

Instrumentation & Measurements

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Verificatio:
Under process

Introduction

Measurements:

The measurement of a given quantity is essentially an act or the result of comparison between the quantity (whose magnitude is unknown) and a predefined standard. The result is expressed in numerical values. "Measurement is a process by which one can convert physical parameters to meaningful numbers.

In order that the results of the measurement are meaningful, there are two basic requirements:

1. The standard used for comparison purpose must be accurately defined and should be commonly accepted.
2. The apparatus used and the method adopted must be provable.

Methods of Measurements.

The methods for measurements are classified into two categories.

- Direct Method.
- Indirect method.

Direct method.

In these methods, the unknown quantity is directly compared against a standard. The result is expressed as a numerical number and a unit. Direct methods are quite common for the measurement of physical quantities like length, mass and time.

Indirect Method.

Measurements by direct methods are not always possible, feasible and practicable. In engineering applications Measurement Systems are used which require need of indirect methods for measuring purposes.

Instruments and Measurement Systems.

The instrument serves as an extension of human faculties and enables the man to determine the value of unknown quantity or variable. The instrument consists of a single unit which gives an output reading according to the unknown variable applied to it. A measuring instruments may consists of several separate elements, which convert the measurand to and analogous form, which is processed by some intermediate means and fed to end devices to present the result. Due to this fact the instruments are referred as measurement system.

Electronic Instruments.

These days most of the scientific and industrial measurements require very fast responses. The necessity to step up response time (i.e. in milli secs, micro-secs) has led to the design of today's electronic instruments and their associated circuitry. Since in electronic devices the only movement involved is that of electrons, the response time is extremely small. For example: a cathode ray oscilloscope is capable of following dynamic and transient changes of the order of a few ns (10^{-9}).

Electronically controlled power supplies are used to provide stable voltages for studies in the field of chemical reactions and nuclear instrumentation. Electronic instruments are steadily becoming more reliable on account of improvements in design and manufacturing process of semi-conductor devices. The fore most importance of electronic instruments is the power amplification provided by the electronic amplifiers, which results in higher sensitivity. Another advantage of electronic instruments is the ability to obtain indication at a remote location which helps in monitoring inaccessible or dangerous quantities. Electronic instruments are light compact, have a high degree of reliability and low power consumption.

Communication is a field which is entirely dependent upon the electronic instruments and associated apparatus. Space communications, especially, makes use of air borne transmitters and receivers and job of interpreting the signals is left entirely to the electronic instruments.

Summarizing, it may be stated that in general electronic instruments have;

- High sensitivity.
- A faster response.
- A greater flexibility ,
- Lower weight and power consumption and,
- A higher degree of reliability than mechanical or purely electrical counterparts.

CLASSIFICATION OF INSTRUMENTS:

Broadly instruments are classified into two categories.

1. Absolute Instruments.

These instruments give the magnitude of the quantity measurement in terms of physical constants of the instrument.

Example; tangent Galvanometer and Rayleigh's Current balance.

2. Secondary Instruments.

These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument. These instruments are calibrated,

by comparison with an absolute instrument or another secondary instrument which has already been calibrated against a calibrated instrument.

Measurement System Performance.

The treatment of instrument and measurement system characteristics can be divided into two categories:

1. Static characteristics.
2. Dynamic characteristics.

Some applications involve the measurement of quantities that are either constant or vary slowly with time. These criteria are called Static Characteristics. However many measurements are concerned with rapidly varying quantities and, therefore for such cases dynamic relations between output and input must be examined. Performance criteria based upon dynamic relations constitute the dynamic Characteristics.

Terms in Measurement System:

1. Accuracy: is the measure of closeness with which instrument measure to true value.
2. Sensitivity: is the measure of the change in reading of instrument by given change in quantity.
3. Resolution; is smallest change in measured quantity that will produced a detectable change in instrument reading.
4. Error: is deviation from true value of measured quantity. Error can be expressed as 'absolute' or 'percent' error.

$$\text{Absolute error} = XE - XM \text{-----(i)}$$

$$\% \text{ error} = \frac{XE - XM}{XE} * 100 \text{----- (ii)}$$

XE → expected value.

XM → measured value.

5. Range: of instrument describes the limits of magnitude over which the quantity may be measured.
6. Span: the algebraic difference between upper and lower limits of instruments.

Types of errors:

No measurement can be made with perfect accuracy. A study of errors is a first step in finding ways to reduce them. Errors may arise from different sources and are classified as under:

1. Gross Errors.

This class of errors mainly covers human mistakes in reading instruments and calculating measurement results. Gross errors may be of any amount and therefore their mathematical analysis is impossible. However, they can be avoided by adopting two means.

- i). Great care should be taken in reading and recording the data.
- ii). Two, three or more readings should be taken for the quantity under measurement. It is always to take a large number of readings as a close agreement between readings assures that no gross error has been committed.

2. Systematic Errors:

These errors arise from inaccuracies in the manufacture of an instrument or from improper adjustment or application of instrument. They are observed as errors that do not change (or change very slowly) with time. These types of errors are divided into three categories:

These errors arise due to three main reasons;

- ◆ Inherent shortcomings in the instrument.

These errors may be due to construction or operation of the instruments or measuring devices. These errors may cause instruments to read too low or too high.

- ◆ Due to misuse of the instruments.

The errors caused in measurements are due to the fault of the operator than that of the instrument. For example overheating or overloading of instrument may cause damage to instrument.

- ◆ Due to loading effects of instruments.

One of the most common errors committed by beginners is the improper use of an instrument for measurement work.

3. Random (Residual) Errors:

These errors are due to a multitude of small factors which change or fluctuate from one measurement to another and are due surely to change. The quantity being measured is affected by many happenings through out the universe. The happenings or disturbance about which we are unaware are lumped together and called 'random' or 'Residual' errors.

- ◆ Noise: The sensitivity of the instrument is changed, or the reading is altered by outside interference.

- ◆ Backlash: The reading either lags or leads the correct value because of mechanical play, friction or damping.

- ◆ Ambient influences: Due to conditions external to the measuring system, such as variation in temperature, humidity, or atmospheric pressure.

Random errors can't normally be predicted or corrected, but they can be minimized by a skilled observer using a well-maintained quality instrument.

Indicating Instruments.

Indicating instruments are those instruments which indicate the magnitude of a quantity being measured. They generally make use of a dial and a pointer for this purpose. Ordinary voltmeters, ammeters and wattmeters belong to this category.

Recording Instruments:

Recording instruments give a continuous record of the quantity being measured over a specified time interval. The record may be used for future reference or computation work. The variations of the quantity being measured are recorded usually on a sheet of paper.

Integrating Instruments:

Integrating instruments totalize events over a specified period of time. The summation, which they give, is the product of time and an electrical quantity. The integration is generally given by a register consisting of a set of pointers, dial and displays.

Operating forces:

Three types of forces are needed for the satisfactory operation of any indicating instrument. These are;

1. Deflecting Force.

The deflecting or operating force is required for moving the pointer from its zero position. The system producing the deflecting force is called 'deflecting system' or

‘moving system’. The deflecting force can be produced by utilizing any of the effects mentioned earlier. Thus the deflecting system of an instrument converts the electric current or potential into a mechanical force called deflecting force. The deflecting system thus acts as the prime mover responsible for deflection of pointer.

2. Controlling Force.

This force is required in an indicating instrument in order that the current produces deflection of the pointer proportional to its magnitude. The system producing a controlling force is called a ‘controlling system’. The functions of controlling system are:

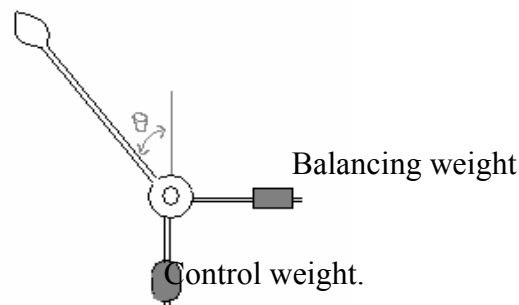
- To produce a force equal and opposite of the deflection force at the final steady position of pointer in order to make the deflection of the pointer definite for a particular magnitude of current.
- To bring the moving system back to zero when the force causing the instrument moving system to deflects is removed.

3. Damping Force.

When the deflecting force is applied to the moving system, it deflects and it should come to rest at a position where the deflecting force is balanced by the controlling force the deflecting and controlling forces are produced by systems which have inertia and, therefore the moving system cannot immediately settle at its final position but overshoots or swings ahead of it. The pointer thus oscillates about its final steady (equilibrium) position with decreasing amplitudes till its kinetic energy is dissipated in friction and therefore, it will settle down at its final steady position. If extra forces are not provided to “damp” these oscillations, the moving system will take a considerable time to settle to the final position and hence time consumed in taking readings will be very large. Therefore, damping forces are necessary so that the moving system comes to its equilibrium position rapidly and smoothly without any oscillations.

Balancing:

The balance of the pointer ensures that the deflection is unaffected by the position of the pointer and there are no reading errors. The balance can be achieved by using balance weights carried on arms attached to the moving system. The balance weight shoes position is adjustable compensates for the weight of pointer and any other part attached to the moving system.



Calibration.

Calibration is the process of comparing a measuring instrument with a measurement standard to establish the relationship between the values indicated by the instrument and those of the standard.

To provide confidence in the accuracy of calibration results, the measurement must have demonstrable traceability. In addition, it is important that appropriate equipment and procedures

are used in the calibration process, in that they are used by trained and authorized personnel operating in an adequate experimental environment.

Instruments usually need to be calibrated, whether they are simple devices with modest performance or state-of-the-art systems, as it is only by this process that their measurement capabilities can be determined.

All measuring devices-whether they are simple, “Fundamental” or sophisticated-change characteristics with time New devices should be calibrated relatively frequently in order to establish their reproducibility – essentially their metrological stability or change in their measuring ability between calibrations.

The cost of a calibration is sometimes the main factor in deciding not to have a device calibrated and clearly it is important to take economic issues into account. But there can be hidden costs and significant risks taken through not calibrating an instrument and hence not controlling or understanding a process adequately-that ought to tip the balance.

Ammeter and Voltmeter

Analog ammeters and voltmeters are classed together as there are no fundamental differences in their operating principles. The actions of all ammeters and voltmeters, with the exception of electrostatic type of instruments, depend on a deflecting torque produced by an electric current.

The main types of instruments used as ammeters and voltmeters are:

- i). Permanent magnet moving coil (PMMC).
- ii). Moving Iron.
- iii). Electro-dynamometer.
- iv). Hot wire.
- v). Thermocouple.
- vi). Induction.
- vii). Electrostatic.
- viii). Rectifier.

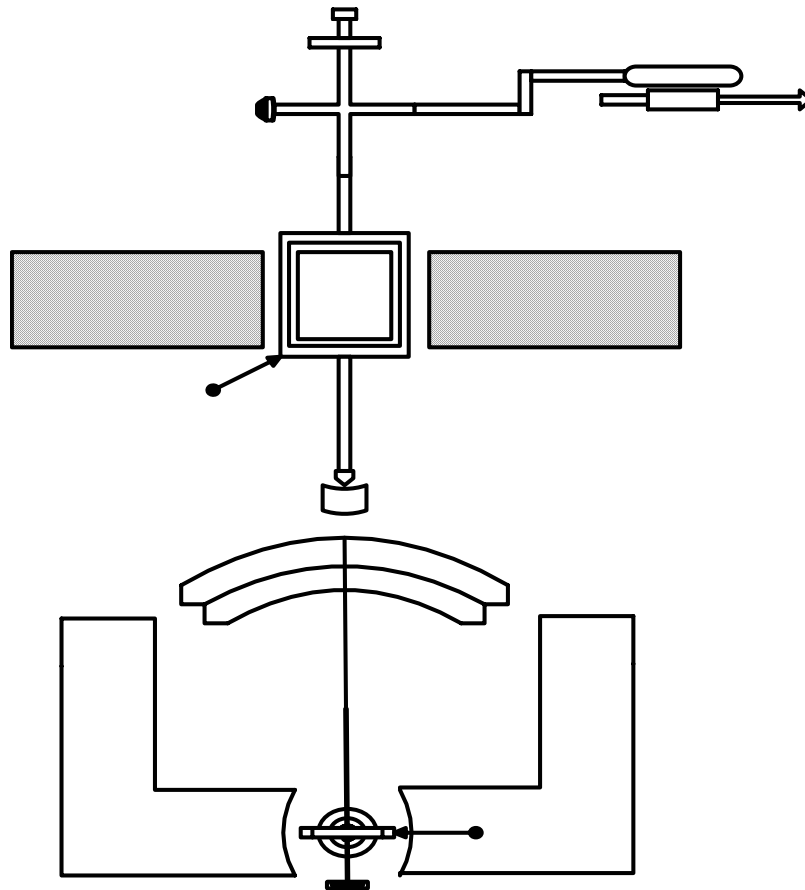
Of these the PMMC can be used for direct-current measurement only and the induction type for alternating current measurements only. The other types of meters can be used with either direct or alternating currents.

