Chapter 2

Sensors & Actuators

In this chapter...

2.1 INTRODUCTION TO SENSORS

Sensor is the equipment which is used to produce a signal or indicating through many sources like (HORN or vibration) to the quantity being measured. The sensor is a device through which we sense the present condition, situation or state of the object. The variable values on output which reflects the complete condition and change the final results.

Examples of sensors in daily life:

- In the automobile Anti locking system, brake system, are the example of sensor.
- In ordinary dial indicator the indicating spindle work as a sensor/detector.

2.2 TYPES OF SENSORS

There are mainly eight types of sensors used according to these working process and utility.

1. Potentiometer sensors 2. Proximity sensors

3. Pneumatic sensors
4. Light sensors
5. Tactile sensors
6. Hall effect sensors
7. Pyroelectric sensors
8. Smart sensors

2.2.1 Potentiometer sensors

In this type of sensor a resistance element is attached with a sliding contact and that element is able to move in a particular range. The elements are generally used for linear or rotary displacements, the produced displacement is being converted into a potential difference.

The potentiometer as shown in fig. 2.1 with a circular wire wound track, in which a Rotatable and supportable sliding contact can be rotated. The track may be helical in shape.

V_S = Constant input voltage between switch 1 and 3.

V_0 = Output voltage between switch 2 and 3, is a fraction of input voltage.

R_{23} = Resistance between switch 2 and 3

R_{13} = Resistance between switch 1 and 3

Therefore $\left[\dfrac{V_0}{V_S} = \dfrac{R_{23}}{R_{13}}\right]$

If the track has a constant resistance per unit length, then the output is proportional to the angle through which the slider has rotated.

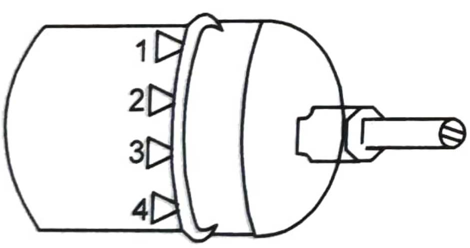


Fig. 2.1 : A rotary potentiometer

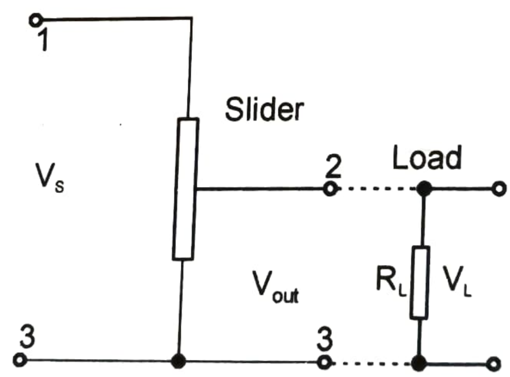


Fig. 2.2 : The circuit connected to the load

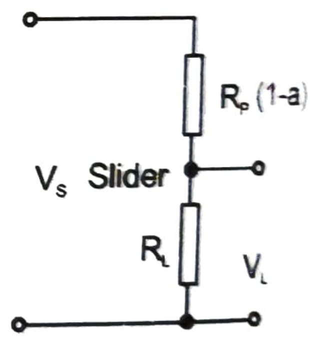


Fig. 2.3 : Circuit as a potential divider

After the complete process the angular displacement can be converted into a potential difference. The voltage output will changes with the every turn of the slider on a wire wound track.

If the potentiometer has N turns then the resolution, as a percentage is equal to $\dfrac{100}{N}$. Thus the resolution of a wire depends on the diameter of the wire used on the rotary track, and generally the range of diameter is 1.5 mm for a coarsely wound track to 0.5 mm for a finely wound one.

In potentiometer the effect of a load R_L connected across the output. If the load resistance is infinite than only the potential difference across the load V_L is directly proportional to V_0.

In finite loads, depends on the linear relationship between output voltage and angle into a non-linear relationship.

R_L = parallel resistance with the fraction (a)

R_P = resistance potentiometer

$$\text{Combined resistance } (R_C) = \frac{R_L a R_P}{(R_L + aR_P)}$$

$$\therefore \quad \text{Total resistance } (R_t) = R_P(1-a) + \frac{R_L a R_P}{(R_L + aR_P)}$$

The ratio of potential difference (V_L) across the load and constant input voltage (V_S) is equal to the ratio of combined resistance (R_C) and total resistance (R_t).

$$\frac{V_L}{V_S} = \frac{R_c}{R_t}$$

$$\frac{V_L}{V_S} = \frac{aR_L R_P/(R_L + aR_P)}{R_P(1-a) + aR_L R_P/(R_L + aR_P)}$$

$$\boxed{\frac{V_L}{V_S} = \frac{a}{(R_P/R_L)a(1-a)+1}}$$

If the load is of infinite resistance then $[V_L = a\,V_S]$

$\therefore$ Error introduced by the load having a finite resistance error

$$= aV_S - V_L = aV_S - \frac{aV_S}{(R_P/R_L)a(1-a)+1} = V_s \frac{R_P}{R_L}(a^2 - a^3)$$

2.10 INTRODUCTION TO ACTUATORS

An actuator is a motor device which is used to control the system or moves the mechanism of the system.

An actuator is a mechanism used in the manufacturing of machines and equipment to control the initiate value to start or stop a functions.

Applications :-

Actuators play an very important role in various fields like in engineering, electronic engineering, computer science, in mechanical engineering, etc. Mostly actuators produces linear, Rotary or oscillatory motion.

An important part in machines, in computer system, actuators is work as a fluid, air or electric current for smooth & easy motion of the equipment. By the use of actuators, it make easy for machine to allow more load, ruggedness, speed etc.

There are basically four types of Actuators :-

1. Hydraulic Actuators
2. Pneumatic Actuators
3. Electric Actuators
4. Mechanical Actuators

2.10.1 Hydraulic Actuators

Hydraulic actuator consist of a cylindrical shape fluid motor to assist (make easy) mechanical operations that utilizes hydraulic power.

The mechanical motion gives an output in terms of linear, rotary or oscillatory motion.

Hydraulic actuators operate with minimal mechanical parts. They use fluid to pressurize pistons, as hydraulic fluid cannot be compressed, due to this the hydraulic actuators take long time to gain high speed and while requiring according to the time. Therefore, they are more commonly used where time is not the major issue, used over extended periods of time in power equipment that will run at constant speed with infrequent stops, they can also be equipped with fail-safe features to permit quick stops for emergency condition ex:- Hydraulic machines.

2.10.2 Pneumatic Actuators

The working of Pneumatic actuator is same as hydraulic actuators. The major difference is in Pneumatic compressed gas used instead of **liquid**.

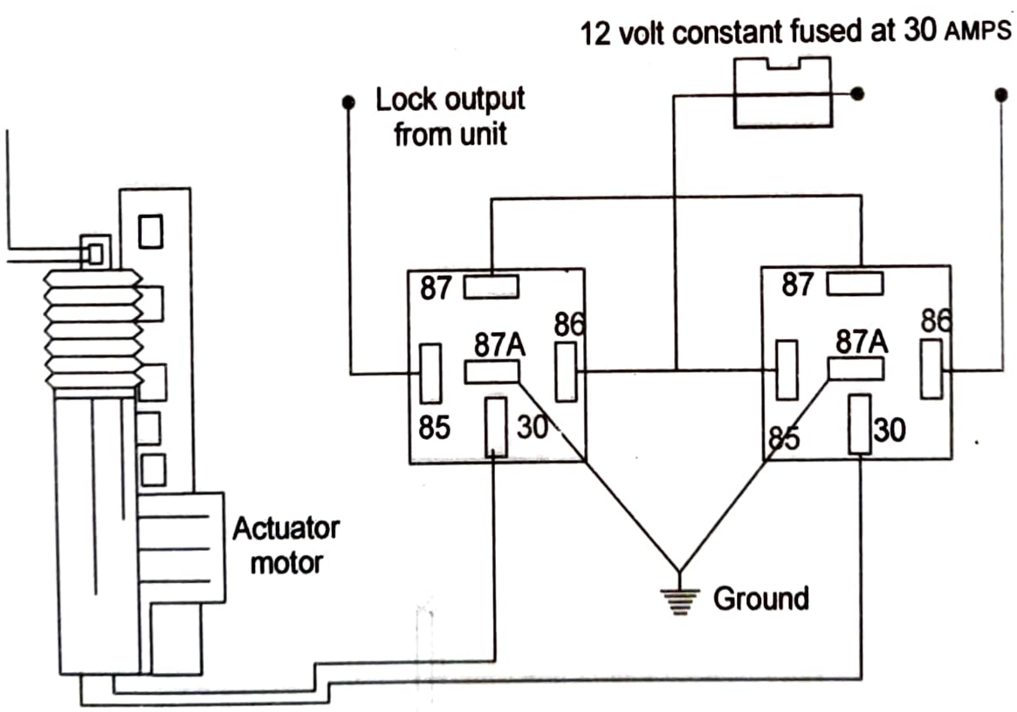


Fig. 2.31 : Pneumatic actuator

The energy present in the form of compressed gas is converted into linear or rotary motion first, that depends on the actuator.

