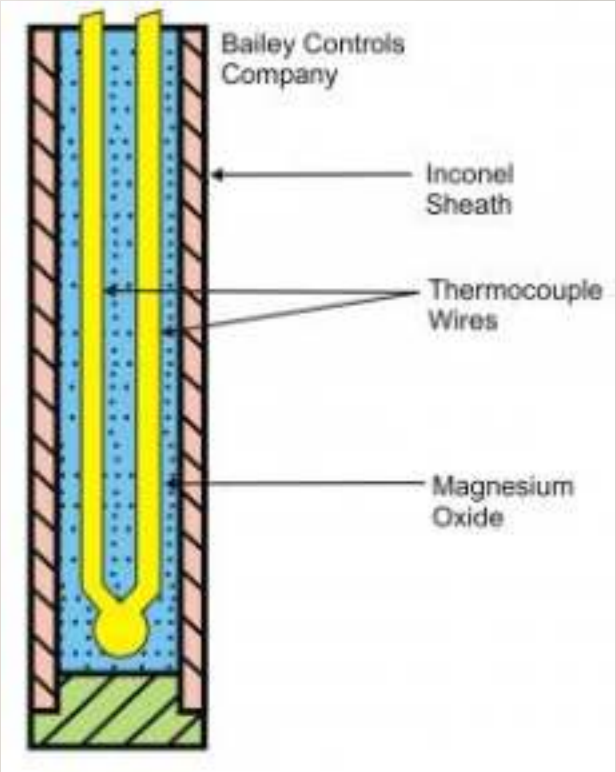
In this type of junction, the metal wires as well as protecting cover are connected together. This function is used to measure the temperature in the acidic atmosphere, and it supplies resistance to the noise.

Exposed-Junction:

The exposed junction is applicable in the areas where a quick response is required. This type of junction is used to measure the gas temperature. The metal used to make the thermocouple basically depends on the calculating range of temperature.

CONSTRUCTION OF THERMOCOUPLE:

Generally, a thermocouple is designed with two different metal wires namely iron and constantan that makes in detecting element by connecting at one junction that is named as a hot junction. This consist of two junctions, one junction is connected by voltmeter or transmitter where the cold junction and second junction is associated in a process that is called as a hot junction.



WORKING PRINCIPLE OF THERMOCOUPLE:

The thermocouple schematic diagram is shown in the below figure. This circuit can be built with two different metals, and that are coupled together by generating two junctions. The two metals are surrounded by the connection through welding.

In the above diagram, the junctions are denoted by P & Q, and the temperatures are denoted by T1, & T2. When the temperature of the junction is dissimilar from each other, then the electromagnetic force generates in the circuit.

If the temperate at the junction end turn into equivalent, then the equivalent, as well as reverse electromagnetic force, produces in the circuit, and there is no flow of current through it. Similarly, the temperature at the junction end becomes imbalanced, then the potential variation induces in this circuit.

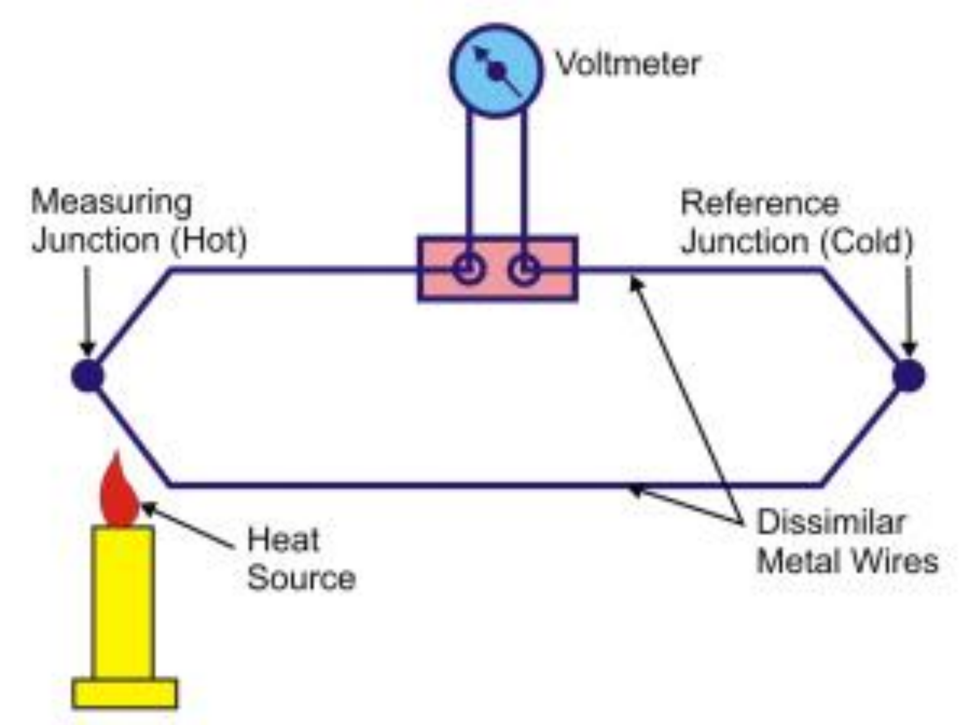
WORKING PRINCIPLE OF THERMOCOUPLE:

The magnitude of the electromagnetic force induces in the circuit relies on the sorts of material utilized for thermocouple making. The entire flow of current throughout the circuit is calculated by the measuring tools.

The electromagnetic force induced in the circuit is calculated by the following equation

$E = a\ (\Delta\Theta) + b\ (\Delta\Theta)2$

Where $\Delta\Theta$ is the temperature difference among the hot thermocouple junction end as well as the reference thermocouple junction end, a & b are constants



ADVANTAGES OF THERMOCOUPLE:

The advantages include the following.

- Accuracy is high
- It is Robust and can be used in environments like harsh as well as high vibration.
- The thermal reaction is fast
- The operating range of the temperature is wide.
- Wide operating temperature range
- Cost is low and extremely consistent

DISADVANTAGES OF THERMOCOUPLE:

The disadvantages include the following.

- Nonlinearity
- Least stability
- Low voltage
- Reference is required
- least sensitivity
- The thermocouple recalibration is hard

THERMOCOUPLE APPLICATIONS:

Some of the applications of thermocouple include the following.

- These are used as the temperature sensors in thermostats in offices, homes, offices & businesses.
- These are used in industries for monitoring temperatures of metals in iron, aluminum, and metal.
- These are used in the food industry for cryogenic and Low-temperature applications. Thermocouples are used as a heat pump for performing thermoelectric cooling.
- These are used to test temperature in the chemical plants, petroleum plants.
- These are used in gas machines for detecting the pilot flame.

RADIATION PYROMETER:

Pyrometers are used to measure the temperature which is difficult to measure. They are non-contact devices, used to measure temperature above 1500 degree Celsius, contact devices may melt at this temperature.

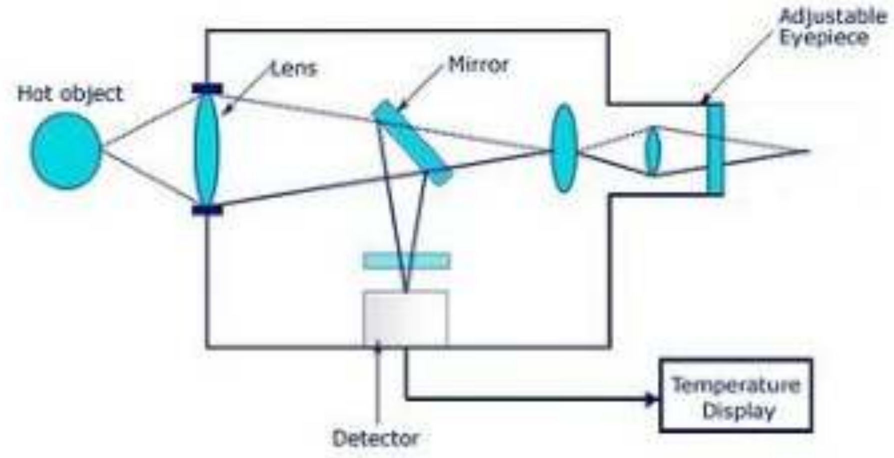
The main reason behind that, this type of temperature sensors or thermometer is not required to be brought in touch with the object whose temperature to be measured. For very high temperature, conventional thermometer is not at all suitable to touch with the hot object as there may be always a chance severe damage of the thermometer.