Permanent Magnet Moving Coil Instrument (PMMC).

The MPPC is the most accurate type for D.C. measurements. The working principle of these instruments is same as galvanometer, the difference being that a direct reading instrument is provided with a pointer and a scale.

Construction of PMMC Instruments.

The general construction features of this instrument are shown in figure:



1. Moving Coil:

The moving coil is wound with many turns of enameled or silk covered copper wire. The coil is mounted on rectangular aluminum former which is pivoted on jeweled bearings. The coil moves freely in the field of a permanent magnet. The coil itself provides electromagnetic damping.

2. Magnet Systems:

The magnet assemblies have undergone a lot of change in the recent past. Old style magnet system consisted of relatively long U shaped permanent magnets having soft iron pole pieces. The flux densities used in PMMC instruments vary from 0.1 to 1 Wb/m². In order to obtain the longer movement of the pointer and a longer angular swing of the coil a concentric magnet construction. Since the magnet is concentric type it produces a radial flux pattern which extends over 250° or more.

The active sides of the moving coil are located in the uniform radial field between pole pieces and the steel yoke. This arrangement has the obvious advantage of being relatively unaffected by the external magnetic fields. It also eliminates the magnetic shunting effects in steel panel construction.

3. Control:

When the coil is supported in between two jewel bearings the control torque is provided by two phosphor bronze hair springs. These springs also serve to lead current in

and out of the coil. The control torque is provided by the ribbon suspension. This method is comparatively new and is claimed to be advantageous.

4. Damping:

Damping torque is produced by movement of the aluminum former moving in the magnetic field of the permanent magnet.

5. Pointer and Scale:

The pointer is carried by the spindle and moves over a graduated scale. The pointer is of light-weight and construction, apart from those used in some inexpensive instruments. This helps to reduce parallax errors in the readings of the scale. The weight of the instrument is normally counter balanced by weight situated diametrically opposite and rigidly connected to it.

6. Torque Equation:

Deflecting torque,

$$Td = NBIdl = GI \text{-----(1).}$$

$$G = \text{a constant} = NBdl \text{-----(2).}$$

The spring control provides a restoring torque $TC = K\theta$ -----(3).

Where K = spring constant.

For final steady deflection $TC = Td$ or $GI = K\theta$

$$\therefore \text{Final steady deflection } \theta = (G/K).I \text{-----(4).}$$

$$\text{Or current } I = (K/G). \theta \text{-----(5).}$$

Where,

N = number of turns.

I = current flowing in coil.

B = flux density.

d = diameter of coil.

l = length of coil.

As the deflection is directly proportional to the current passing through the meter (K and G being constants so we get a uniform (linear) scale for the instrument.

Advantages of PMMC:

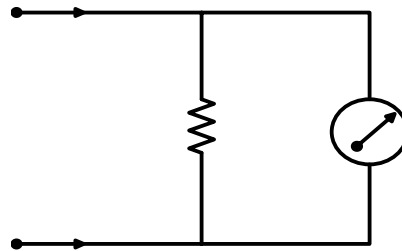
- i). Scale is uniformly divided.
- ii). Power consumption is very low as $25\mu\text{W}$ to $200\mu\text{W}$.
- iii). Torque ratio is high which gives high accuracy.

Disadvantages of PMMC:

- i). They are only useful for d.c. The torque reverse if the current reverses.
- ii). These instruments cannot be used for a.c. measurements.
- iii). More expensive than moving iron instruments.

Shunts for PMMC (Ammeter Shunts):

The coil winding of a basic movement is small and light and can carry very small currents. When heavy currents are to be measured, the major part of current is by passed through a low resistance called a "shunts". Figure shows the basic movement (meter) and its shunt to produce an ammeter.



Basic ammeter circuit

The resistance of the shunts can be calculated using conventional circuit analysis.

R_m = internal resistance of movement.

R_{sh} = resistance of the shunt

$I_m = I_{fs}$ = full scale deflection current of movement, the voltage drops across shunt and movement must be the same.

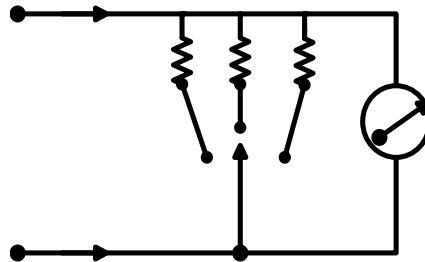
$$R_{sh} = I_m R_m / I_{sh}$$

But $I_{sh} = I - I_m$, therefore we can write $R_{sh} = I_m R_m / (I - I_m)$

Where I = required current to be measured.

Multi range Ammeters.

The current range of a d.c ammeter may be further extended by a number of shunts selected by a switch range as shown in figure;

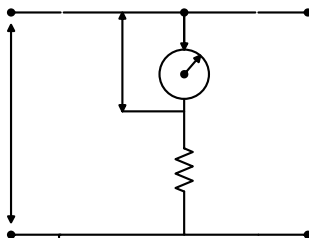


Multi range ammeter

For this ckt, it is important that the switch is of the *make before-break type* so that the meter movement is never without a shunt when the range switch moves from one position to another.

Voltmeter Multipliers:

The multiplier limits the current through the meter so that it does not exceed the value for scale deflection and thus prevents the movement from being damaged.



The value of a multiplier, required to extend the voltage range, is calculated as;

Let $I_m = I_{fs}$ = full scale deflection current of meter,

R_m = internal resistance of meter movement,

R_s = multiplier resistance,

v = voltage across the meter movement for current I_m ,

V = full range voltage of instrument.

For the ckt in fig:

$$\begin{aligned}v &= I_m R_m \\V &= I_m (R_m + R_s) \\V &= (V - I_m R_m) / I_m \\R_s &= V / I_m - R_m,\end{aligned}$$

Construction of Multipliers.

The essential requirements of multipliers are:

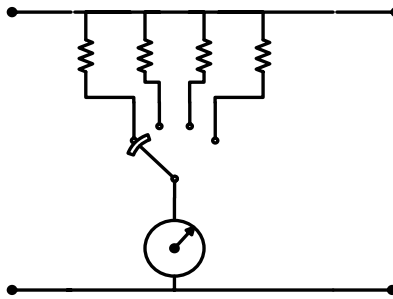
- ◆ Their resistance should not change with time,
- ◆ The change in their resistance with temperature should be small,
- ◆ They should be non-inductivity wound for a.c. meters.

Multi-range d.c Voltmeters.

In a multi-range voltmeter, different full scale voltage ranges may be obtained by the use of individual multiplier resistors or by a potential divider arrangement.

1. Individual multipliers.

We can obtain different voltage ranges by connecting different values of multiplier resistors in series with the meter. The number of these resistors is equal to the number of ranges required.



For this ckt, it is important that the switch is of the *make before-break type* so that the meter movement is never without a series resistor when the range switch moves from one position to another.

2. Potential Divider Arrangement.

Another multi-range voltmeter is shown in figure, in which the connections are made at the junctions of resistances in series to obtain the voltage ranges. These connections are brought out to binding posts on the instrument, and the instrument is connected to the proper binding post for the desired voltage range.

Errors in PMMC instruments:

The main sources of the errors in moving coil instruments are due to;

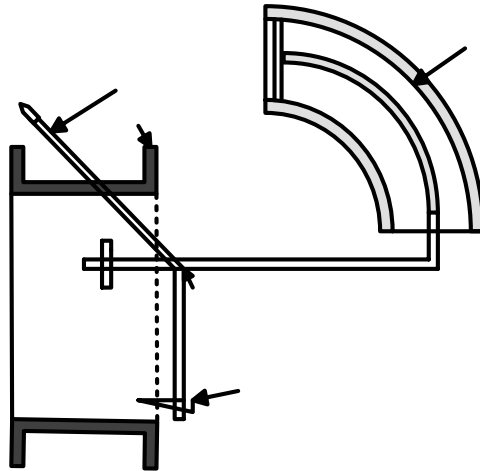
- Weakening of permanent magnets due to ageing at temperature effects.
- Weakening of springs due to ageing and temperature effects.
- Change of resistance of moving coil with temperature.

Moving Iron (M.I) Instruments.

The most common ammeters and voltmeters for laboratory or switch-board use at power frequencies are the moving iron instruments. The general principle of working of a moving iron instruments can be explained as under;

A plate or vane of soft iron or of high permeability steel forms the moving element of the system. This iron bane is so situated that it can move in a magnetic field produced by a stationary coil. The coil is excited by the current or voltage under measurement. When the coil is excited, it

becomes an electromagnet and the iron vane moves in such a way so as to increase the flux of the electromagnet. Thus the force produced is always in such direction so as to increase the inductance of the coil.



Classification of Moving Iron Instruments:

Moving Iron instruments are of two types;

- 1). Attraction type.
- 2). Repulsion Type.

1). Attraction type.

The coil is flat and has a narrow slot like opening. The moving iron is a flat disc or a sector eccentrically mounted. When the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the stronger field inside it or in other words the moving iron is attracted in. the controlling torque is provided by springs but gravity control can be used for panel type of instruments which are vertically mounted.

Damping is provided by air friction with the help of a light aluminum piston which moves in a fixed chamber closed at one end, or with the help of a vane which moves in a fixed sector shaped chamber.

2). Repulsion Type.

In the repulsion type, there are two vanes inside the coil vane fixed and other movable. These are similarly magnetized when the current flows through the coil and there is a force of repulsion between the two vanes resulting in the movement of the moving vane.

Two different designs are in common use:

i). Radial Vane Type:

In this type, the vanes are radial strips of iron. The strips are placed within the coil. The fixed vane is attached to the coil and the movable one to the spindle of the instrument.

ii). Co-axial Vane Type.

In this type of instrument, the fixed and moving vanes are sections of co-axial cylinders.

The controlling torque is provided by springs. Gravity control can also be used in vertically mounted instruments. The damping torque is produced by air friction as in attraction type instruments.

The operating magnetic field in moving iron instruments is very weak and therefore eddy current damping is not used in them as introduction of a permanent magnet required for eddy current damping would distort the operating magnetic field.