Pneumatic energy is more desirable for main engine controls because the energy is quickly respond in starting (initial phase) and stopping as the power does not need to be stored in reserve for operations.

Pneumatic actuators are normally preferred where cleanliness is important, since the fluid in hydraulic actuators might leak and contaminate the surroundings, which effects the complete system They also operate with minimal parts, but use air to pressurize pistons. Regulation is not required in Pneumatic actuators for air compression.

Demerits of Pneumatic actuators :- A lot of space is required, create a lot noise while working and are difficult to transport once installed in a place.

2.10.3 Electric Actuators

Electric actuators are devices powered by motors that is used to convert the electrical energy to mechanical torque. The electrical energy is used to create motion in equipment that require multi-turn valves like gate or globe valves.

Electrical actuator is mainly considered as most clean actuator as there is no need of oil in this. Electric actuators are mainly installed in engines, where they open and close different valves.

The also require a battery backup to ensure safe operation should electric current somehow be prohibited.

The design of electric actuators is depend on their function in the engine that they are installed in.

2.10.4 Mechanical Actuators

Mechanical actuators function through converting rotary motion to linear motion. Devices such as pulley, chain, rails, gears and other are used to help convert the motion.

Screws are one of the common actuators with simple mechanisms, where the rotation of the actuator's nut causes the screw shaft to more in a straight line, the axle and the wheel, where the rotating motion of a wheel causes a belt or something similar to move in a linear motion.

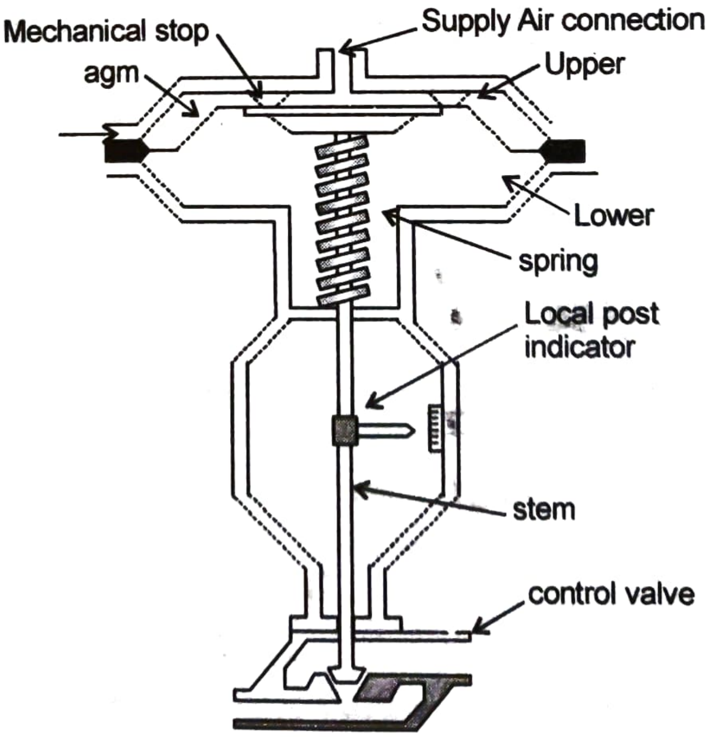


Fig. 2.32 : Mechanical actuator

Hydralic Systems:

→ Hydraulically operated components are frequently used in hydraulic feedback system and in combined electromechanical - hydraulic systems.

- In these elements power is transmitted through the action of fluid flow under pressure. The fluid used is relatively incompressible such as petroleum base oils or certain non-inflammable synthetic fluids.

- The main advantage of the hydraulic systems lies in the hydraulic motor which can be made much smaller in physical size than an electric motor for the same power o/p.

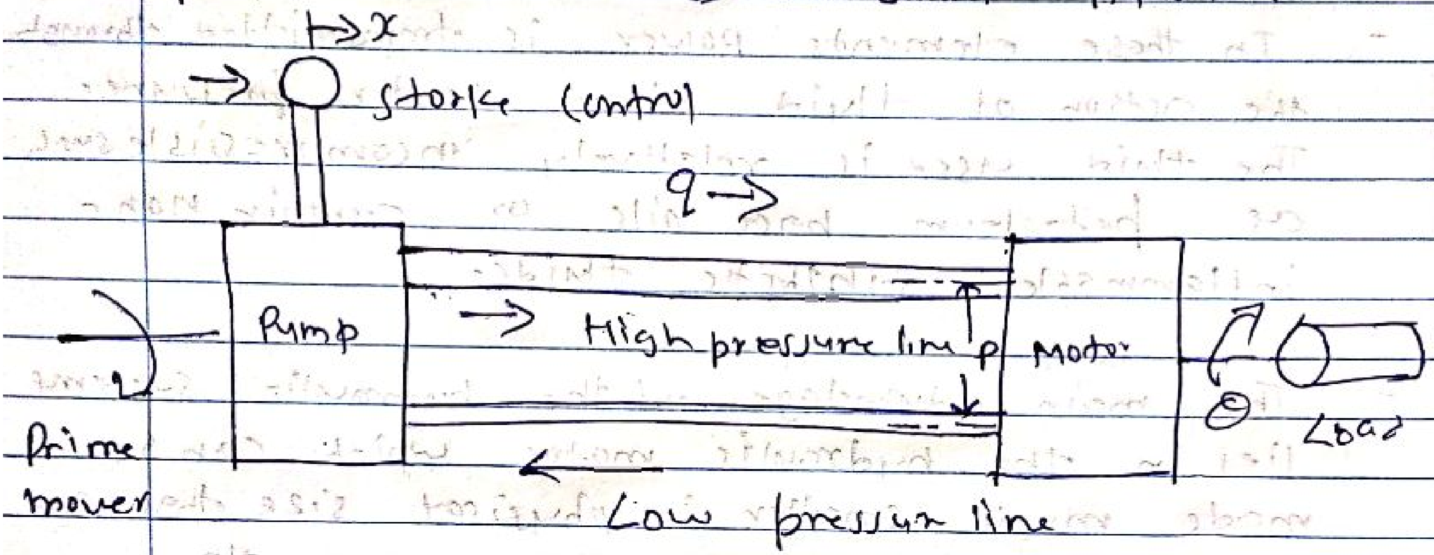
- Common hydraulic control application are power steering and brakes in automobiles, the steering mechanisms of large ships, the control of large machine tools.

→ The hydraulic o/p device used in control systems are generally of two type. ~~x~~, those intended to produce rotatory ~~motion~~ motion and those whose o/p is translational. the first type of device are known as hydraulic motors and the second ones are known as hydraulic linear actuators.

HYDRAULIC Pumps and motors:

A device freq. used in control systems giving large output torque and short response time is the hydraulic transmission.

- It consists of a variable stroke hydraulic pumps and fixed ~~storke~~ stroke hydraulic motor.



- Control of the motor is exercised by varying the amount of oil delivered by the pump. This carried out by mechanically changing the pump stroke, like in a DC generator and motor.