Not only that, some time the hot object is located in so narrow passage of system, it is impossible to bring a thermometer near to that. In this situation too, radiation pyrometer is successfully used for temperature measurement. The main working principle of this type of instruments is that, it senses the heat radiation from a targeted hot body and reads and records its temperature, depending upon the intensity of radiation.

RADIATION PYROMETER CONSTRUCTION:

The pyrometer has an optical system, including a lens, mirrors and adjustable eyepiece and a detector circuit.

An optical system collects the visible and infrared energy from an object and focuses it on a detector.



RADIATION PYROMETER APPLICATIONS:

Pyrometers are suited especially to the measurement of moving objects or any surfaces that cannot be reached or cannot be touched. Contemporary multispectral pyrometers are suitable for measuring high temperatures inside combustion chambers of gas turbine engines with high accuracy.

Temperature is a fundamental parameter in metallurgical furnace operations. Reliable and continuous measurement of the metal temperature is essential for effective control of the operation. Smelting rates can be maximized, slag can be produced at the optimum temperature, fuel consumption is minimized and refractory life may also be lengthened. Thermocouples were the traditional devices used for this purpose, but they are unsuitable for continuous measurement because they melt and degrade.

Salt bath furnaces operate at temperatures up to 1300 °C and are used for heat treatment. At very high working temperatures with intense heat transfer between the molten salt and the steel being treated, precision is maintained by measuring the temperature of the molten salt. Most errors are caused by slag on the surface which is cooler than the salt bath.

RADIATION PYROMETER APPLICATIONS:

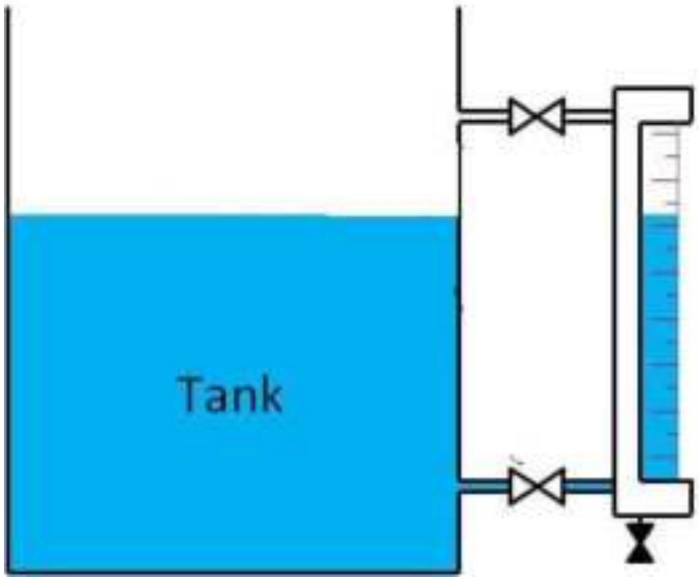
The tuyère pyrometer is an optical instrument for temperature measurement through the tuyeres which are normally used for feeding air or reactants into the bath of the furnace.

A steam boiler may be fitted with a pyrometer to measure the steam temperature in the superheater.

A hot air balloon is equipped with a pyrometer for measuring the temperature at the top of the envelope in order to prevent overheating of the fabric.

Pyrometers may be fitted to experimental gas turbine engines to measure the surface temperature of turbine blades. Such pyrometers can be paired with a tachometer to tie the pyrometer output with the position of an individual turbine blade. Timing combined with a radial position encoder allows engineers to determine the temperature at exact points on blades moving past the probe.