It is cleared that whatever the direction of the current, the iron vanes are so magnetized that there is always a force of repulsion in repulsion type of instrument. Thus moving iron instruments are unpolarised instruments

General torque equation:

$$\text{Mechanical work done} = Td.d\theta$$

Suppose initial current I, the instrument inductance L, and deflection θ . If current increase by dI then deflection change by $d\theta$ and change in inductance is dL .

$$\therefore \text{Electrical energy supplied} = eIdt \text{----- (i)}$$

Where

$$e = d/dt(LI) = I.d/dt(L) + L.d/dt(I).$$

Putting in equation (i).

$$\begin{aligned} \text{The electrical energy supplied} &= \{ I.d/dt(L) + L.d/dt(I) \} * Idt \\ &= \{ I.d(L) + L.d(I) \} * I \\ &= I^2 dL + ILdI \text{----- (ii)}. \end{aligned}$$

$$\begin{aligned} \text{The store energy change from} &= \frac{1}{2}(I^2 L) \Rightarrow \frac{1}{2}(I + dI)^2 (L + dL) \\ &= \frac{1}{2}(I + dI)^2 (L + dL) - \frac{1}{2}(I^2 L) \\ &= \frac{1}{2}(I^2 + 2IdI + d^2 I)(L + dL) - \frac{1}{2}(I^2 L) \\ &= \frac{1}{2}(I^2 L) + I^2 dI.L + \frac{1}{2}(d^2 I.L) + \frac{1}{2}(I^2 .dL) + LI dL + \\ &\quad \frac{1}{2}(dI^2 .dL) - \frac{1}{2}(I^2 .dL) \end{aligned}$$

Neglecting 2nd and higher differential terms,

$$\text{Change in stored energy} = ILdI + \frac{1}{2}(I^2 .dL).$$

According to law of conservation of energy = increase in stored energy + Mechanical work done.

$$\begin{aligned} I^2 dL + ILdI &= ILdI + \frac{1}{2}(I^2 dL) + Tdd\theta \\ Tdd\theta &= ILdI + I^2 dL - ILdI - \frac{1}{2}(I^2 dL) \\ &= I^2 dL - \frac{1}{2}\{I^2 dL (1 - \frac{1}{2})\} \\ &= \frac{1}{2}(I^2 dL) \\ \therefore \text{Deflecting torque} &= \frac{1}{2}(I^2 dL/d\theta). \end{aligned}$$

The moving system is provided with control spring and it turns the deflecting torque, it's balanced by the controlling torque.

$$\begin{aligned} Td &= TC \\ \frac{1}{2}(I^2 dL/d\theta) &= K\theta \\ \text{Deflection } \theta &= \frac{1}{2}(I^2 dL/Kd\theta). \end{aligned}$$

Hence deflection is proportional to the square of R.M.S value of the operating current.

In general it may be said that attraction-type instruments possess the same advantages, and are subjected to the limitations, described for repulsion type. An attraction type instrument usually has a lower inductance than the corresponding repulsion type instruments. On the other hand, repulsion instruments are more suitable for economical production in manufacture, and a nearly uniform scale is more easily obtained.

Errors in Moving Iron Instruments:

1). Errors with both D.C. and A.C.

There are three types of errors in moving iron instrument, for both a.c. and d.c.

i). Hysteresis Error:

The value of flux density is higher for descending values of current and therefore, the instrument tends to read for descending values of current than for ascending

values. This is overcome by making the iron parts small so that they demagnetize themselves quickly.

ii). Temperature Error:

The effect of Temperature changes on moving iron instruments arises chiefly from the temperature coefficient of spring. The error may be 0.2 percent per degree Celsius.

iii). Stray Magnetic Fields.

Such errors depend upon the direction of the stray magnetic field relative to the field of the instrument. These errors can be minimized by using an iron cases or a thin iron shield over the working parts.

2). Errors with A.C. only

i). Frequently Errors:

Changes in frequency may cause errors due to changes of reactance of the working coil and also due to changes of magnitude of eddy current set up in the metal parts of instrument.

a). Reactance of Instrument Coil:

The change of reactance of the instrument coil is important in case of voltmeters where an additional resistance R_s is used in series with the instrument coil. If the resistance and inductance of the coil is given by R and L , then the current is given by;

$$I = \frac{V}{\sqrt{(R + R_s)^2 + \omega^2 L^2}}$$

b). Eddy Currents:

These errors may caused by the eddy currents induced in the iron parts of the instrument. Let the mutual inductance b/w the instrument coil and iron parts be M . the induced voltage due to current I in the instrument coil lags the current by 90° . As a result of this induced voltage an eddy current I_e flows and its magnitude is

$$I_e = \frac{\omega MI}{\sqrt{R_e^2 + \omega^2 L_s^2}}.$$

Advantages of Moving Iron Instruments.

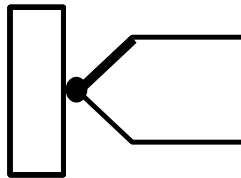
- 1) These instruments can be used for both A.c. and d.c.
- 2) Errors due to the friction are quite small as torque-weight ratio is quite high in these instruments.
- 3) It is cheaper instrument, as depending upon the magnitude of current the coil may have few turns of very heavy section conductor.
- 4) These instruments ate capable of giving accuracy within the limits of precisions and industrial grades.

Disadvantages of Moving Iron Instruments:

- 1) These instruments are subjected to serious errors due to hysteresis, frequency changes and stray magnetic fields.
- 2) There is a difference b/w d.c. and a.c calibrations on account of effect of inductance of the meter and the eddy currents when is used on a.c.
- 3) They must be calibrated for frequencies at which they are used.

Thermocouple instruments:

When two metals having different work functions are placed together, a voltage is generated at the junction which is nearly proportional to the temperature. This junction is called a ***Thermocouple***.



The heat at the junction is produced by the electrical current flowing in the heater element while the thermocouple produces an emf at its output terminals which can be measured with the help of a PMMC instrument. The emf produced is proportional to the temperature and hence to the rms value of the current.

Principle of operation of Thermo-electric Instruments:

The thermal emf developed in a circuit composed of two dissimilar metals with junctions kept at absolute temperatures T_1 and T_2 (with $T_1 > T_2$).

$$E = a(T_1 - T_2) + b(T_1 - T_2)^2.$$

Where a and b are constants whose values depend upon the metals used.

Construction of Thermo-electric Instruments.

The thermo-electric instruments consist of the following major parts:

1. Thermocouple element .
2. Indicating instrument.

The emf produced in the thermo-electric instruments is D.C. in nature and of the few order of a few mV. The Thermo-element consists of a heater wire through which current to be measured, or current proportional to the voltage being measured is passed. The other part of thermo-element is thermo-couple which develops an emf proportional to the difference between the hot junction and the cold reference junction.

Heater Element:

The heater element of the instrument should be free from the skin effect.

The skin effect refers to a condition where at high frequencies the current is forced to pass through the outer surface of the conductor as the inductance and consequently the reactance of the inner parts of the conductor is much larger than that of the outer parts. In order to reduce the skin effect the heater wire is designed with a small area of cross-section. In fact, a very fine wire of non-magnetic material having a very resistivity is used.

Thermo-Elements:

The thermo-elements used in thermocouple instruments are described as;

1. Contact Type:

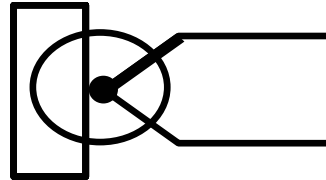
The contact type thermo-element has a separate heater wire and the thermocouple has one junction(hot junction) with the heater wire as shown in figure.

2. Non-Contact Type;

In the separate heater type there is no electric contact between the heating element and the thermo-element, the two being separated by electrical insulation. The heat is conducted from heater to junction across the insulation. This makes the instrument sluggish and less sensitive than the contact type. However the separation between the heater and the thermo-element becomes essential for measurements of currents in circuits operated at potentials considerably above ground potential.

3. Vacuum Thermo-Elements:

In order to make the thermo-couple more sensitive, both the heater and the thermocouple assembly are enclosed in a glass tube which is then evacuated. The efficiency is increased because there is no cooling of heater and the thermo-couple junction.



4. Bridge Type:

No heater element is used; instead the current to be measured passes directly through the thermocouples and raises their temperature proportional to I^2R .

The cold junctions are at the pins that are embedded in the bakelite. The thermocouples are oriented, so that the resultant thermal emfs give rise to a d.c. difference of potential. This construction gives a greater output than is given by a single thermo-couple used in vacuum and is much more robust in withstanding mechanical shocks and overloads.

Advantages of Thermo-couple instruments:

- 1) the thermo-couple instruments correctly indicate the rms value of voltage or current irrespective of the waveform.
- 2) These instruments are not affected by stray magnetic fields.
- 3) These instruments are free from frequency errors and hence they can be used over a very wide frequency range.
- 4) These instruments can measure currents in the range of 0.5 to 20 A.
- 5) These instruments have a high sensitivity.
- 6) They are very useful when used as transfer instruments to calibrate, d.c. instruments by potentiometer and standard cell.

Disadvantages:

- 1) if the current is doubled its rated value, then temperature becomes 4 times greater.
- 2) The overload capacity of thermo-couple instruments is small as compared with other instruments.

Instrument Transformer:

Transformers are used in a.c. system for the measurement of current, voltage, power and energy. They are also used in connection with measurement of power factor, frequency and for indication of synchronism. Transformer used in conjunction with measuring instrument of current is called a "Current Transformer" or simply "C.T". Transformers used for voltage measurements are called "Voltage Transformer" or simply "P.T".

1. Current Transformer:

The current transformer is used with its primary winding connected in series with line carrying the current to be measured.

The primary winding consists of very few turns and therefore, there is no appreciable voltage drop across it. The secondary winding of the current transformer has larger number of turns. The ammeter, or wattmeter current coil, are connected directly across the secondary winding terminals. thus a current transformer operates its secondary winding nearly under short circuit conditions. One of the terminals of the secondary winding is earthed so as to protect equipment in the event of an insulation breakdown.

Construction of a current transformer:

The current transformer may be classified as:

1. Wound type:

A current transformer having a primary winding of more than one full turn wound on core.

2. Bar Type:

A current transformer in which the primary winding consists of a bar of suitable size and material forming an integral part of transformer.

Current transformers use hot rolled steel which consist of stack of ring stampings. The latter is insulated by means of end collars and circum ferential wraps of elephantide or presspahn. After the secondary winding has been placed on the core, the ring type transformer is completed by exterior taping.

* In a bar type current transformer, the core and secondary windings are the same as in a ring type transformer but the fully insulated bar conductor constituting the single turn primary winding is an integral part of the current transformer.

Note that while the PT is a step-down device, the Current Transformer (or CT) is a step-up device (with respect to voltage), which is what is needed to step down the power line current. Quite often, CTs are built as donut-shaped Devices through which the power line conductor is run, the power line itself acting as a single-turn primary winding:

Some CTs are made to hinge open, allowing insertion around a power conductor without disturbing the conductor at all. The industry standard secondary current for a CT is a range of 0 to 5 amps AC. Like PTs, CTs can be made with custom winding ratios to almost any application. Because their "full load" secondary current is 5 amps, CT ratios are usually described in terms of full-load primary amps to 5 amps, like this:

600 : 5 ratio (*for measuring up to 600 A line current*)

100 : 5 ratio (*for measuring up to 100 A line current*)

1k : 5 ratio (*for measuring up to 1000 A line current*)

* Clamp On Ammeters:

A current transformer with a single conductor is used in combination with a bridge rectifier and a d.c. milli-ammeter to produce a very useful service meter. The corer of the transformer can be split with the help of a trigger switch and therefore the core can be clamped around a live conductor to measure the current. This arrangement avoids the necessity of breaking the circuit in order that a current measuring device be inserted in series with it to measure the value of current flowing. By hanging the shunt resistance of the milli-ammeter circuit ranges from 0-5 to 0-600 A can be obtained.

This type of clamp-on transformer is used with recording ammeters. These transformers are designed for a voltage of 5KV between the primary and the secondary windings. There are several variations of this clamp o transformer which are used for measuring maximum current in line real and reactive powers and the power factor.

Effects of Secondary Open Circuit.

Current transformers are always used with the secondary winding circuits closed through ammeters, watt meters or relay coils.

“Never open the secondary winding circuit of a current transformer while its primary winding is energized”.

Potential Transformer:

Potential transformers are used to operate voltmeters, the potential coils of watt meters and relays from high voltage lines. The primary winding of the transformer is connected across the line

carrying the voltage to be measured and the voltage circuit is connected across the secondary winding.

The design of a potential transformer is quite similar to that of a power transformer but the loading of a potential transformer is always small, sometimes only a few volt-amperes. The secondary winding is designed so that a voltage of 100 to 120 V is delivered to the instrument load. The normal secondary voltage rating is 110V.

Construction of Potential Transformers:

The design and construction of potential transformer are basically the same as those of power transformer but there are few major points of difference.

i). Core :

The core may be of shell or core type of construction. Shell type of construction is normally used only for low voltage transformers.

ii). Windings:

The primary and secondary windings are coaxial to reduce the leakage reactance to minimum. The secondary winding is put next to the core, the primary winding may be a single coil, sub divided into a number of short coils.

iii). Insulation:

Cotton tape and varnished cambric are used as insulation for coil construction. Hard fiber separators are used between the coils.

iv). Bushings:

Oil filled bushings are usually used for oil filled potential transformers as this minimizes the overall size of the transformer.