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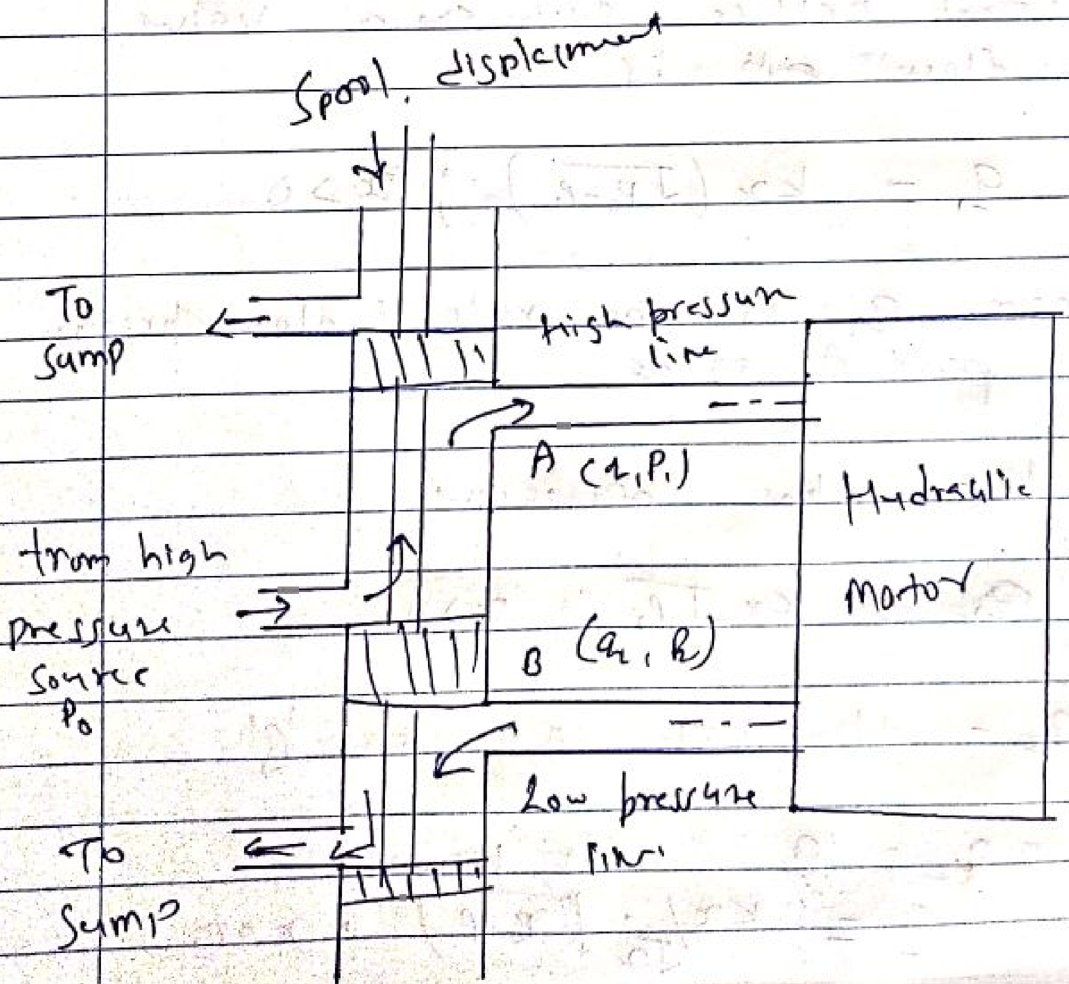
Hydraulic valve:

- Is a ~~device~~ constant pressure source and a valve to control the flow of oil to the hydraulic motor.
- This system has the advantage that the movable parts of the valve canbe made such higher than those of the stroke control mechanism in the pump. as a result of which, the time contants are reduced and the system becomes fast acting.

- The disadvantage of this system is that the valve has nonlinear characteristics and introduces problem of its own.

Three way spool valve controlling the oil flow to the hydraulic motor.



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- When the spool is in the neutral position ($x=0$) the oil flow is blocked completely.
- As the spool is moved downwards (x positive) the upper pipe line to the motor gets connected to the high pressure source and the lower pipe line to the ~~motor~~ sump causing the motor to rotate in a particular direction.

- If the spool is moved upward (x negative) the lower pipe line to the motor gets connected to the high pressure source and the upper pipe line to the sump.

- The direction of oil flow in the motor and hence direction of its rotation is reversed.

- Because turbulent flow exists at a sharp edged orifice such as a valve, the ~~ta~~ flow ~~eq~~ is

$$q_1 = Kx\left(\sqrt{P_0 - P_1}\right); \quad x > 0$$

where q_1 is the rate of flow through port A ~~are~~ ck

K - flow coefficient

$$q_2 = Kx\sqrt{P_2}; \quad x > 0$$

q_2 - flow rate at port 'B'

$q_1 = q_2 = q$ we have

$$q = \frac{Kx}{\sqrt{2}}\left(\sqrt{P_0 - P}\right); \quad x > 0$$

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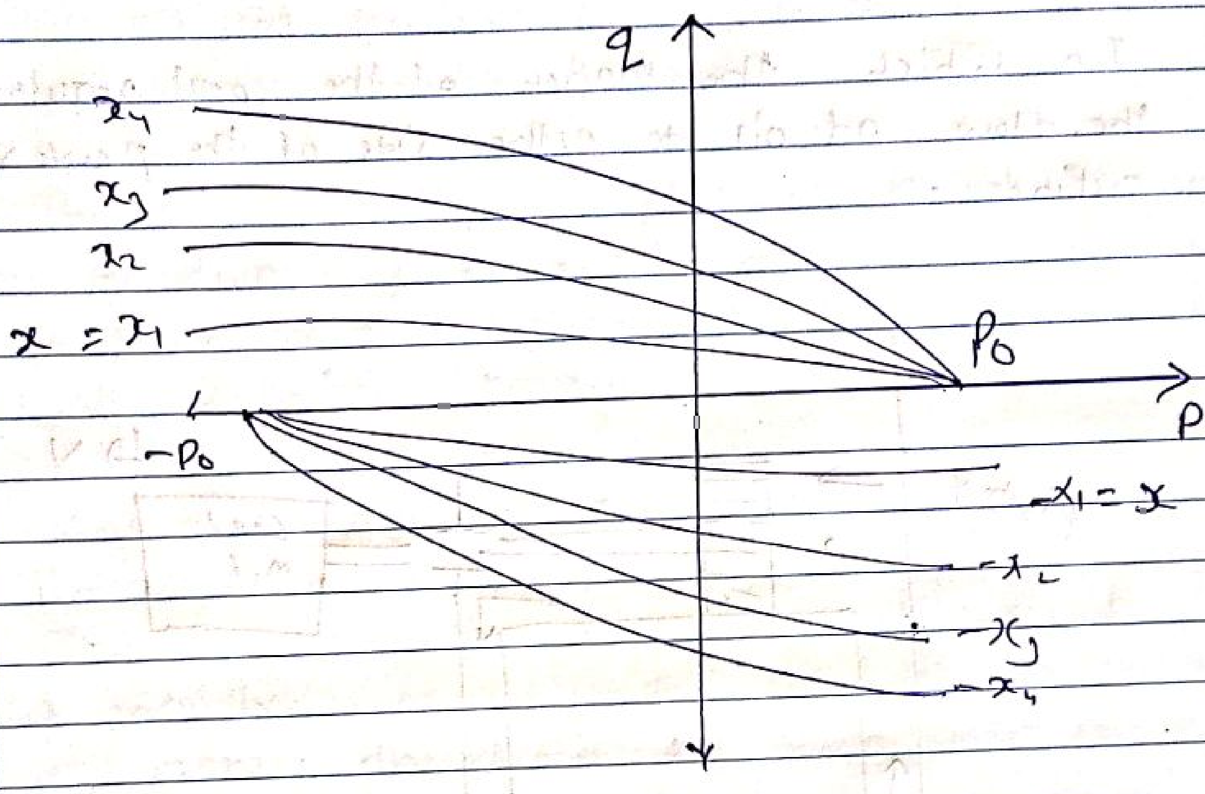
Where $p = P_1 - P_2$

Typical valve characteristics



The transfer function is obtained as

$$G(s) = \frac{\theta(s)}{X(s)} = \frac{K_1}{s\left[\frac{J(K_2+K_c)}{K_m} s + K_m + \left(\frac{K_2+K_c}{K_m}\right) f\right]}$$

$$= K/s(\tau s+1)$$

$$K = \frac{K_1}{K_m + \left(\frac{K_2+K_c}{K_m}\right) f} \qquad \tau = \frac{J(K_2+K_c)}{K_m^2 + (K_2+K_c) f}$$