Level Measurements Using Sight glass



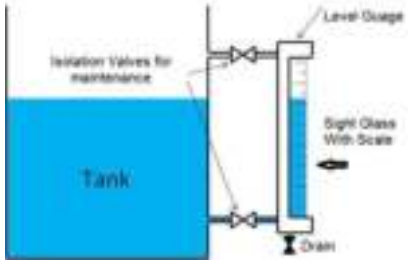
Construction

Working Principle

Applications

Advantages & Disadvantages

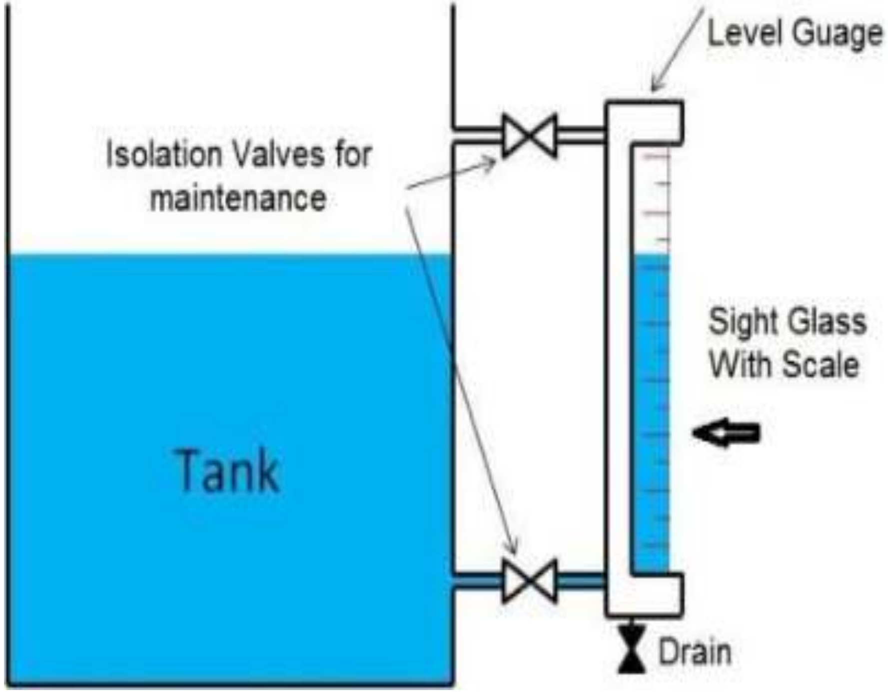
Level Measurements Using Sight glass



Construction of Sight glass

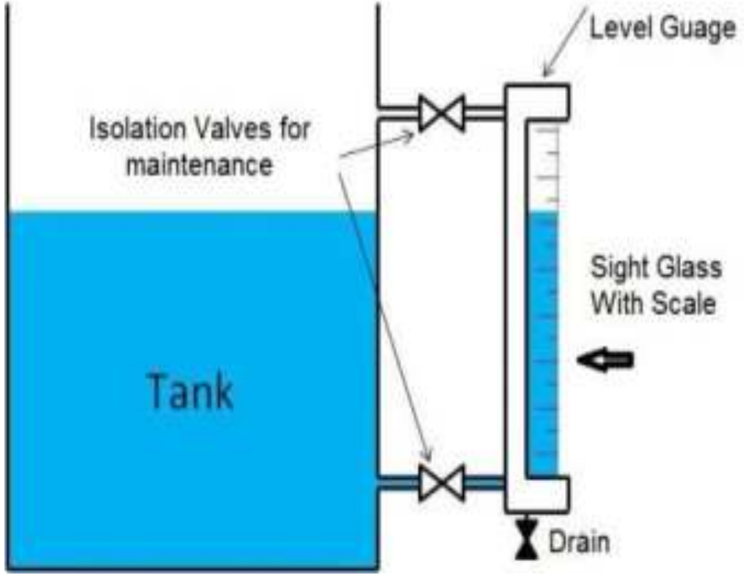
It consists of a transparent Level Gauge employ transparent glass fitted with a liquid chamber/tank on one side or either sides of the tank. The sight glass is marked with graduations to allow the level to be measured.

It Consists of two Isolation valves which can be used during maintenance.



Construction of Sight glass

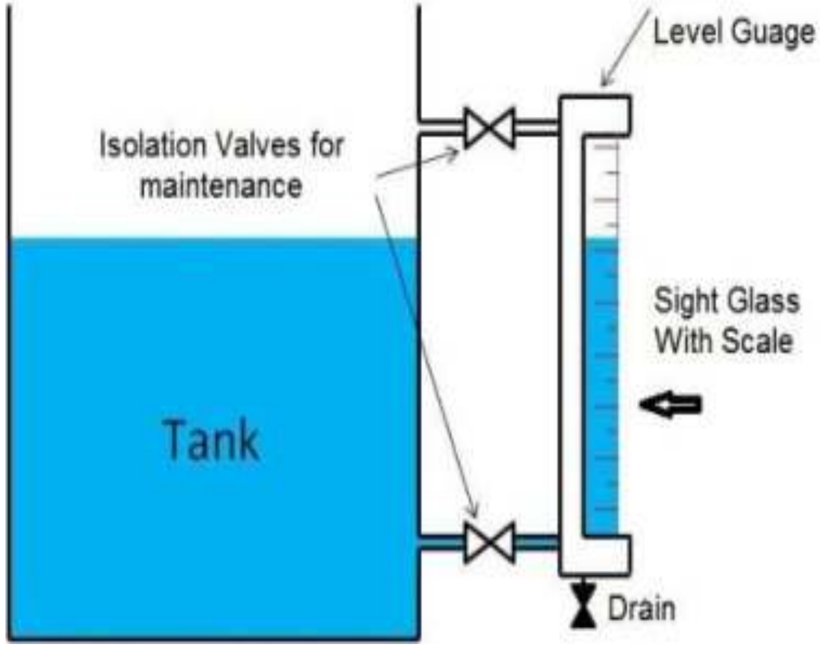
A drain is provided at the bottom of gauge as shown in figure.
For water / steam applications, an illuminator is mounted on the rear side of the gauge with its light rays deflected upward into the water column.