Difference between C.T. and P.T.

There are a few differences in the operation of a current transformer and a potential transformer.

	POTENTIAL TRANSFORMER	CURRENT TRANSFORMER
i).	The potential transformer may be considered as 'parallel' transformer with its secondary winding operating nearly under open circuit conditions.	The current transformer may be thought as a 'series' transformer under virtual short circuit conditions.
ii).	the primary winding current in a potential transformer depends on the secondary circuit burden	The primary winding current in a C.T is independent of the secondary winding circuit conditions.
iii).	In a P.T., full line voltage is impressed upon its terminals.	The C.T carries full line current, with small voltage across its terminals.
iv).	The flux density and exciting current of a potential transformer varies over a restricted range.	The primary winding current and excitation of a C.T vary over wide limits in normal operation.

Burden of an Instrument Transformer.

The rated burden is the volt-ampere loading which is permissible without errors exceeding the limits for the particular class of accuracy.

Total secondary winding burden

$$= \frac{(\text{secondary winding induced voltage})^2}{(\text{impedance of secondary winding circuit including impedance of secondary winding})}$$

$$= (\text{secondary current})^2 * (\text{impedance of secondary ckt including secondary winding})$$

secondary winding burden due to load

$$= \frac{(\text{secondary winding terminal voltage})^2}{(\text{Impedance of load on secondary winding})}$$

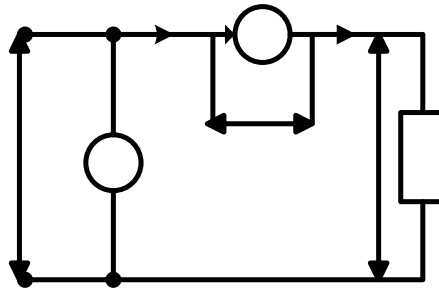
$$= (\text{secondary current})^2 * (\text{impedance of load on secondary winding circuit}).$$

Power and Energy Meters

Power in D.C. circuits:

The power taken by a load from d.c. supply is given by the product of readings of an ammeter and a voltmeter when connected in the circuits as shown in Fig:

$$\text{Power, } P = VI$$



The voltmeter not only indicates the voltage across the load, but in addition voltage drop V_a across the ammeter. If R_a is the resistance of the ammeter, voltage drop across ammeter, $V_a = IR_a$.

$$\begin{aligned} \text{Power consumed by the load} &= VLI = (V - V_a)I = VI - V_a I = VI - I^2 R_a \\ &= \text{pow: indicated by instrument} - \text{pow: loss in ammeter.} \end{aligned}$$

In order to obtain the true power, correction must be applied for power loss in instruments.

Power In A.C Circuit:

In the case of alternating currents, the instantaneous power varies continuously as the current and voltage go through a cycle.

True, Reactive, and Apparent power

We know that reactive loads such as inductors and capacitors dissipate zero power, yet the fact that they drop voltage and draw current gives the deceptive impression that they actually do dissipate power. This "phantom power" is called reactive power, and it is measured in a unit called Volt-Amps-Reactive (VAR), rather than watts. The mathematical symbol for reactive power is the capital letter Q.

The actual amount of power being used, or dissipated, in a circuit is called true power, and it is measured in watts (symbolized by the capital letter P, as always). The combination

of reactive power and true power is called apparent power, and it is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S. As a rule, true power is a function of a circuit's dissipative elements, usually resistances (R). Reactive power is a function of a circuit's reactance (X). Apparent power is a function of a circuit's total impedance (Z). There are several power equations relating the three types of power to resistance, reactance, and impedance (all using scalar quantities):

$$P = \text{true power} \quad P = I^2R \quad P = \frac{E^2}{R}$$

*Measured in units of **Watts***

$$Q = \text{reactive power} \quad Q = I^2X \quad Q = \frac{E^2}{X}$$

*Measured in units of **Volt-Amps-Reactive (VAR)***

$$S = \text{apparent power} \quad S = I^2Z \quad S = \frac{E^2}{Z} \quad S = IE$$

*Measured in units of **Volt-Amps (VA)***

Power factor

Power Factor is defined as the ratio of real power to apparent power. Power factor is related to the phase angle between voltage and current when there is a clear linear relationship. But it can still be defined when there is no apparent phase relationship between voltage and current.

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

Power factor is a simple way to describe how much of the current contributes to real power in the load. A power factor of one (*unity or 1.00*) indicates that 100% of the current is contributing to power in the load while a power factor of zero indicates that none of the current contributes to power in the load.

For the purely resistive circuit, the power factor is 1 (perfect), because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length.

For the purely inductive circuit, the power factor is zero, because true power equals zero. Here, the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length.

Power factor correction.

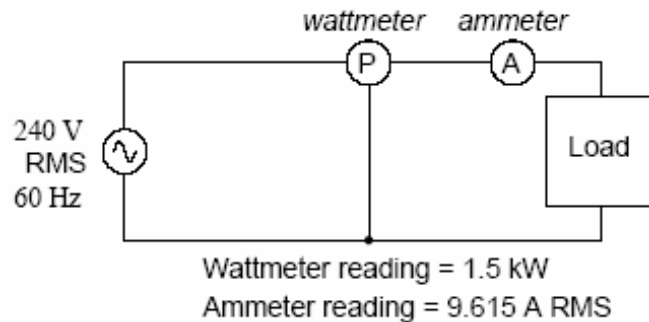
The current in an ac line can be thought of as consisting of two components: real and imaginary. The real part results in power absorbed by the load while the imaginary part is power being reflected back into the source, such as is the case when current and voltage are of opposite polarity and their product, power, is *negative*. Reflected power is undesirable for three reasons:

Firstly, the transmission lines or power cord will generate heat according to the total current it carries. Secondly, the reflected power that isn't wasted in the resistance of the power cord may generate unnecessary heat in the source. It is desirable to get the most power possible from the given current available. This can only happen when the power factor is close to or equal to unity.

Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel as the additional load.

The effect of these two opposing reactances in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal, or at least closer, to zero).

Let's do an example problem to see how this works:



First, we need to calculate the apparent power in kVA. We can do this by multiplying load voltage by load current:

$$S = IE$$

$$S = (9.615 \text{ A})(240 \text{ V})$$

$$S = 2.308 \text{ kVA}$$

As we can see, 2.308 kVA is a much larger figure than 1.5 kW, which tells us that the power factor in this circuit is rather poor (substantially less than 1). Now, we calculate the power factor of this load by dividing the true power by the apparent power:

$$\text{Power factor} = \frac{P}{S}$$

$$\text{Power factor} = \frac{1.5 \text{ kW}}{2.308 \text{ kVA}}$$

$$\text{Power factor} = 0.65$$

$$\text{Reactive power} = \sqrt{(\text{Apparent power})^2 - (\text{True power})^2}$$

$$Q = 1.754 \text{ kVAR}$$

we can calculate the size of capacitor needed to counteract its effects:

$$Q = \frac{E^2}{X}$$

... solving for X ...

$$X = \frac{E^2}{Q}$$

$$X_C = \frac{1}{2\pi fC}$$

$$X = \frac{(240)^2}{1.754 \text{ kVAR}}$$

... solving for C ...

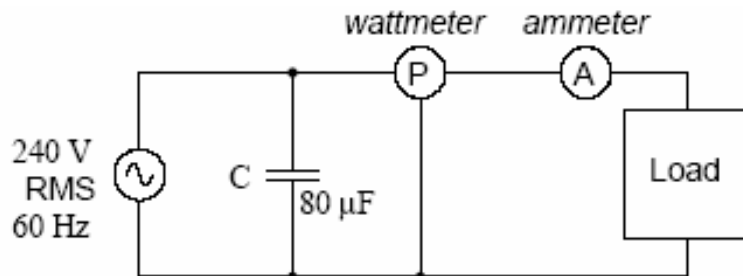
$$X = 32.845 \Omega$$

$$C = \frac{1}{2\pi fX_C}$$

$$C = \frac{1}{2\pi(60 \text{ Hz})(32.845 \Omega)}$$

$$C = 80.761 \mu\text{F}$$

Rounding this answer to 80 μF , we can place that size of capacitor in the circuit and calculate the results:



$$\text{Inductive kVAR} - \text{Capacitive kVAR} = \text{Total kVAR}$$

$$1.754 \text{ kVAR} - 1.737 \text{ kVAR} = 16.519 \text{ VAR}$$

This correction, of course, will not change the amount of true power consumed by the load, but it will result in a substantial reduction of apparent power, and of the total current drawn from the 240 Volt source:

The new apparent power can be found from the true and new reactive power values, using the standard form of the Pythagorean Theorem

$$\text{Apparent power} = \sqrt{(\text{Reactive power})^2 + (\text{True power})^2}$$

$$\text{Apparent power} = 1.50009 \text{ kVA}$$

This gives a corrected power factor of (1.5kW / 1.5009 kVA), or 0.99994, and a new total current of (1.50009 kVA / 240 Volts), or 6.25 amps, a substantial improvement over the uncorrected value of 9.615 amps! This lower total current will translate to less heat losses in the circuit wiring, meaning greater system efficiency (less power wasted).

Energy Meters:

The important parameter of energy meter is to record and to display electrical energy used over a period of time. The moving system of energy meter revolves continuously unlike indicating instruments.

One of the most common energy meter used for domestic or commercial use is Induction Type Energy Meter.

Single Phase Induction Type meters:

Theory of induction type Meters.

In all induction instruments there are two fluxes produced by currents flowing in the windings of the instrument, these fluxes are alternating in nature and so they produce emfs in a metallic disc or a drum provided for this purpose.

Main parts of Energy meter are:

1. Driving system.
2. Moving System.
3. Braking system.
4. Registering system.

1. Driving system

The meter consists of two electromagnets. The core of the electromagnet is made of silicon steel lamination. The coil of one of the electromagnets is excited by the load current. This coil is called the current coil. The coil of second electromagnet is connected across the supply and carries a current proportional to the supply voltage. This coil is called pressure coil.

2. Moving System:

This consists of an aluminum disc mounted on a light alloy shaft. This disc is positioned in the air gap between two electromagnet poles. These poles produce a resultant flux, that sweeps across the disc and produces eddy currents in disc. These eddy currents react with flux that causes the disc to rotate. The torque produced is proportional to power.

3. Braking System:

Permanent magnet is positioned near the edges of aluminum disc, forms a braking system. The moving disc moves in the field of permanent magnet and thus braking the torque.

4. Registering (counting) System:

The function of Registering system is to record continuously a number proportional to revolution made by moving system.

Errors in Single Phase Energy Meters:

The errors caused by the driving system are:

i). Incorrect magnitude of fluxes.

The shunt magnet flux may be in error due to changes in resistance of coil or due to abnormal frequencies.

ii). Incorrect Phase Angles.

This may be due to improper lag adjustments, abnormal frequencies, change in resistance with temperature, etc.

iii). Lack of symmetry in magnetic circuit:

- a) The errors caused by the braking system are:
- b) Changes in strength of brake magnet,
- c) Changes in disc resistance,
- d) Self-braking effect of series magnet flux and,
- e) Abnormal friction of moving parts.

Electronic Instruments:

Digital Voltmeters:

A digital voltmeter(DVM) displays the value of a.c. or d.c. voltage being measured directly as discrete numerals in the decimal number system, which eliminates observational errors. The errors on account of parallax and approximations are entirely eliminated.