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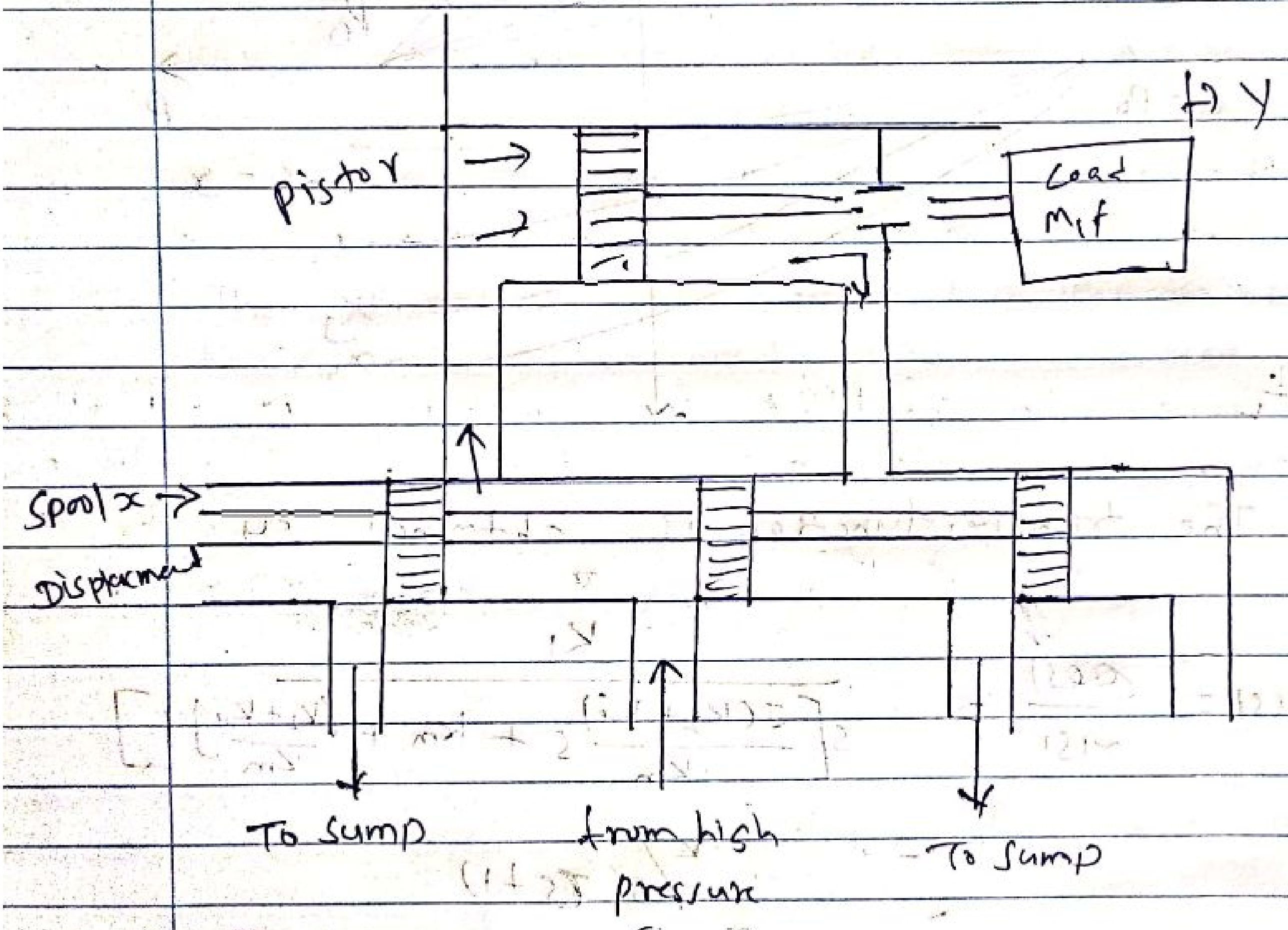
Hydraulic Linear Actuator.

- The linear actuators are piston devices.
- In which the motion of the spool regulates the flow of oil to either side of the power cylinder.



" Hydraulic Linear actuator "

- When the spool moves to the left, the oil from the high pressure source enters into the power cylinder, on the left of the power piston.
- This create a differential pressure across the piston, which causes the power piston

to move to the right, pushing the oil in front of it to the ~~B~~ sump.

- The oil is pressurized by a pump and is recirculated in the system.

- The load rigidly coupled to the piston moves a distance y from its ref. position in response to the displacement x of the valve spool from its neutral position.

- Let us carry out a simplified analysis of the linear actuator.
- The relationship b/w. the volumetric oil flow rate q into the power piston and the differential pressure p across the piston for small values of spool displacement x, has already been given in.

$$K_2 p = K_1 x - q$$

Assuming leakage and compressibility flow to ~~the~~ be negligible, the rate of oil flow into the piston is proportional to the rate ~~of~~ at which the piston moves

$$q = A\, dy/dt$$

A — area of the piston.

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P/E

PNEUMATIC SYSTEMS.

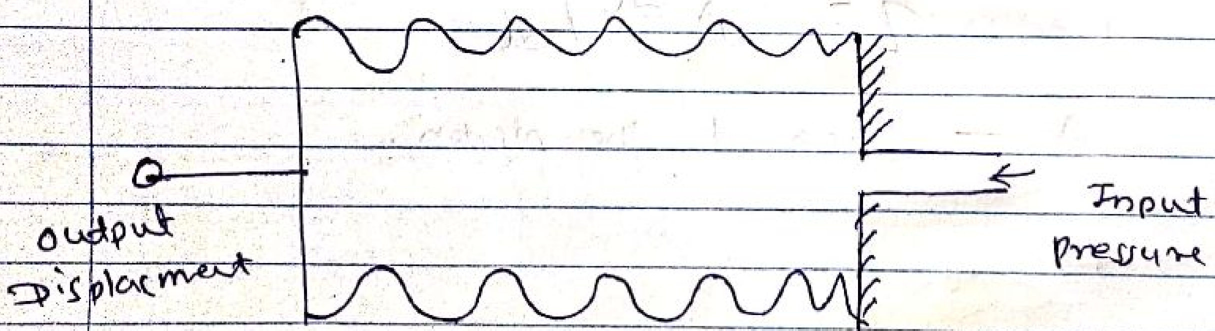
- Air medium is used in pneumatic control system.

- air medium has the advantage of being non-inflammable and having almost negligible viscosity compared to the high viscosity of hydraulic fluids, which also varies considerably with temp. causing a marked effect on the performance of control systems.

- Pneumatic systems find considerable application in the process control field. These are sometimes used in guided missiles and aircraft systems

PNEUMATIC Bellows :

- It consists of a hollow chamber with thin metallic walls. the side walls of bellows are corrugated, while the input and out surface are flat.



" Pneumatic Bellows"

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- The action of the bellows is similar to that of a spring. An increase in the pressure within the bellows results in an increase in the separation b/w the input and output surface.

The force ~~opposing the separation two~~ acting to separate two surface

$$= (\Delta P) A$$

A - area of each flat surface
ΔP - Differential pressure

The force opposing the separation $= K(\Delta x)$

K = stiffness of the bellows.
Δx - Displacement of movable surface.

$$\frac{\Delta X(s)}{\Delta P(s)} = \frac{A}{K}$$

This is the transfer function of the bellows.

PNEUMATIC Flapper Valve.

- This is an important component of many pneumatic systems.

- The power source for this device is the supply of air at constant pressure.

- Pressurized air is fed through the orifice and is ejected from the nozzle opening ~~and the nozzle back~~ towards the flapper.