Working Principle of Sight glass

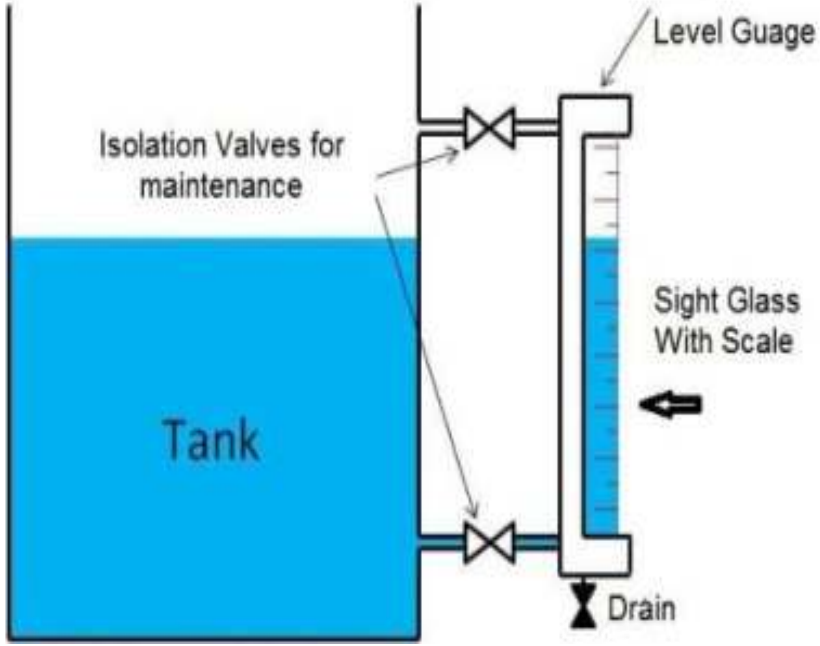
sight glass is probably the simplest method of measuring liquid level.

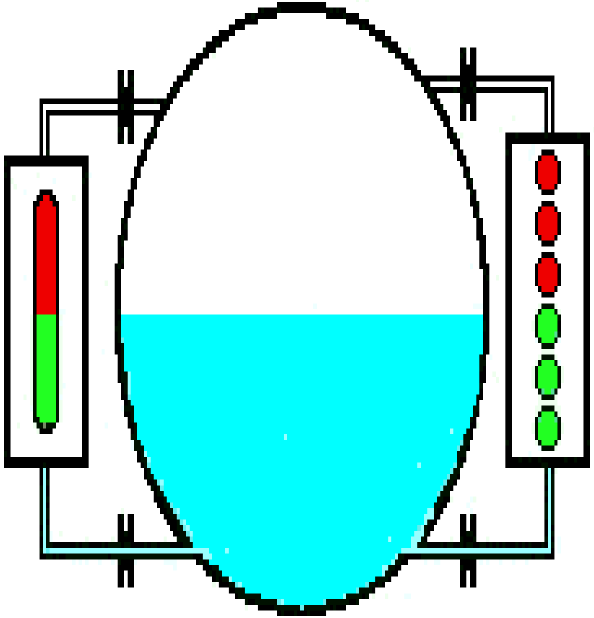
The sight glass is attached to the outside of the tank so that the liquid level can be seen through the glass. . The liquid level is indicated as a result of difference in the transparent properties of the two media.