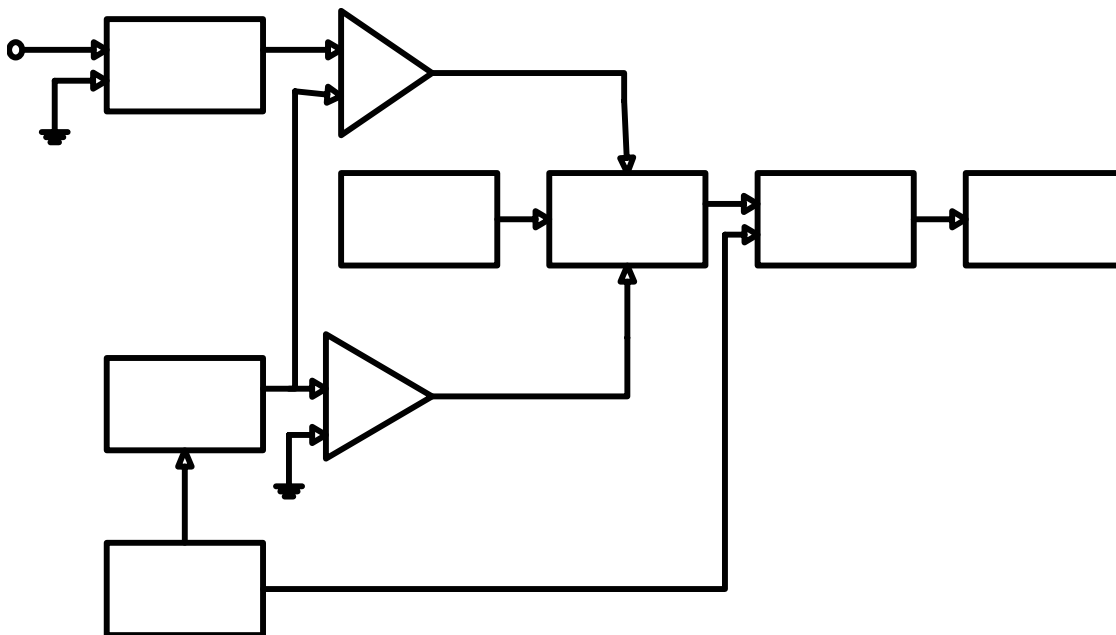
A digital voltmeter is a versatile voltmeter which has many laboratory applications. For the same accuracy, a digital voltmeter now is less costly than its analog counterpart.

Types of DVMs;

1. Ramp type DVM.
2. Integrating Type DVM.
3. Potentiometric type DVM.
4. Successive Type DVM.
5. Continuous balance type DVM.

1. Ramp Type DVM:

The operating principle of a ramp type digital voltmeter is to measure the time interval that a linear ramp voltage Ramps takes to change from level of input voltage to zero voltage(or vice versa). This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter.

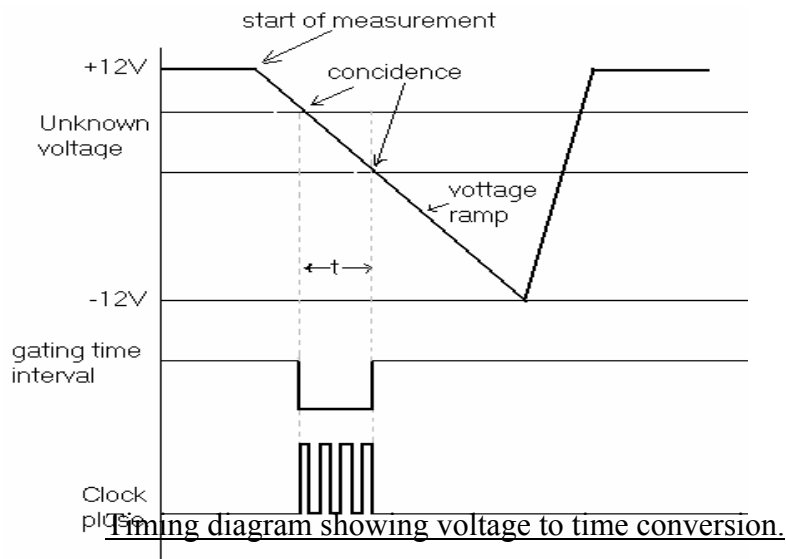


Block diagram of a ramp DVM

At the start of the measurement a ramp voltage is initiated. The ramp voltage value is continuously compared with the voltage being measured. At the instant the value of ramp voltage is equal to that of unknown voltage a coincidence ckt, called an input comparator, and generates a pulse which opens a gate. The ramp voltage continues to decrease till it reaches ground level. At this instant another comparator called ground comparator generates a pulse and closes the gate.

During this time interval pulse from the clock pulse generator pass through the gate and are counted and displayed. The sample rate multivibrator determines the rate at which the measurement cycles are initiated. The sample rate ckt provides an initiating pulse for the ramp generator to start its next ramp voltage.

At the same time it sends a pulse to the counter which sets all of them to zero.



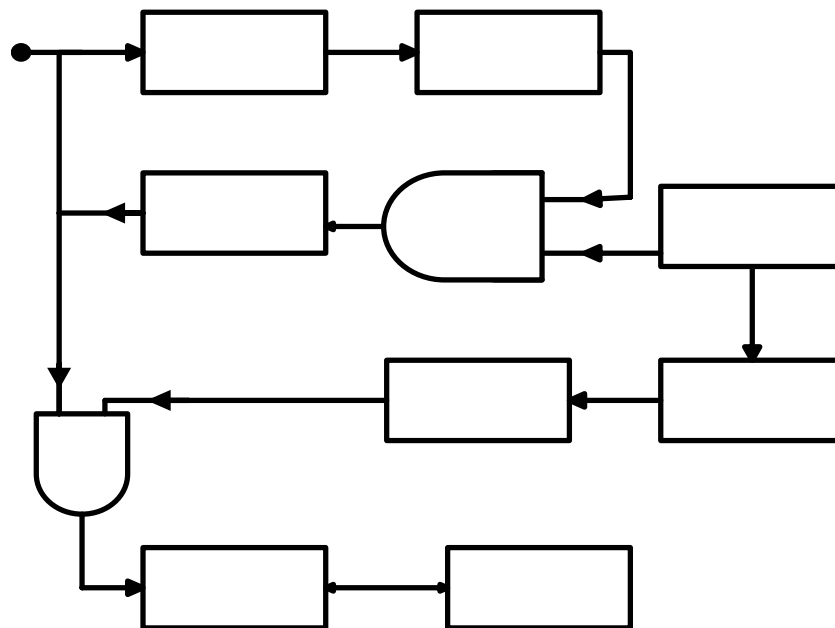
2. Integrating Type Digital Voltmeter:

This voltmeter measures the true average value of the input voltage over a fixed measuring period. The voltage to frequency converter functions as a feedback control system which governs the rate of pulse generation in proportion to the magnitude of input voltage. Since the frequency of the pulses is a function of unknown voltage, the number of pulses counted in that period of time is an indication of the input voltage.

The heart of this technique is the operational amplifier acting as an integrator.

$$\text{Output voltage of integrator } E_o = - E_i \left(\frac{1}{RC} \right) t.$$

Thus for a constant input voltage E_i is applied, an output voltage E_o is produced which rises at uniform rate and has a polarity opposite to the input voltage.

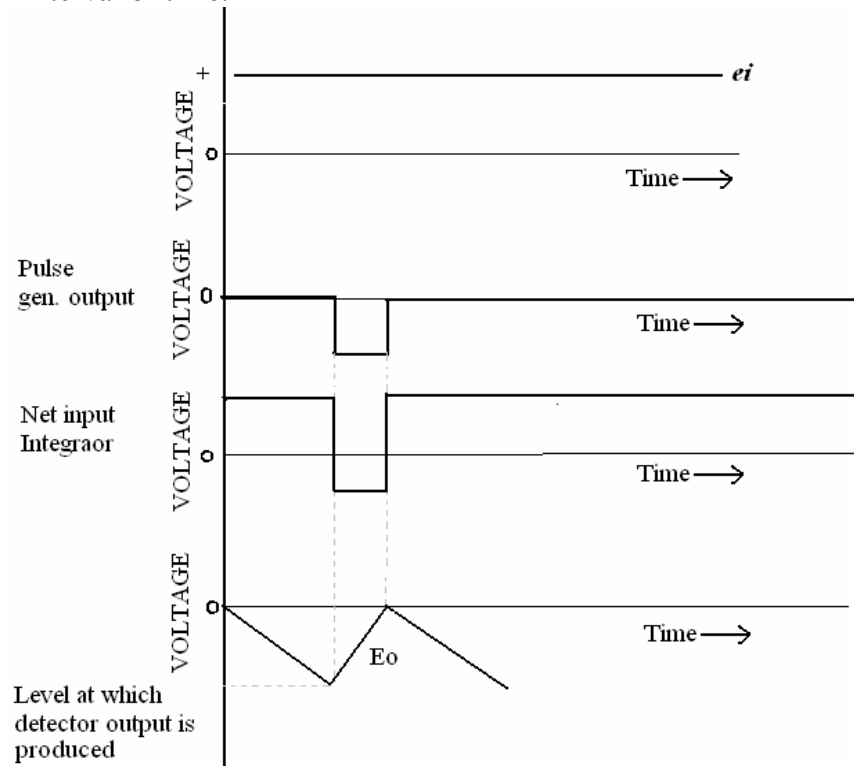


Block diagram of integrating type DVM

The voltage E_o is applied to the input of the integrator, and the output voltage starts to rise. The voltage is fed to a level detector (device similar to voltage comparator), and when E_o reaches a certain level, the detector sends a pulse to the Pulse generator gate.

The output pulse of the level detector opens the pulse generation gate, permitting pulses from a fixed frequency Clock oscillator, to pass through Pulse generator, that produces an output pulse of fixed amplitude and width. This output pulse, whose polarity is opposite to E_i and has a greater amplitude is feedback to input of the integrator. As a result of this reversed input, the output voltage E_o drops back to its original level. Since E_o is now below the reference level of the level detector, there is no output from the detector to the pulse generator gate and gate gets closed. Thus no more pulse from clock oscillator can pass through pulse generator.

The waveform of E_o is a sawtooth wave whose rise time is independent upon the value of input voltage E_i . The frequency of sawtooth wave may be measured by counting the number of pulses in a given interval of time.



Wave form of output voltage.

Pulse from the clock oscillator are applied to a time selector. The first pulse passes through start-stop gate, producing an output which is applied to the main gate, thus opening gate. The next pulse from the time base closes the start-stop gate and also the main gate. The counter and their associated readout indicate the number of pulses that have passed during a known interval of time. This count is indication of the voltage being measured.

Cathode Ray Tube (CRT).

A cathode ray oscilloscope is a very useful and versatile laboratory instrument used for display, measurement and analysis of wave forms and other phenomena in electrical and electronic circuits. CROs are in fact fast X-Y plotters, displaying an input signal versus another signal or versus time. The luminous spot which moves over the display is produced by a beam of electron striking a fluorescent screen.

The normal form of a CRO uses a horizontal input voltage which is an internally generated ramp voltage called "Time Base". This horizontal voltage moves the luminous spot periodically in a horizontal direction from left to right over the display area of screen. The vertical input to the

CRO is the voltage under investigation. The vertical input voltage moves the luminous spot up and down in accordance with the instantaneous value of the voltage.

CROs operates on voltages. However, it is possible to convert the current, strain, acceleration, pressure and other physical quantities into voltages with the help of transducers.

The main parts of Oscilloscope are:

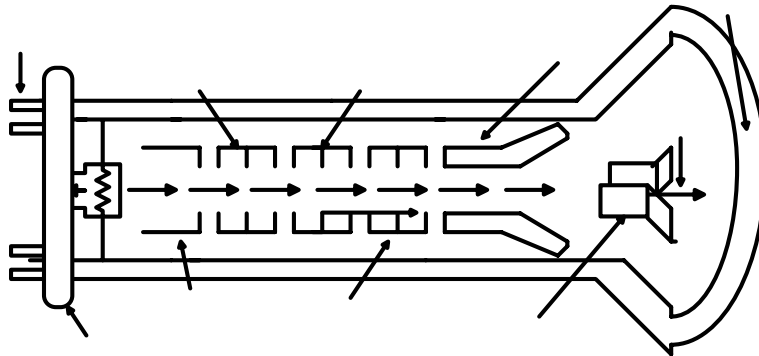
1. Cathode ray tube.
2. Amplifiers and deflection system.
3. Time base circuit.
4. Trigger circuit.
5. Power supply.