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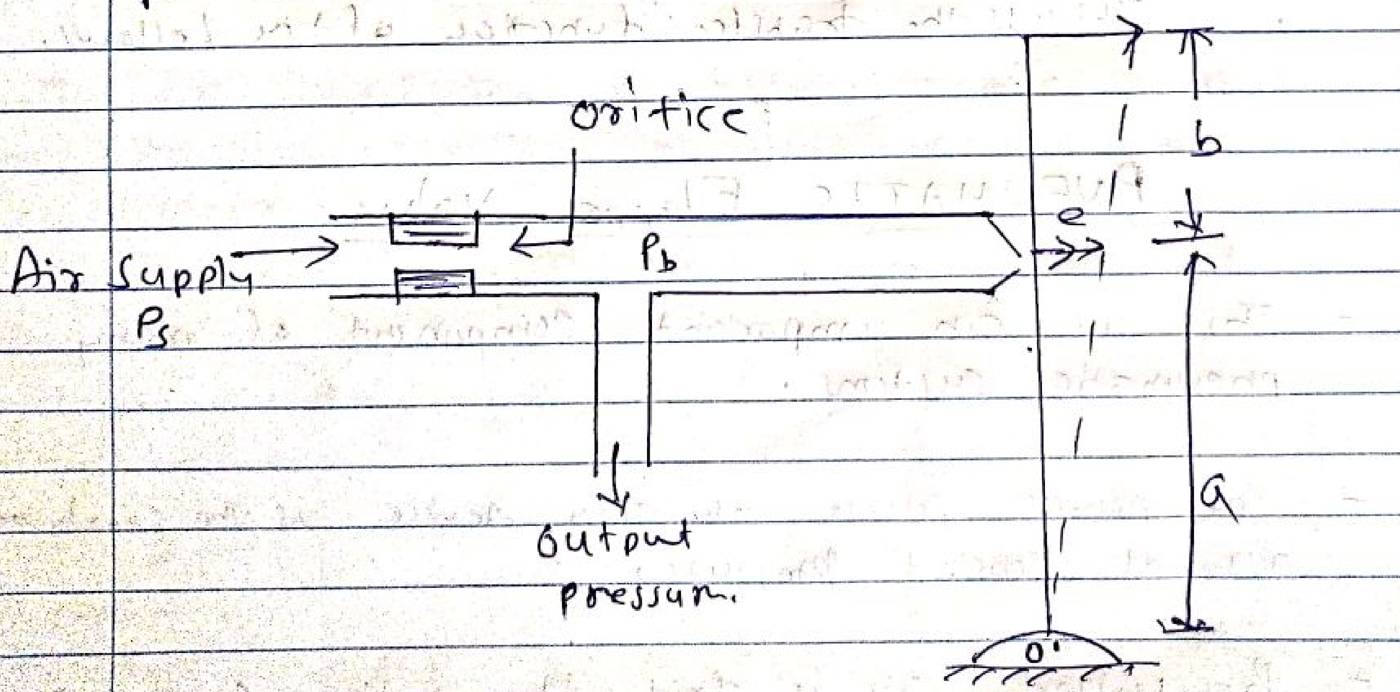
- The flapper is positioned against the nozzle opening and the nozzle back pressure P_b is controlled by the nozzle - flapper distance.

- As the flapper approaches the nozzle, the resistance to the flow of air through the nozzle increase with the result that the nozzle back pressure increase.

- If the nozzle is completely closed by the flapper, the nozzle back pressure P_b becomes equal to the supply pressure P_s.

- If the flapper is moved away from the nozzle so that nozzle flapper distance is larger then there is practically no restriction to flow and the nozzle back pressure take on a minimum value close to the ambient pressure.



A flapper valve

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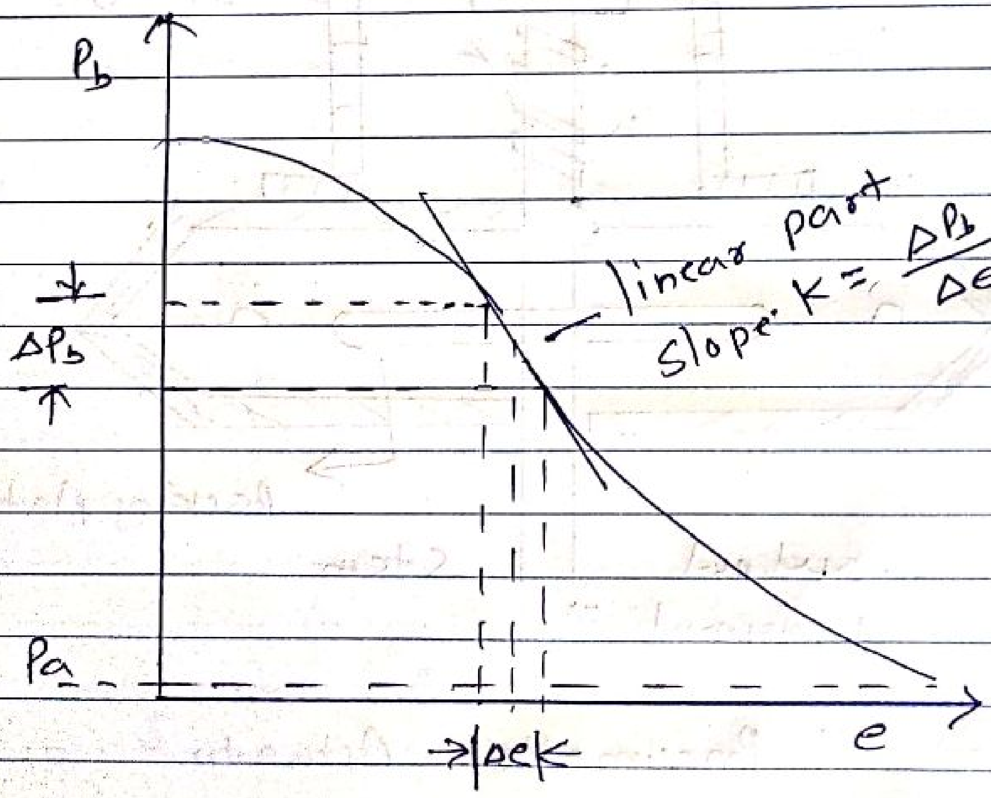
- Thus the flapper valve converts small changes in the position of the flapper into larger changes in the back pressure.

The transfer function of the valve is

$$\frac{\Delta P_b(s)}{\Delta X(s)} = \left(\frac{a}{(a+b)}\right) K$$

where $K<0$ is the slope of the linear part of the curve.

$e = \left(\frac{a}{a+b}\right) x$ is the nozzle flapper distance



"flapper valve characteristic"

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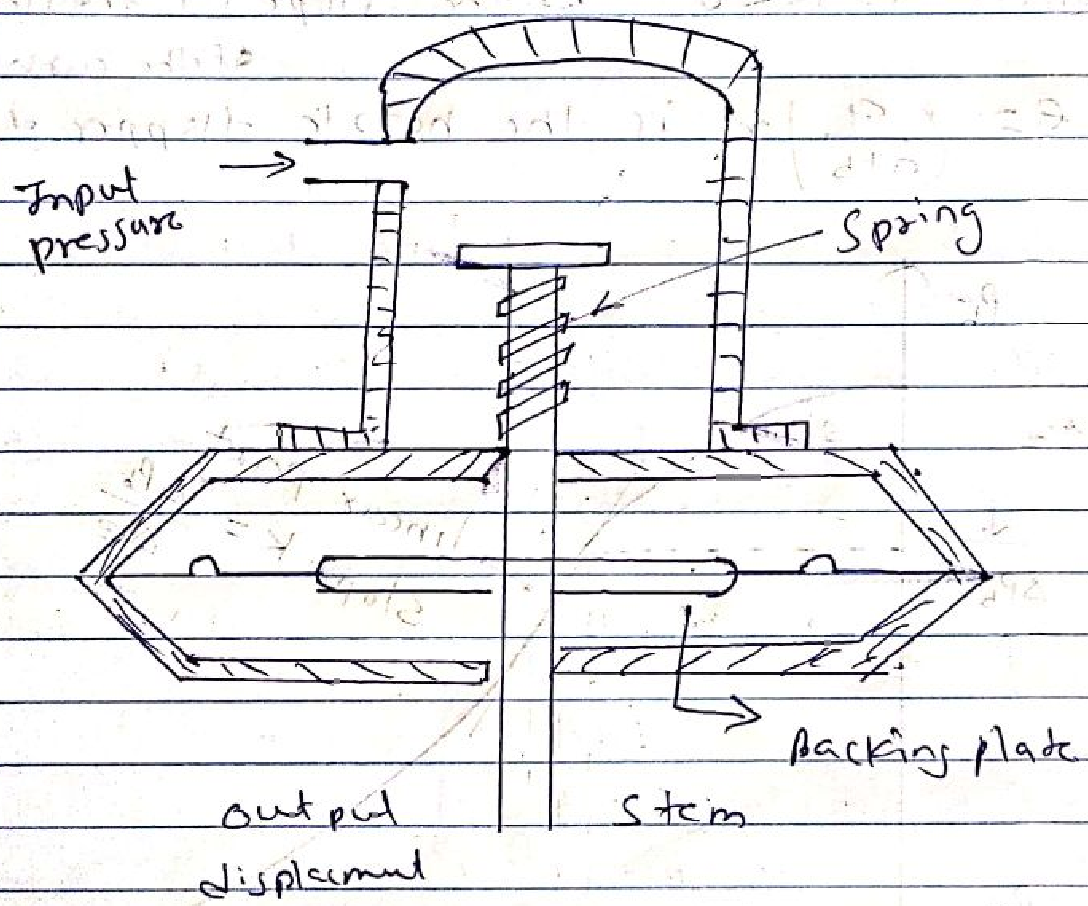
PNEUMATIC ACTUATOR:

- The majority of the modern pneumatic control systems require translatory output motion.