Working Principle of Sight glass

A visual indication of the level can be obtained when part of the vessel is constructed from transparent material or the liquid in a vessel is bypassed through a transparent tube





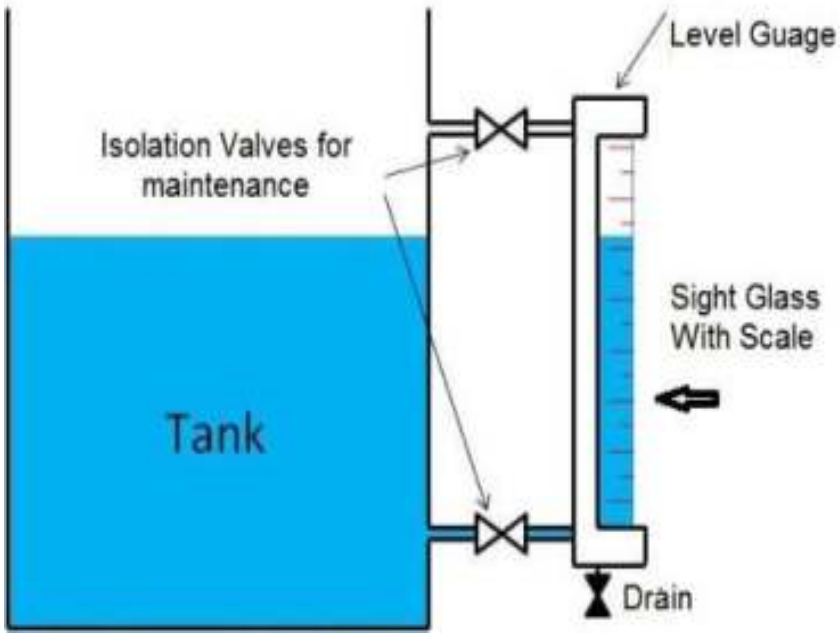
Sight glass

Applications

1. Applications of such level measuring devices can be seen in tanks for the storage of lubricating oils or water

Limitations

1. Sight glasses are also not suitable for dark or dirty liquids
2. This type should not be used when measuring hazardous liquids as the glass-tube is easily damaged or broken.



Level Measurements Using Sight glass

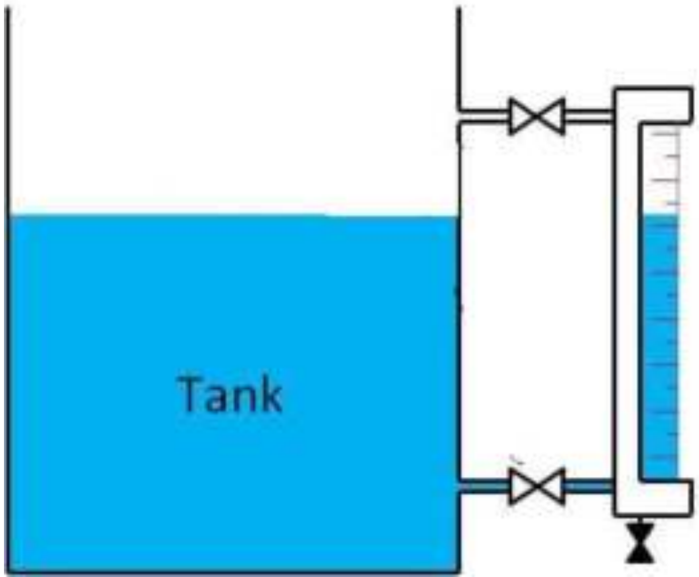
Advantages

1. It is very simply constructed.
2. It is less costly.

Disadvantages

1. It is not suitable for automated control.
2. It can easily be damaged (broken)
3. It requires maintenance and cleaning.