1. Cathode Ray Oscilloscope.

A cathode ray oscilloscope consists of a cathode ray tube(CRT), which is the heart of the CRO, and some additional circuitry to operate the CRT. The main parts of a CRT are:

- i. Electron Gun.
- ii. Deflection Plate assembly,
- iii. Fluorescent screen,
- iv. Glass envelope.
- v. Base, through which connections are made to various parts.

The main parts of CRT are shown in figure.



Internal structure of a CRT.

1. Electron Gun Assembly.

The source of focused and accelerated electron beam is the electron gun. The electron gun, which emits electrons and forms them into a beam, consists of a heater, a cathode, a grid, pre-accelerating anode, a focusing anode and an accelerating anode.

The electrons emitted from indirectly heated cathode and passing through the hole in the control grid are accelerated by the high positive potential which is applied to the “pre-accelerating” and accelerating anodes”. The cathode beam is focused by the “focusing beam”. The accelerating and focusing anodes are cylindrical in form, with small openings located in the center of each electrode, coaxial with the tube axis.

After leaving the focusing anodes, the electron beam through the vertical and horizontal deflection plates and then goes on to the fluorescent screen.

The pre-accelerating anode and the accelerating anode are connected to a common positive high voltage of about 1500V. The focusing anode is connected to a lower adjustable voltage of 500V. There are two methods of focusing an electron beam:

1. Electrostatic focusing.

2. Electromagnetic focusing.

Deflection plates:

After leaving the electron gun, beam passes through the two pairs of deflecting plates. This pair produces a vertical and horizontal deflection and thus is called “vertical” and “horizontal deflecting plates”. The plates are flared so as to allow the beam to pass through them without striking the plates.

Screens for CRTs:

The front of the CRT is called the face plate. It is flat for screen size up to about 100mm x 100mm, and slightly curved for larger displays. The inside surface of the face plate is coated with phosphor. A phosphor converts electrical energy to light energy. When beam strikes phosphor crystals it raises their energy levels, and light is emitted and this is called fluorescence.

The luminance of phosphor is a measure of its brightness. It is determined by the luminance efficiency of the phosphor, and by the beam energy, which is a product of the beam current density, the accelerating potential and the writing time.

3. Oscilloscope Amplifiers.

There are basically two amplifiers in the Oscilloscope.

1. Vertical Amplifier.

The vertical amplifier is the principle factor in determining the sensitivity and bandwidth of an oscilloscope. The gain of the vertical amplifier determines the smallest signal that the oscilloscope can satisfactorily reproduce on the CRT screen. The sensitivity of the oscilloscope is directly proportional to the gain of the vertical amplifier. the vertical sensitivity is the smallest deflection factor that can be selected with the rotary switch, on front panel.

The bandwidth determines the range of frequencies that can be accurately reproduced on the CRT screen.

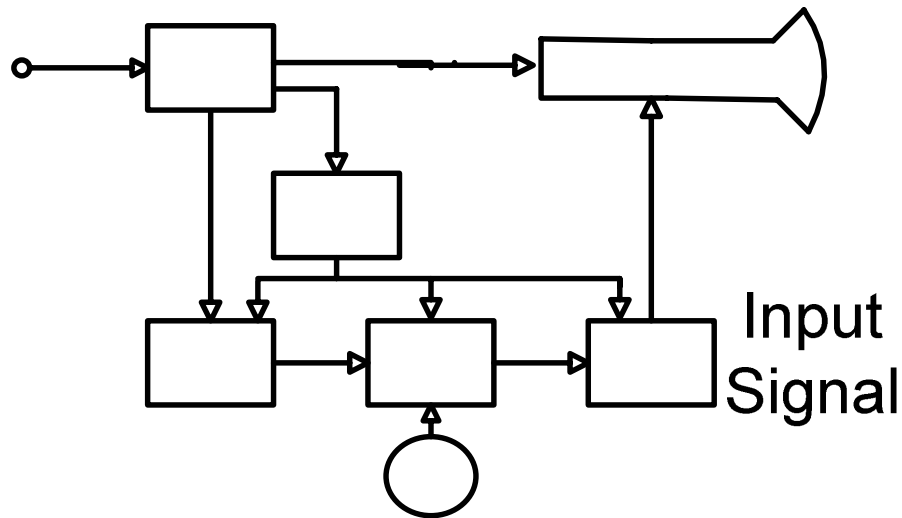
a. Horizontal Amplifier:

The horizontal amplifier basically serves two purposes.

- i. When the oscilloscope is being used in ordinary mode of operation to display a signal applied to the vertical input. The horizontal amplifier will amplify the sweep generator output.
- ii. When the oscilloscope is being used in the X-Y mode, the signal applied to the horizontal input terminal will be amplified by the horizontal amplifier.

Attenuators:

The term attenuate means to “reduce in size”. The purpose of the attenuator is to reduce the amplitude of the vertical input signal before applying it to the vertical amplifier. The most basic attenuator is a simple resistive voltage divider.



Vertical(Y) Deflection System.

The signals to be examined are usually applied to the vertical or Y deflection plates through an input attenuator and a number of amplifier stages. Vertical amplifier is required because the signals are not strong enough to produce measurable deflection of the CRT screen. The amplifier response must be wide enough to pass faithfully the entire band of frequencies to be measured.

When high voltage signals are to be examined, they must be attenuated to bring them within the range of vertical amplifiers. The vertical amplifier output is also applied to the synchronizing amplifier through the synchronizer selector switch in the internal position. This permits the horizontal sweep circuit to be triggered by the signal being investigated.

Horizontal(X) Deflection System.

The horizontal deflection plates are fed by a sweep voltage that provides a time base. The horizontal plates are supplied through an amplifier, via the sweep selector switch in the external position. When the sweep selector switch is in the internal position, the horizontal amplifier receives an input from the saw tooth sweep generator which is triggered by the synchronizing amplifier.

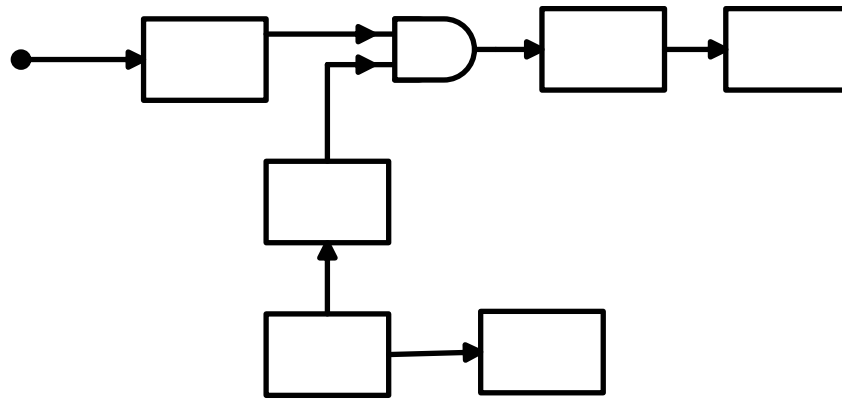
DIGITAL FREQUENCY METER.

The signal whose frequency is to be measured is converted into a train of pulses, one pulse for each cycle of the signal. Then the number of pulses appearing in a definite interval of time is counted by means of an electronic counter. Since the electronic counters are extremely fast, the frequency of high frequency signals may be known.

Basic Circuit:

The block diagram of the basic circuit of a digital frequency meter is shown in figure.

Basic C



The unknown frequency signal is fed to a signal conditioning circuit, which attenuates or amplifies the strength of the input signal to the required range of the device and converts the signal to a train of pulses according to the input frequency. On the same time the clock oscillator sends a high pulse to the Flip flop, opening the start/stop gate. Allowing the train of pulses to pass to counter. When another pulse goes to the FF the FF toggles closing the gate. When the gate is closed, the pulses path stops and the counter counts the number of pulses that have been passed through it in the time interval b/w start and stop, and displays it in digits.

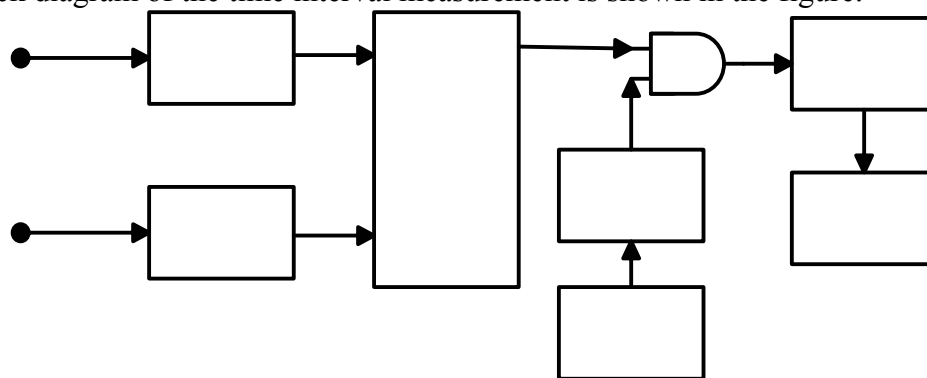
Time Base:

The time interval between the start stop gate must be accurately known. This time interval known as time base can be determined by a simple circuit. The time base consists of clock oscillators. The duty cycle can be adjusted by a rotating Knob. The time period of this clock oscillator is the time on which the gate is open.

TIME INTERVAL MEASUREMENT:

In this measurement the electronic counter used as an output readout device performs the function of an electronic stop watch.

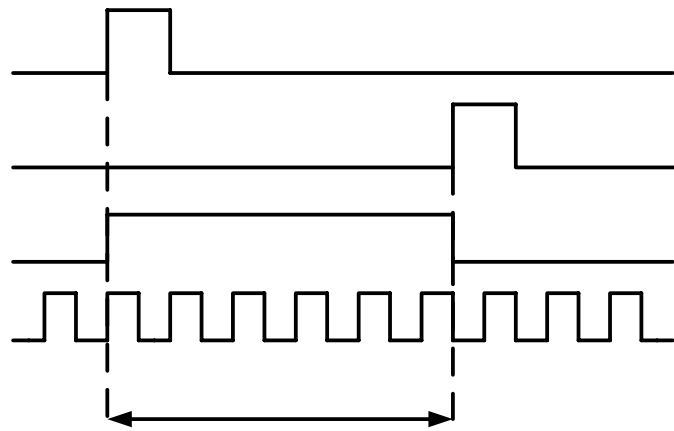
The block diagram of the time interval measurement is shown in the figure.



Block diagram of a Time interval meter.

There are two parallel inputs channels where one channel supplies the enabling pulse for the main gate and the other disabling pulse. The main gate is opened at a point on the leading edge of the start input signal and closed on the leading edge of the stop signal. When the gate is open the pulses from the clk oscillator are counted by the decade counter assemblies. Thus the count displayed is in a way a yardstick to measure the time elapsed between opening and closing of gate.

Since the time interval during which the gate remains open and closed depends upon the wave shape of the input signal, the device for measurement must have slope selection feature.



General pulse working of Time interval Meter

Start

TRANSDUCERS:

An electronic instrumentation system consists of a number of components to perform a measurement and record its results. The generalized measurement system consists of three major components.

- i. An input device.
- ii. A signal conditioning or processing device, and
- iii. An output device.

Stop

The first stage of a measurement system simply be called a transducer stage. A transducer, in general form, may be defined as a device which converts energy from one form to another. However this definition is restricted, hence a transducer may be defined as a device that converts a physical quantity or a physical condition into an electrical quantity. Another name for transducer is pick up.

Gate

Classification of transducers.

The transducers may be classified according to whether they are passive or active.

1. Passive Transducers.

Passive transducers derive the power required for transduction from an auxiliary power source. They also derive part of the power required for conversion from the physical quantity under measurement. They are also known as externally power transducers. Typical examples of passive transducers are resistive, inductive and capacitive transducers.

Pulses
form
Clk

2. Active Transducers:

Active transducers are those which do not require an auxiliary power source to produce their output. They are also known as self generating type since they develop their own voltage or current output. Best example is a piezoelectric transducer.

Osci:

Resistive Transducers:

There are a number of ways by which resistance can be change by a physical phenomenon. Usually there are Four different transducers used for this purpose.