- This motion is achieved by pneumatic actuators responding to changes in input air pressure.



" Pneumatic Actuator "

Assume that the actuator is used to position a load consisting of a spring with stiffness 'k', viscous friction with coefficient 'f' and mass 'M'.

- for a small variation ΔP_c in the input pressure, the force acting on the diaphram is $A(\Delta P)$ when A is the area of the diaphragm

if Δy is the displacment of the actuator stem because of this force, then the force balance eqn is

$$A(\Delta P) = M\Delta\ddot{y} + f\Delta\dot{y} + K\Delta y$$

Transfer Fun. eqn of the actuator is

$$\frac{\Delta Y(s)}{\Delta P(s)} = \frac{A}{Ms^2 + fs + K}$$

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UNIT-1

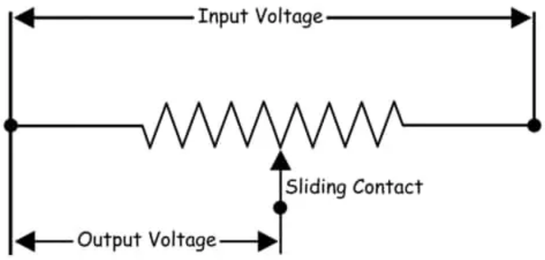
INTRODUCTION TO CONTROL SYSTEM

1.1 POTENTIOMETER

A potentiometer (also known as a pot or potmeter) is defined as a 3 terminal variable resistor in which the resistance is manually varied to control the flow of electric current. A potentiometer acts as an adjustable voltage divider.

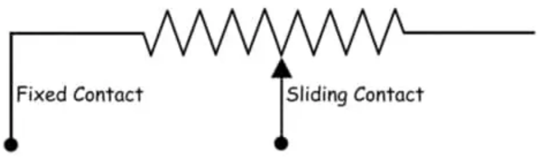
1.1.1 Working

A potentiometer is a passive electronic component. Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact as shown below.



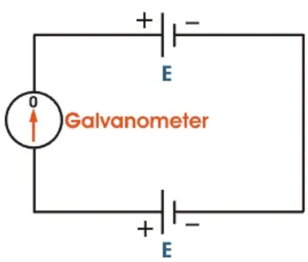
A potentiometer has the two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.

This is different to a rheostat, where here one end is fixed and the sliding terminal is connected to the circuit, as shown below.



Rheostat

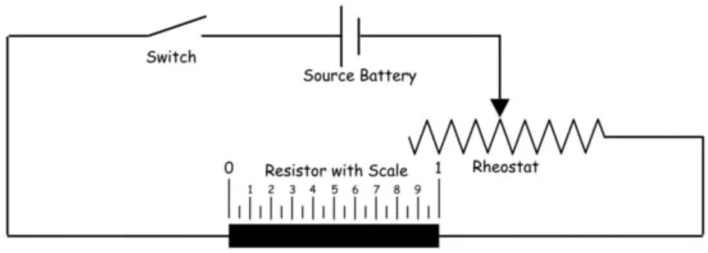
This is a very basic instrument used for comparing the emf of two cells and for calibrating ammeter, voltmeter, and watt-meter. The basic working principle of a potentiometer is quite simple. Suppose we have connected two batteries in parallel through a galvanometer. The negative battery terminals are connected together and positive battery terminals are also connected together through a galvanometer as shown in the figure below.

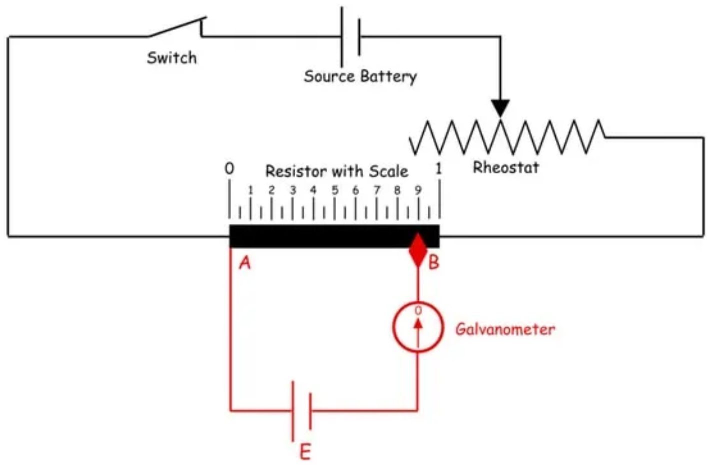


Here, if the electric potential of both battery cells is exactly the same, there is no circulating current in the circuit and hence the galvanometer shows null deflection. The working principle of potentiometer depends upon this phenomenon.

Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below. The resistor has the uniform electrical resistance per unit length throughout its length.

Hence, the voltage drop per unit length of the resistor is equal throughout its length. Suppose, by adjusting the rheostat we get v volt voltage drop appearing per unit length of the resistor.





Now, the positive terminal of a standard cell is connected to point A on the resistor and the negative terminal of the same is connected with a galvanometer. The other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this sliding end, a point like B is found where there is no current through the galvanometer, hence no deflection in the galvanometer.

That means, emf of the standard cell is just balanced by the voltage appearing in the resistor across points A and B. Now if the distance between points A and B is L, then we can write emf of standard cell E = Lv volt.

This is how a potentiometer measures the voltage between two points (here between A and B) without taking any current component from the circuit. This is the specialty of a potentiometer, it can measure voltage most accurately.

1.1.2 Potentiometer Types

There are two main types of potentiometers:

- Rotary potentiometer
- Linear potentiometer

Although the basic constructional features of these potentiometers vary, the working principle of both of these types of potentiometers is the same. Note that these are types of DC potentiometers – the types of AC potentiometers are slightly different.

1.1.2.1 Rotary Potentiometers

The rotary type potentiometers are used mainly for obtaining adjustable supply voltage to a part of electronic circuits and electrical circuits. The volume controller of a radio transistor is a popular example of a rotary potentiometer where the rotary knob of the potentiometer controls the supply to the amplifier.

This type of potentiometer has two terminal contacts between which a uniform resistance is placed in a semi-circular pattern. The device also has a middle terminal which is connected to the resistance through a sliding contact attached with a rotary knob. By rotating the knob one can move the sliding contact on the semi-circular resistance. The voltage is taken between a resistance end contact and the sliding contact. The potentiometer is also named as the POT in short. POT is also used in substation battery chargers to adjust the charging voltage of a battery. There are many more uses of rotary type potentiometer where smooth voltage control is required.

1.1.2.2 Linear Potentiometers

The linear potentiometer is basically the same but the only difference is that here instead of rotary movement the sliding contact gets moved on the resistor linearly. Here two ends of a straight resistor are connected across the source voltage. A sliding contact can be slide on the resistor through a track attached along with the resistor. The terminal connected to the sliding is connected to one end of the output circuit and one of the terminals of the resistor is connected to the other end of the output circuit.

This type of potentiometer is mainly used to measure the voltage across a branch of a circuit, for measuring the internal resistance of a battery cell, for comparing a battery cell with a standard cell and in our daily life, it is commonly used in the equalizer of music and sound mixing systems.