Level Measurements Using Sight glass



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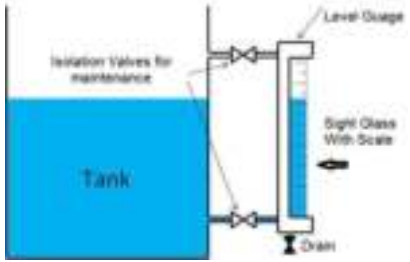

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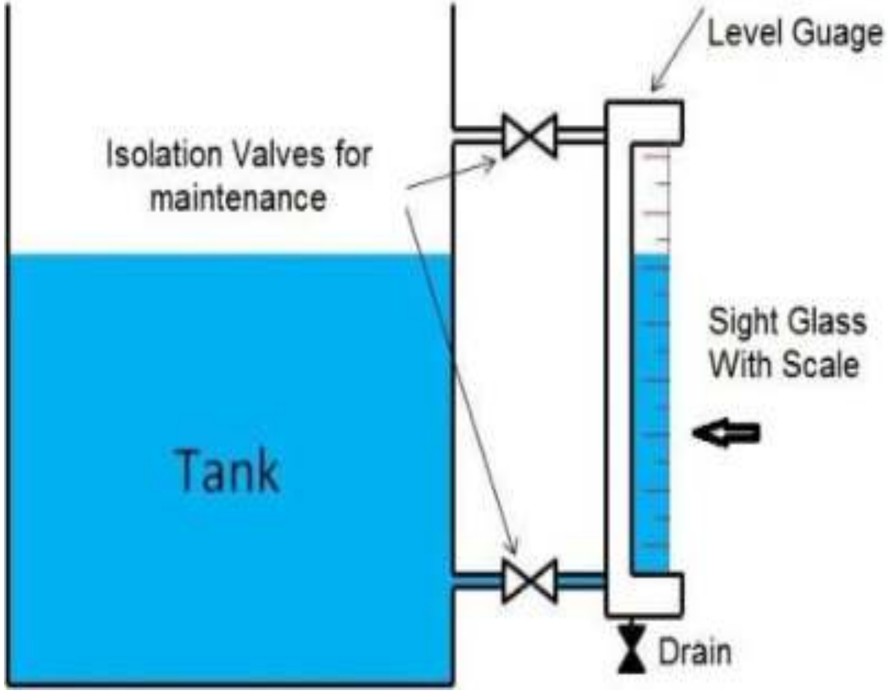

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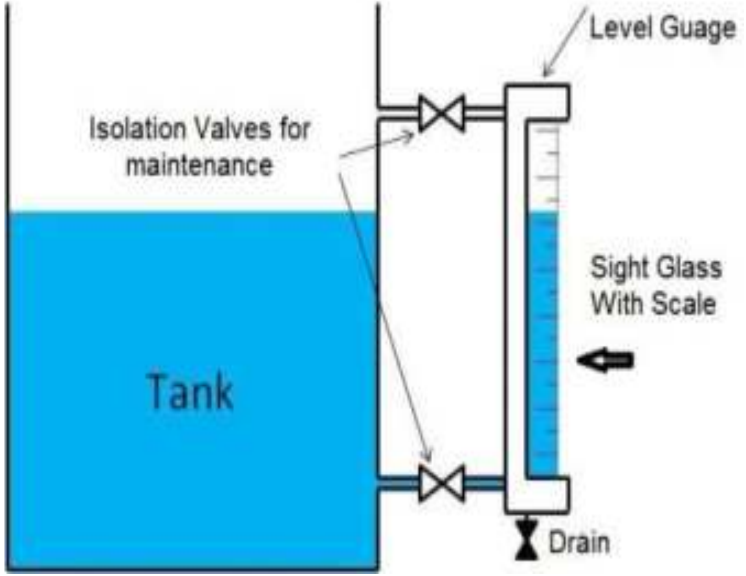

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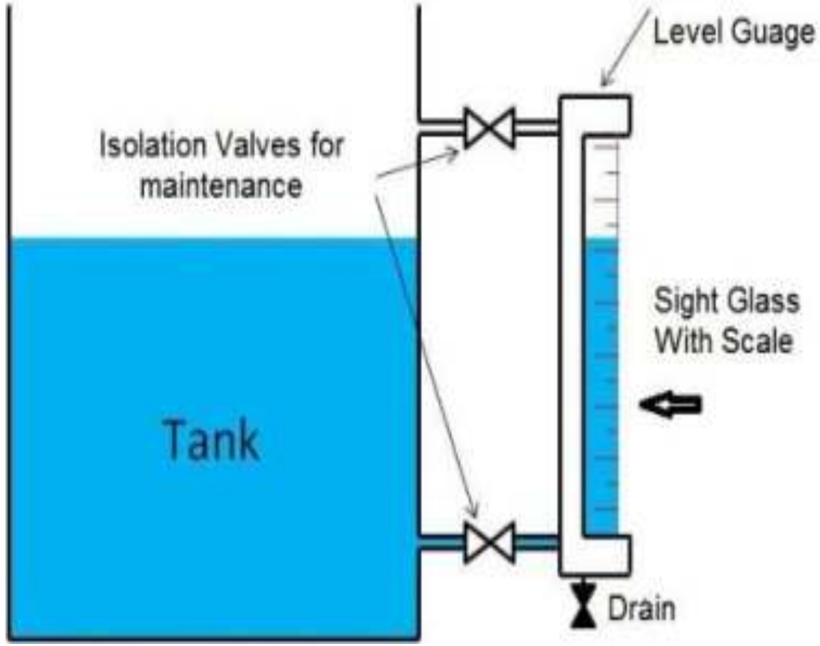