1. Thermistor.
2. RTD.
3. Photoconductive cells.
4. Potentiometric.

1. Thermistor.

A Thermistor is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature. Thermistor is a portmanteau of the words thermal and resistor.

If we assume that the relationship between resistance and temperature is linear (i.e. we make a first-order approximation), then we can say that:

$$\Delta R = k\Delta T$$

Where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Thermistors can be classified into two types depending on the sign of k . If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor, Posistor. If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor. Resistors that are not thermistors are designed to have the smallest possible k , so that their resistance remains almost constant over a wide temperature range.

Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron and uranium. General symbol of a thermistor is given below



Self-heating effects

When a current flows through a thermistor, it will generate heat which will raise the temperature of the thermistor above that of its environment. this self-heating effect will introduce an error if a correction is not made.

The electrical power input to the thermistor is just,

$$P_E = IV$$

where I is current and V is the voltage drop across the thermistor. This power is converted to heat, and this heat energy is transferred to the surrounding environment. The rate of transfer is well described by Newton's law of cooling:

At equilibrium, the two rates must be equal. As a simple example, if the voltage across the thermistor is held fixed, then by Ohm's Law we have $I = V / R$ and the equilibrium equation can be solved for the ambient temperature as a function of the measured resistance of the thermistor:

$$T_0 = T(R) - \frac{V^2}{KR}$$

The dissipation constant is a measure of the thermal connection of the thermistor to its surroundings. It is generally given for the thermistor in still air, and in well stirred oil.

Applications

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is

large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase, and therefore causing even more heating. This creates a self-reinforcing effect that drives the resistance upwards, reducing the current and voltage available to the device.

- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.
- NTC thermistors can be used as inrush-current limiting devices in power supply circuits. They present a higher resistance initially which prevents large currents from flowing at turn-on, and then heat up and become much lower resistance to allow higher current flow during normal operation. These thermistors are usually much larger than measuring type thermistors, and are purpose designed for this application.
- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.

RTD(resistance temperature detector/resistance thermometers):

Resistance thermometers, also called **resistance temperature detectors (RTDs)**, are temperature sensors. As they are almost invariably made of platinum, they are often called **platinum resistance thermometers (PRTs)**.

There are two broad categories, "film" and "wire-wound" types.

- *Film thermometers* have a layer of platinum on a substrate; the layer may be extremely thin, perhaps 1 micrometer. Advantages of this type are relatively low cost and fast response. Such devices have improved in performance although the different expansion rates of the substrate and platinum give "strain gauge" effects and stability problems.
- *Wire-wound thermometers* can have greater accuracy, especially for wide temperature ranges. The coil diameter provides a compromise between mechanical stability and allowing expansion of the wire to minimize strain and consequential drift.

How do resistance thermometers work?

Thermocouples use the Seebeck effect to generate a voltage, resistance thermometers use electrical resistance and require a small power source to operate. The resistance ideally varies linearly with temperature.

Resistance thermocouples are usually made using platinum, because of its linear resistance-temperature relationship and its chemical inertness. The platinum detecting wire needs to be kept free of contamination to remain stable. The sensor is usually made to have a resistance of 100 Ω at 0 °C.

Resistance thermometers require a small current to be passed through in order to determine the resistance. This can cause self-heating. Care should also be taken to avoid any strains on the resistance thermometer in its application. Lead wire resistance should be considered, and adopting three and four wire connections can eliminate connection lead resistance effects from measurements.

Advantages and limitations

Advantages of platinum resistance thermometers:

- High accuracy
- Low drift
- Wide operating range
- Suitability for precision applications

Limitations:

- RTDs in industrial applications are rarely used above 660 °C. At temperatures above 450 °C it becomes increasingly difficult to prevent the platinum from becoming contaminated by impurities

from the metal sheath of the thermometer. This is why laboratory standard thermometers replace the metal sheath with a Glass construction.

- Compared to thermistors, platinum RTDs are less sensitive to small temperature Changes and have a slower response time. However, thermistors have a smaller Temperature range.

Resistance thermometer elements

Resistance thermometers elements are available in a number of forms. The most common are:

- Wire-wound in a ceramic insulator - works with temperatures to 850 °C.
- Wires encapsulated in glass - resists vibration, offers the most protection to the detecting wire, and is inexpensive to mass-produce.

Resistance thermometer construction

These elements nearly always require insulated leads attached. At low temperatures PVC, silicon rubber or PTFE insulators are common to 250 °C. Above this, glass fiber or ceramic are used. The measuring point and usually most of the leads require a housing or protection sleeve. This is often a metal alloy which is inert to a particular process.

Temperature to resistance equation

The relation between temperature and resistance is given by the Callendar-Van Dusen equation,

$$R_T = R_0 [1 + AT + BT^2 + cT^3(T - 100)] \quad (-200 \text{ }^\circ\text{C} < T < 0 \text{ }^\circ\text{C},$$

$$R_T = R_0 [1 + AT + BT^2] \quad (0 \text{ }^\circ\text{C} \leq T < 850 \text{ }^\circ\text{C}).$$

Here, R_T is the resistance at temperature T , R_0 is the resistance at 0 °C, and the constants (for a platinum RTD) are,

$$A = 3.9083 \times 10^{-3} \text{ }^\circ\text{C}^{-1}$$

$$B = -5.775 \times 10^{-7} \text{ }^\circ\text{C}^{-2}$$

$$C = -4.183 \times 10^{-12} \text{ }^\circ\text{C}^{-3}$$

Since the B and C coefficients are relatively small, the resistance changes almost linearly with the temperature.

PHOTOCONDUCTIVE CELL:

In this type of device the electrical resistance of the material varies with the amount of light energy striking it. Many materials are photoconductive to some degree, but the commercially important ones are cadmium sulfide, germanium and silicon. The essential elements of a photoconductive cell are the ceramic substrate, a layer of photoconductive material, metallic electrodes to connect the device into a circuit, and a moisture-resistant enclosure.

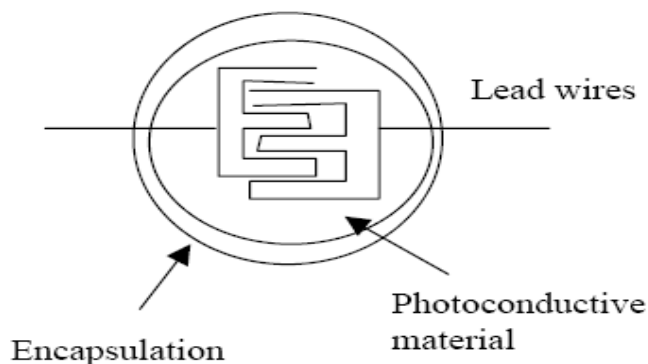


Fig1. Light dependant Resistor



Schematic symbol

Applications of photoconductive cells:

The low resistance of photo-conductive cells when they are exposed to light means that they can and are, designed to carry moderate currents, such as are capable of operating a relay coil directly without any amplification. they can be used ;

- i. for counting packages moving on a conveyor belt.
- ii. In burglar alarm circuits, where in the interception of light actuates an alarm circuit.
- iii. They can also be used as a light activated or dark activated switch.

PONTENTIOMETRIC TRANSDUCER:

A potentiometric transducer is an electromechanical device containing a resistance element that is contacted by a movable slider. Motion of the slider results in a resistance change that may be a linear, logarithmic, exponential and so on, depending on the manner in which the resistance wire is wound. The basic elements of the potentiometric transducer are given in figure;

The potentiometric principle is widely used despite its limitations. Its electric efficiency is very high and it provides a sufficient output to permit control operations without further amplification. The device may be ac-or dc-excited and can therefore serve a wide range of functions. Because of the mechanical friction of the slider against the resistance element, its life is limited and noise may develop as the element wears out. Large displacements are usually required to move the slider along the entire working surface of the potentiometer.

Capacitive Transducers:

The capacitance of a parallel-plate capacitor is given by,

—————

where A= area of plates

d= plate spacing,

$\epsilon_0 = 9.85 \times 10^{12}$.

K = dielectric constant.

Since the capacitance is inversely proportional to the spacing of the parallel plates, any variation in d causes a corresponding variation in the capacitance. the capacitive transducer work on the principle of change of capacitance which may be caused by:

- i. change in overlapping area A,
- ii. change in the distance d between the plates, and
- iii. change in dielectric constant. These changes are caused by physical variables like displacement, force and pressure.

The resultant change in capacitance could be measured with an ac bridge, but it is usually measured with an oscillator circuit.

The capacitive transducer has excellent frequency response and can measure both static and dynamic phenomena.

Advantages:

The major advantages of capacitive transducers are:

1. they require extremely small forces to operate them and hence are very useful in small system.
2. they are extremely sensitive.

3. they have a good frequency response.
4. the force requirements of capacitive transducers is very small and therefore, they require small power to operate them.

Disadvantages:

The principal disadvantages of capacitive transducers are:

1. the metallic parts of the capacitive transducers must be insulated from each other.
2. the capacitive transducers show non-linear behavior many a times on account of edge effects.
3. the output impedance of capacitive transducers tends to be high on account to their small capacitive value. This leads to loading effects.
4. the capacitance of a capacitive transducer may be changed on account of presence of extraneous matter like dust particles and moisture.
5. the capacitive transducers are temperature sensitive and therefore any change in temperature adversely affects their performance.
6. the instrumentation circuitry used with these transducers is very complex.

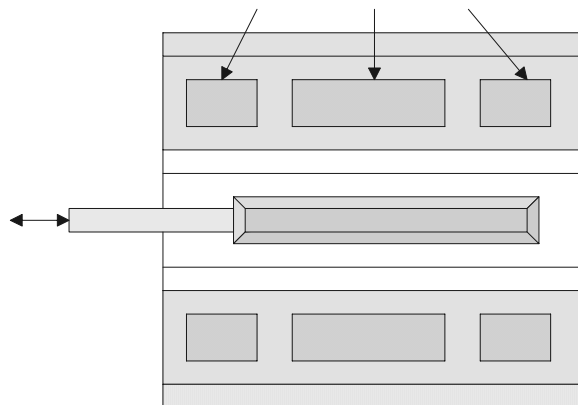
INDUCTIVE TRANSDUCER:

In the inductive transducer the measurement of force is accomplished by the change in the inductance ratio of a pair of coils or by the change of inductance in a single coil. In each case, the ferromagnetic armature is displaced by the force being measured, varying the reluctance of the magnetic circuit. The resultant change in inductance is a measure of the magnitude of the applied force. This type of transducer is used extensively in telemetry systems, with a single coil that modulates the frequency of a local oscillator.

Hysteresis errors of the transducer are almost entirely limited to the mechanical components. The inductive transducer responds to static and dynamic measurements, and it has continuous resolution and a fairly high output. Its disadvantages are that the frequency response is limited by the construction of the force summing member. In addition, external magnetic fields may cause erratic performance.

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT):

The most widely used inductive transducer to translate the linear motion into electrical signals is the linear variable differential transformer (LVDT). The basic construction of LVDT is shown in figure.



Linear Variable differential transformer

The transformer consists of a single primary winding P and two secondary windings, wound on a cylindrical former. The secondary windings have equal number of turns and are identically placed on either side of the primary winding. The primary winding is connected to than

alternating current source. A movable soft iron core is placed inside former. The displacement to be measured is applied to the arm attached to the soft iron core. The frequency applied to the primary must be b/w 50Hz to 20kHz.

The primary winding produces an alternating magnetic field which in turn induces alternating voltages in the two secondary windings. The amount of voltage change in either secondary winding is proportional to the amount of movement of the core.

The amount of voltage may be measured to determine the displacement. The output of an LVDT is a linear function of core displacement within a limited range of motion.

Advantages:

1. the LVDT have high range for measurement of displacement.
2. its operation is frictionless and has an electrical isolation.
3. it has immunity from external effects.
4. The LVDT gives a high output and many a times there is no need for amplification.
5. Most of LVDT consumes low power.