1.1.3 Applications of Potentiometer

There are many different uses of a potentiometer. The three main applications of a potentiometer are:

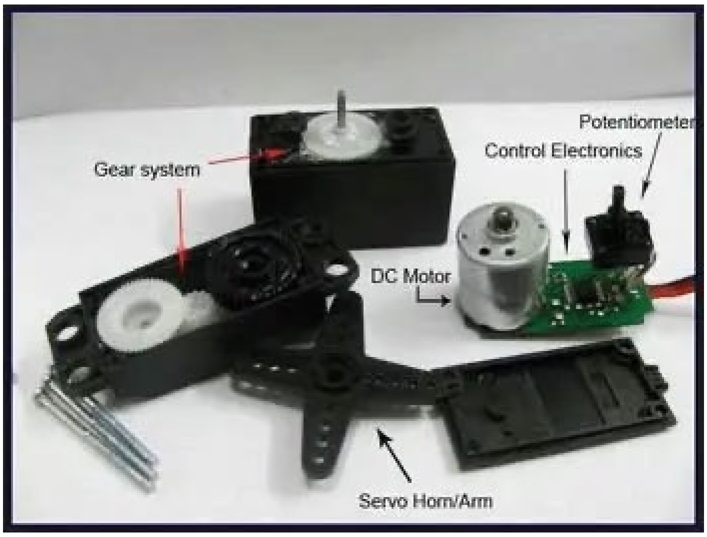
- Comparing the emf of a battery cell with a standard cell
- Measuring the internal resistance of a battery cell
- Measuring the voltage across a branch of a circuit

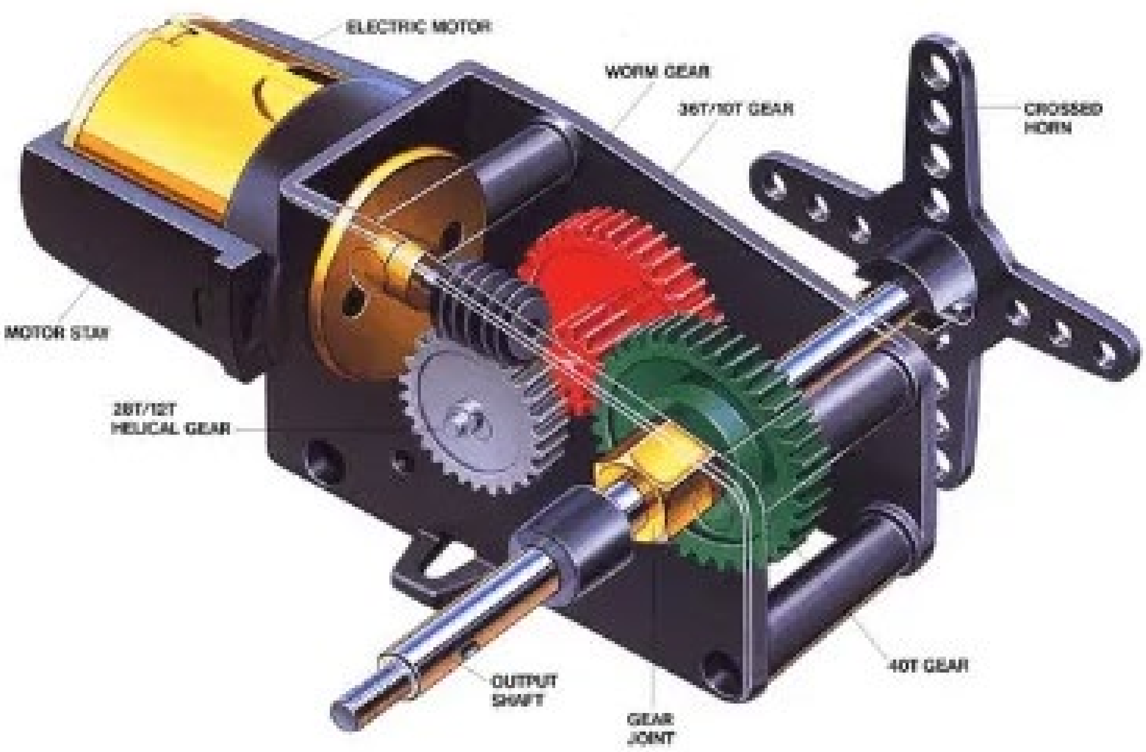
1.1.4 Potentiometer Sensitivity

The sensitivity of a potentiometer implies what the small voltage difference can be measured by the potentiometer. For same driver voltage if we increase the length of the potentiometer resistance, length of the resistance per unit voltage gets increased. Hence the sensitivity of the potentiometer gets increased. So we can say sensitivity of a potentiometer is directly proportional to the length of the resistance. Again if we reduce the driver voltage for a fixed length of potentiometer resistance, then also voltage per unit length of the resistance gets decreased. Hence again the sensitivity of the potentiometer gets increased. So the sensitivity of the potentiometer is inversely proportional to the driver voltage.

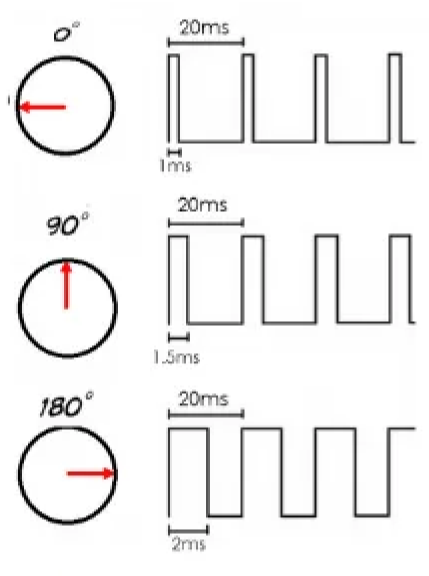
1.2 SERVOMOTOR

A servomotor (or servo motor) is a simple electric motor, controlled with the help of servomechanism. If the motor as a controlled device, associated with servomechanism is DC motor, then it is commonly known as a DC Servo Motor. If AC operates the controlled motor, it is known as a AC Servo Motor.





A servomotor is a linear actuator or rotary actuator that allows for precise control of linear or angular position, acceleration, and velocity. It consists of a motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.



1.2.1 Servo Motor Theory

There are some special types of applications of an electric motor where the rotation of the motor is required for just a certain angle. For these applications, we require some special types of motor with some special arrangement which makes the motor rotate a certain angle for a given electrical input (signal). For this purpose, servo motor comes into the picture.

The servo motor is usually a simple DC motor controlled for specific angular rotation with the help of additional servomechanism (a typical closed-loop feedback control system). Nowadays, servo systems are used widely in industrial applications.

Servo motor applications are also commonly seen in remote-controlled toy cars for controlling the direction of motion, and it is also very widely used as the motor which moves the tray of a CD or DVD player. Besides these, there are hundreds of servo motor applications we see in our daily life.

The main reason behind using a servo is that it provides angular precision, i.e. it will only rotate as much we want and then stop and wait for the next signal to take further action. The servo motor is unlike a standard electric motor which starts turning as when we apply power to it, and the rotation continues until we switch off the power. We cannot control the rotational progress of electrical motor, but we can only control the speed of rotation and can turn it ON and OFF. Small servo motors are included many beginner Arduino starter kits,as they are easy to operate as part of a small electronics projects.

1.2.2 AC Servo Motor

AC servo motor includes an encoder which is used by the controllers to give the feedback as well as closed loop control. AC motor can be located to high accuracy as well as controlled accurately as necessary for the applications. These motors have superior designs in order to achieve better torque. The AC servo motor applications mainly include in robotics, automation, CNC equipment, and many more applications.

1.2.3 Types of AC Servo Motors

The AC servo motors are classified into different types which are

- Positional Rotation Servo Motor
- Continuous Rotation Servo Motor
- Linear Servo Motor

1.2.3.1 Positional Rotation Servo Motor

The most common kind of servo motor is Positional rotation motor. The output of the shaft in motor rotates with 180 degrees. This type of motor mainly comprises includes physical stops that are placed in the gear mechanism to prevent rotating outside to protect the rotation sensor. The applications of positional rotation servo motor include in robots, aircraft, toys, controlled cars, & many more applications.