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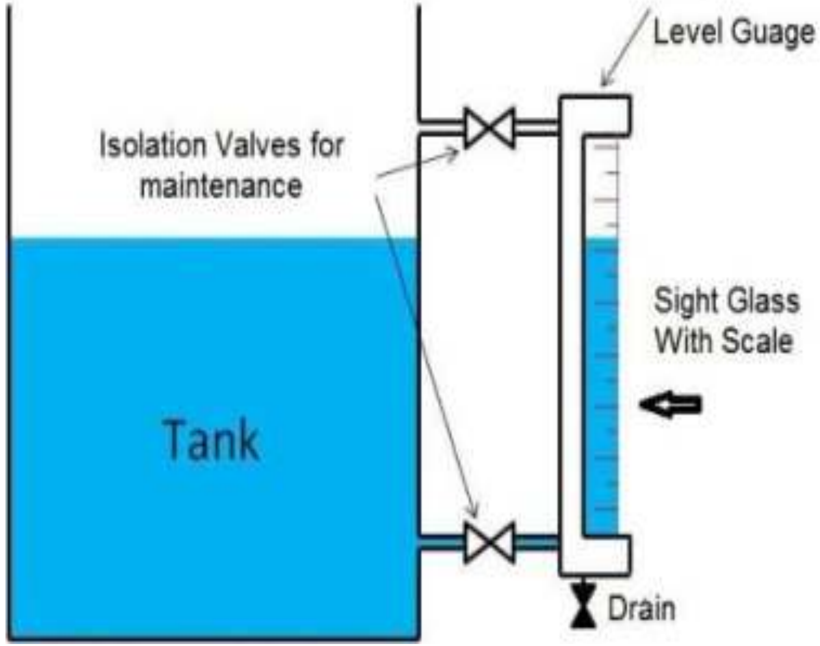

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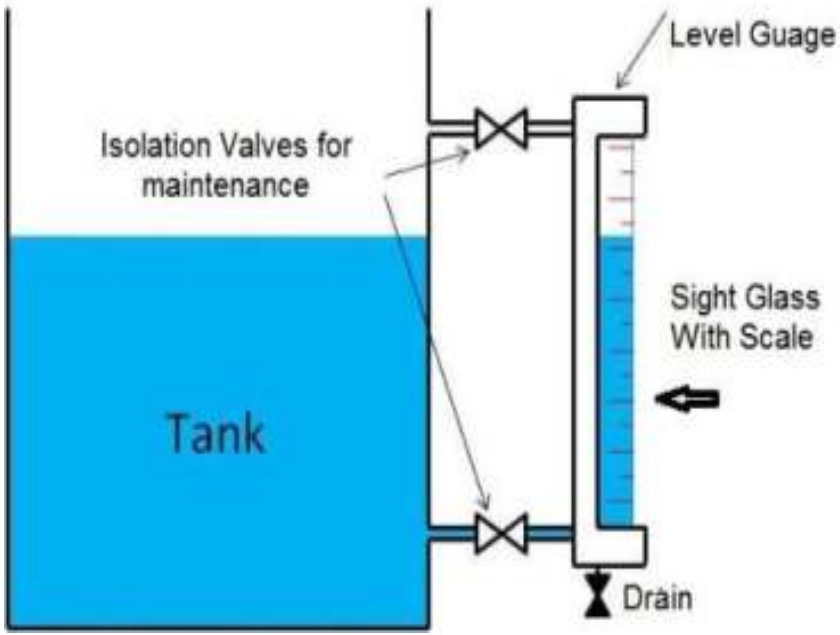

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