Disadvantages:

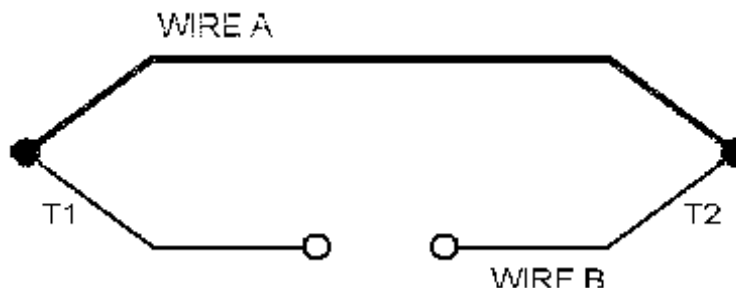
1. Relatively large displacements are required for appreciable differential output.
2. Many times the transducer performance is affected by vibrations.
3. The dynamic response is limited.
4. Temperature affects the performance of the transducer.

THERMOCOUPLE:

In **electronics**, **thermocouples** are a widely used type of **temperature sensor** and can also be used as a means to convert thermal potential difference into electric potential difference. They are cheap, interchangeable, have standard connectors, and can measure a wide range of temperatures.

It is important to note that thermocouples measure the temperature difference between two points, not absolute temperature.

Thermocouples can be connected in series with each other to form a **thermopile**, where all the hot junctions are exposed to the higher temperature and all the cold junctions to lower temperature. Thus, the voltages of the individual thermocouple add up, which allows for a larger voltage.



Usually the thermocouple is attached to the indicating device by a special wire known as the *compensating* or *extension* cable. The extension cable or compensating cable must be selected to match the thermocouple. It generates a voltage proportional to the difference between the hot junction and cold junction, and is connected in the correct polarity so that the additional voltage is added to the thermocouple voltage, compensating for the temperature difference between the hot and cold junctions.

Voltage-Temperature Relationship

The relationship between the temperature difference and the output voltage of a

thermocouple is **nonlinear** and is given by a **polynomial interpolation**. The coefficients are given for n between 5 and 9.

$$T = \sum_{n=0}^N a_n v^n$$

To achieve accurate measurements the equation is usually implemented in a digital controller or stored in a lookup table. Some older devices use analog filters.

Different types

A variety of thermocouples are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research, etc.).

Type K (Chromel (Ni-Cr alloy) / Alumel (Ni-Al alloy))

The "general purpose" thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. They are available in the $-200\text{ }^{\circ}\text{C}$ to $+1200\text{ }^{\circ}\text{C}$ range. Sensitivity is approximately $41\text{ }\mu\text{V}/^{\circ}\text{C}$.

Type E (Chromel / Constantan (Cu-Ni alloy))

Type E has a high output ($68\text{ }\mu\text{V}/^{\circ}\text{C}$) which makes it well suited to low temperature (cryogenic) use. Another property is that it is non-magnetic.

Type J (Iron / Constantan) Limited range (-40 to $+750\text{ }^{\circ}\text{C}$) makes type J less popular than type K.

J types cannot be used above $760\text{ }^{\circ}\text{C}$. Type J's have a sensitivity of $\sim 52\text{ }\mu\text{V}/^{\circ}\text{C}$.

Type N (Nicrosil (Ni-Cr-Si alloy) / Nisil (Ni-Si alloy))

High stability and resistance to high temperature oxidation makes type N suitable for high temperature measurements without the cost of platinum (B, R, S) types. They can withstand temperatures above $1200\text{ }^{\circ}\text{C}$. Sensitivity is about $39\text{ }\mu\text{V}/^{\circ}\text{C}$ at 900°C ,

Thermocouple types B, R, and S are all **noble metal** thermocouples and exhibit similar characteristics. They are the most stable of all thermocouples, but due to their low sensitivity (approximately $10\text{ }\mu\text{V}/^{\circ}\text{C}$) they are usually only used for high temperature measurement ($>300\text{ }^{\circ}\text{C}$).

Type B (Platinum-Rhodium/Pt-Rh)

Suited for high temperature measurements up to $1800\text{ }^{\circ}\text{C}$. This makes them useless below $50\text{ }^{\circ}\text{C}$.

Type R (Platinum /Platinum with 7% Rhodium)

Suited for high temperature measurements up to $1600\text{ }^{\circ}\text{C}$. Low sensitivity ($10\text{ }\mu\text{V}/^{\circ}\text{C}$) and high cost makes them unsuitable for general purpose use.

Type S (Platinum /Platinum with 10% Rhodium)

Suited for high temperature measurements up to $1600\text{ }^{\circ}\text{C}$. Low sensitivity ($10\text{ }\mu\text{V}/^{\circ}\text{C}$) and high cost makes them unsuitable for general purpose use. Due to its high stability type S is used as the standard of calibration for the melting point of **gold** ($1064.43\text{ }^{\circ}\text{C}$).

Type T (Copper / Constantan)

Suited for measurements in the -200 to $350\text{ }^{\circ}\text{C}$ range. The positive conductor is made of **copper**, and the negative conductor is made of constantan. Type T thermocouples have a sensitivity of $\sim 43\text{ }\mu\text{V}/^{\circ}\text{C}$

Thermocouples are usually selected to ensure that the measuring equipment does not limit the range of temperatures that can be measured. Note that thermocouples with low sensitivity (B, R, and S) have a correspondingly lower resolution.

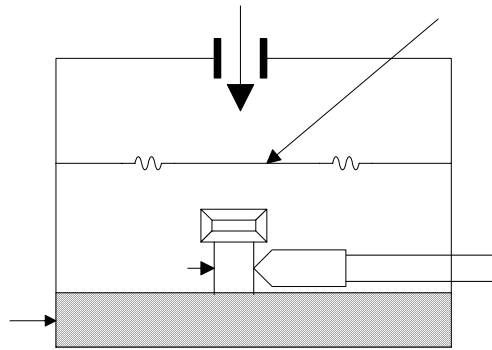
PHOTOVOLTAIC CELLS:

Photovoltaic cells may be used in a number of applications. The silicon solar cell converts the radiant energy of the sun into electrical power. The solar cell consists of a thin slice of a single p-type silicon, up to 2sq:cm, into which a very thin layer of n-type material is diffused. The conversion efficiency depends on the spectral content and the intensity of the illumination.

Multiple-unit silicon photovoltaic devices may be used for sensing light in applications such as reading punched cards in the date processing industry.

PIEZOELECTRIC TRANSDUCER:

Asymmetrical crystalline materials, such as quartz, Rochelle salt, and barium tatanite, produce an emf when thy are placed under stress. This property is used in piezoelectric transducers, where a crystal is placed between a solid base and the force summing member as shown in figure.



An externally applied force entering the transducer through its pressure port, applies pressure to the top of a crystal. This produces an emf across the crystal, proportional to the magnitude of the applied pressure.

Since the transducer has a very good frequency response, its principal use in high frequency accelerometers. In this application its output voltage is typically on the order of 1 to 30mV per g of acceleration. The device needs no external power source and is therefore self-generating. The principal disadvantage of this transducer is that it cannot measure static conditions. The output voltage is also affected by temperature variations of the crystal.

DATA ACQUICTION SYSTEMS:

Data acquisition systems are used to measure and record analog signals in basically two ways:

- i. Signals which originate from direct measurement of electrical quantities. These signals may be dc or ac. Voltages, frequency or resistance.
- ii. Signals which originate from use of transducers.

The data acquisition system can be classified into two distinct categories.

1. analog systems:

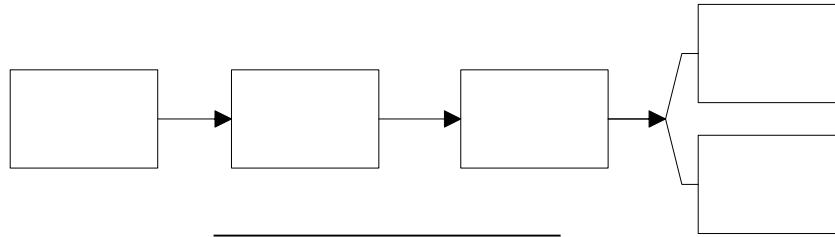
These system deal with information in analog form. An analog signal may be defined as continuous function, such as a plot of voltage versus time of displacement versus force.

2. Digital Systems:

A digital quantity may consist of a number of discrete or discontinuous pulses whose time relationship contains information about the magnitude and the nature of the quantity under measurement.

Components of Analog data Acquisition:

An analog data acquisition system typically consists of some or all of the following elements:



i. Transducers:

It is desirable that an emf obtained from the transducer proportional the quantity being measured, is used as an input to the data acquisition system. Therefore, such as thermocouples, strain gauges, piezo-electric devices and photosensitive.

ii. Signal Conditioning Equipment.

Signal conditioning equipment includes by equipment that assist in transforming the output of transducer to the desired magnitude or form required by the next stage of the data acquisition system. It also produces the required conditions in the transducers so that they work properly. Signal conditioners may include devices for amplifying, refining or selecting certain positions of these signals.

iii. Receiver:

Receivers contains electronic or electromechanically circuitry, which receives the data from the signals and produces it in as a instrumentation data.

iv. Display:

Displays are required for continuous monitoring of the input signals. These devices include panel mounted on meters, numerical displays, single or multi-channel CROs and storage type CROs.

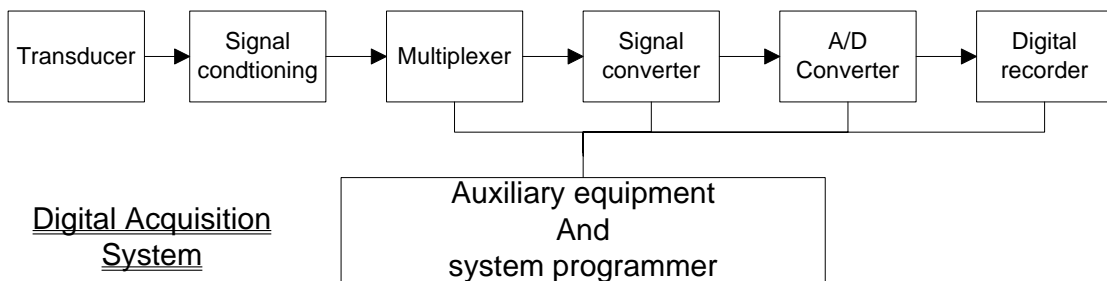
v. Recorders:

Analog recorders include strip chart recorders, Duddell’s oscilloscope, whose purpose is to store data for further work.

Components of Digital Acquisition System:

A generalized diagram of a digital data acquisition system is shown in figure:

Transducer



i. Transducers.

They convert a physical quantity into an electrical signal which is acceptable by the data acquisition system.

ii. Signal Conditioning Equipment.

Signal conditioning equipment includes by equipment that assist in transforming the output of transducer to the desired magnitude or form required by the next stage of the data acquisition system. It also produces the required conditions in the transducers so that they work properly. Signal conditioners may include devices for amplifying, refining or selecting certain positions of these signals.

iii. Multiplexer.

Multiplexing is the process of sharing a single channel with more than one input. Thus a multiplexer accepts multiple analog inputs and connects them sequentially to one measuring instrument. Another name for a multiplexer is “scanner”.

iv. Signal Converter.

A signal converter translates the analog signal to a form acceptable by the analog to digital (A/D) converter. An example of the signal converter is an amplifier for amplifying the low-level signal voltages produced by transducers.

v. Analog to Digital Converter (A/D Converter).

An A/D converter converts the analog voltage to its equivalent digital form. The output of the A/D converter may be fed to digital display devices for visual display or may be fed to digital recorders for recording. It may be fed to a digital computer for data reduction and further processing.

Auxiliary Equipment.

This contains devices for system programming functions and digital data processing. Some of the typical functions done by auxiliary equipment are linearization and limit comparison of signals. These functions may be performed by individual devices or by a digital computer.

Digital Recorders:

Records of information in digital form may be had on punched cards, perforated paper tapes, types written pages, floppy, discs magnetic tape, or combination of these systems.

Uses of data Acquisition System:

1. Analog DAS are used when wide frequency width is required or when lower accuracies can be tolerated.
2. Digital data acquisition systems are used when the physical quantity being monitored has a narrow bandwidth.

Digital DAS are also used when high accuracy and low per channel cost is required