1.2.3.2 Continuous Rotation Servo Motor

Both common positional rotation servo motor and continuous rotation servo motor are same, except it can go in every direction without a fixed limit. The control signal alternately locates the static point of the servo to understand the direction as well as the speed of rotation. The variety of potential commands will cause the motor for rotating in the directions of clockwise otherwise anticlockwise as chosen by altering speed, based on the control signal. The application of continuous rotation servo motor includes a radar dish. For example, if you are traveling single on a robot otherwise you can employ one like a drive motor over a mobile robot.

1.2.3.3 Linear Servo Motor

The Linear servo motor is one kind of motor and it is similar to the positional rotation servo motor, however with extra mechanisms for changing the output from circular in the direction of back-and-forth. We cannot find these motors easily, although occasionally you can discover them at hobbyist stores everywhere they are used like actuators within advanced model airplanes.

Thus, this is all about types of servo motors. This motor is a division of servomechanism and coupled with some type of encoder for providing positioning, speed feedback as well as some fault correcting apparatus which activates the supply signal. The basic characteristics to be required for any servo motor includes, the output torque of the motor must be proportional to the applied voltage. The torque direction which is expanded by the motor must be depending on the instantaneous polarity of the control voltage.

1.3 LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

The term LVDT stands for the Linear Variable Differential Transformer. It is the most widely used inductive transducer that converts the linear motion into the electrical signal.

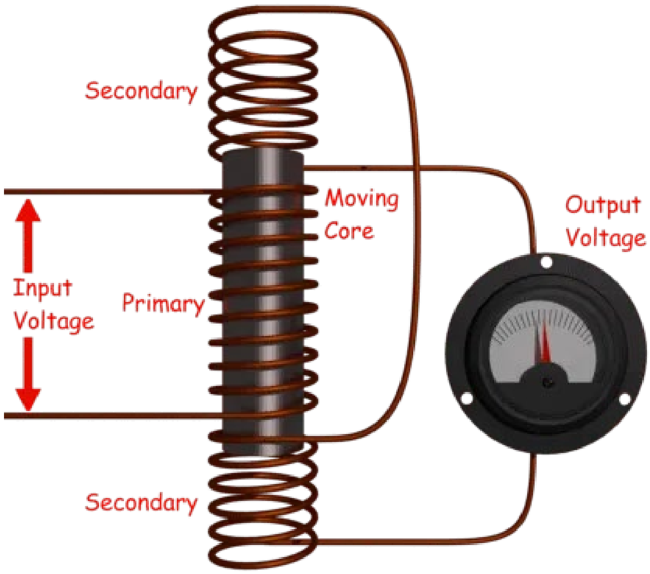
The output across secondary of this transformer is the differential thus it is called so. It is very accurate inductive transducer as compared to other inductive transducers.

1.3.1 Construction of LVDT

Main Features of Construction

- The transformer consists of a primary winding P and two secondary windings S1 and S2 wound on a cylindrical former (which is hollow in nature and contains the core).
- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.

- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.



1.3.2 Principle of Operation and Working

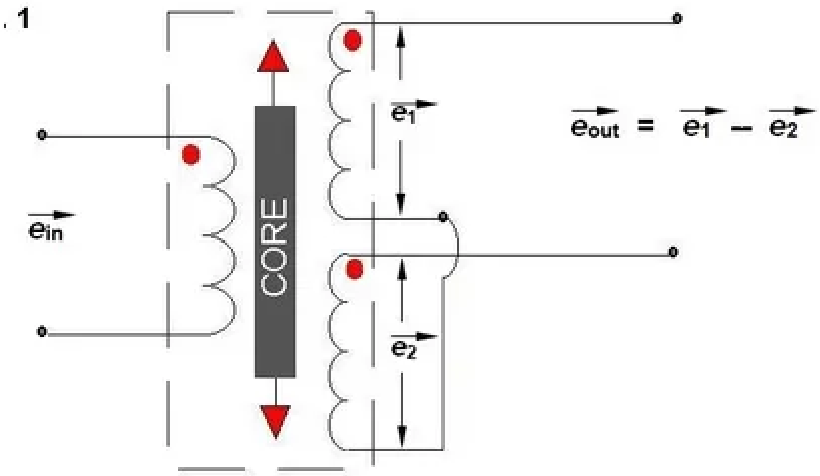
As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S1 is e1 and in the secondary S2 is e2. So the differential output is,

$$e_{out} = e_1 - e_2$$

This equation explains the principle of Operation of LVDT.

Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

- CASE I When the core is at null position (for no displacement): When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output eout is zero as e1 and e2 both are equal. So it shows that no displacement took place.
- CASE II When the core is moved to upward of null position (For displacement to the upward of reference point): In the this case the flux linking with secondary winding S1 is more as compared to flux linking with S2. Due to this e1 will be more as that of e2. Due to this output voltage eout is positive.
- CASE III When the core is moved to downward of Null position (for displacement to the downward of the reference point). In this case magnitude of e2 will be more as that of e1. Due to this output eout will be negative and shows the output to downward of the reference point.



Some important points about magnitude and sign of voltage induced in LVDT

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.
- By noting the output voltage increasing or decreasing the direction of motion can be determined
- The output voltage of an LVDT is linear function of core displacement .

1.3.3 Advantages of LVDT

- High Range – The LVDTs have a very high range for measurement of displacement they can used for measurement of displacements ranging from 1.25 mm to 250 mm
- No Frictional Losses – As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.
- High Input and High Sensitivity – The output of LVDT is so high that it doesn't need any amplification. The transducer posseses a high sensitivity which is typically about 40V/mm.
- Low Hysteresis – LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
- Low Power Consumption – The power is about 1W which is very as compared to other transducers.
- Direct Conversion to Electrical Signals – They convert the linear displacement to electrical voltage which are easy to process.

1.3.4 Disadvantages of LVDT

- LVDT is sensitive to stray magnetic fields so it always requires a setup to protect them from stray magnetic fields.
- LVDT gets affected by vibrations and temperature.

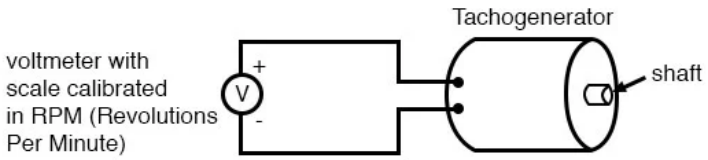
1.3.5 Applications of LVDT

- We use LVDT in the applications where displacements to be measured are ranging from a fraction of mm to few cms. The LVDT acting as a primary transducer converts the displacement to electrical signal directly.
- The LVDT can also act as a secondary transducer. E.g. the Bourbon tube which acts as a primary transducer and it converts pressure into linear displacement and then LVDT coverts this

displacement into an electrical signal which after calibration gives the readings of the pressure of fluid.

1.4 TACHOGENERATORS

An electromechanical generator is a device capable of producing electrical power from mechanical energy, usually the turning of a shaft. When not connected to a load resistance, generators will generate voltage roughly proportional to shaft speed. With precise construction and design, generators can be built to produce very precise voltages for certain ranges of shaft speeds, thus making them well-suited as measurement devices for shaft speed in mechanical equipment. A generator specially designed and constructed for this use is called a tachometer or tachogenerator. Often, the word “tach” (pronounced “tack”) is used rather than the whole world.



By measuring the voltage produced by a tachogenerator, you can easily determine the rotational speed of whatever it's mechanically attached to. One of the more common voltage signal ranges used with tachogenerators is 0 to 10 volts. Obviously, since a tachogenerator cannot produce a voltage when it’s not turning, the zero cannot be “live” in this signal standard. Tachogenerators can be purchased with different “full-scale” (10 volts) speeds for different applications. Although a voltage divider could theoretically be used with a tachogenerator to extend the measurable speed range in the 0-10 volt scale, it is not advisable to significantly overspeed a precision instrument like this, or its life will be shortened.

Tachogenerators can also indicate the direction of rotation by the polarity of the output voltage. When a permanent-magnet style DC generator’s rotational direction is reversed, the polarity of its output voltage will switch. In measurement and control systems where the directional indication is needed, tachogenerators provide an easy way to determine that.

Tachogenerators are frequently used to measure the speeds of electric motors, engines, and the equipment they power: conveyor belts, machine tools, mixers, fans, etc.