unit - I

Characteristics of Instruments

Performance characteristics of instruments :

Measurement involves using an instrument as a physical means of determining the value of a quantity or a variable.

Any instrument may be defined as a device for determining the value or magnitude of a quantity or a variable.

Different instruments are compared & analysed by the performance characteristic parameters.

A knowledge of the performance characteristics of an instrument is essential for selecting the most suitable instrument for specific measuring job.

The treatment of instrument & measurement system characteristics can be divided into two distinct categories i.e

1. Static characteristics
2. Dynamic characteristics

The static characteristics of an instrument are in general considered for instruments which are used to measure an unvarying process condition. All the static performance characteristics are obtained by one form or another of a process called calibration.

Calibration procedure involves a comparison of the particular instrument with either 1. a primary standard or an instrument of known accuracy.

The main static characteristics dicussed here are :

1. Accuracy: Accuracy is the closeness with which an instrument reading approaches the true value of the variable being measured. In other word Accuracy is the degree of exactness (closeness) of a measurement compared to the expected (desired) value. Accuracy in other words indicates the maximum error, which will not be exceeded as assured by the manufacturer of the instruments.

Ex: If the accuracy of a 100V voltmeter is ±1%, the maximum error for any reading will not exceed ±1V.

2. Precision: The meaning may be given as 'sharply or clearly defined'. It is the measure of order or degree to which a particular parameter is measured. A voltage reading expressed as 75.2347 V is precise value. Therefore precision indicates the degree or level or number of decimal places to which a particular quantity can be measured.

Ex: $\pi = 3.14$ is a correct or true value. It can be mentioned as an accurate value. But $\pi = 3.1428574$ is a precise value.

3. Expected value: It is the value of the parameter being measured or computed. To use the right kind of instrument & to select the correct range for measurement, one should know the correct value of the parameter being measured.

Ex: If voltage is being measured, whether the value expected is in μV, mv or tens of volts or hundreds of volts; then the proper range of the instrument is to be chosen. only then will the measurement be accurate.

4. Sensitivity: sensitivity of an instrument indicates the capacity of the instrument to respond truly to the change in the output, corresponding to the change in the input. If the input voltage changes by few millivolts the output should also change by the same amount in the ideal case. If V_i changes by 0.1V, the o/p reading should also change by 0.1V [V_o/V_i is sensitivity]

5. Resolution: Resolution is the smallest change in the measured value to which the instrument can respond. It is the smallest change the instrument can measure.

Ex: A 100V voltmeter may not be able to measure 100mV. only when the minimum input is 0.5V, the needle may deflect or the reading changes from 0. Any i/p less than 0.5V may have no effect on the instrument Therefore the resolution for that particular instrument is 0.5V

6. Error: The difference between the measured value & the true value is called Error.

$\delta A = A_m - A_t$ where δA = error

7. Repeatability: this is defined as the variation of scale reading when the input is randomly applied

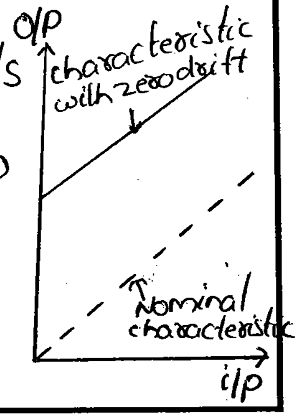
8. Reproducibility: this is a scale reading over a given period of time when the input is continuously connected to the instrument.

Ex: If 10V is applied as input; & the i/p is continuously connected to the instrument, the output reading of the voltmeter must be 10 V only. If it fluctuates & reading changes, reproducibility of the instrument is poor.

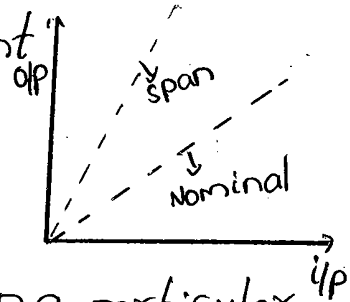
If the input is intermittently applied as long as the input is 10V, the meter reading must be the same If the reading is different each time, the repeatability of the instrument is poor.

9. Drift: There are three types of drifts

1. Zero drift: If the whole calibration shifts by the same amount, because initially zero adjustment is not made, it called zero drift.



2. Span drift: If the drift is not constant but increases gradually with the deflection of the pointer, it is called span drift.



3. Zone drift: If the drift occurs only in a particular zone of ~~meas~~ the instrument, it is called zonal drift.

10. Dead zone: The maximum value of the input to which the instrument does not respond due to hysteresis of the instrument is called the dead zone. It is defined as the largest change of input quantity for which there is no output of the instrument.

11. Threshold: It is the minimum value to which the instrument responds when the input is gradually increased from the zero value.

The Dynamic characteristics of the instrument are important, if the instrument is to be used for varying or dynamic inputs. The dynamic behaviour of an instrument is determined by subjecting its primary element to some unknown & predetermined variations in the measured quantity.

The three most common variations in the measured quantity are as follows:

1. Step change, in which the primary element is subjected to an instantaneous & finite change in measured variable

2. Linear change, in which the primary element is following a measured variable, changing linearly with time

3. Sinusoidal change, in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

The dynamic characteristics of an instrument are

Speed of response: It is the rapidity with which an instrument responds to changes in the measured quantity.

Lag: It is the retardation or delay in the response of ~~the~~ an instrument to change in the measured variable

Fidelity: It is the quality of indication by the instrument with regards to the change in input. It is the degree to which an instrument indicates the change in the measured variable without dynamic error.

Dynamic Error: It is the difference between the true value of a quantity changing with time & the value indicated by the instrument, if no static error is assumed.

The dynamic characteristics of the instrument are represented by the differential equations. The order of the equation represents the order of the instrument. But in general the instrument are classified as.

1. zero order → Ex: displacement measuring potentiometer
2. Second order → Ex: spring balance, amplifiers → two types energy.
3. First order Ex: mecury in glass thermometer → one energy

The relations between any i/p & o/p can, by using suitable simplifying assumptions, be written as

$$a_n \frac{d^n x_o}{dt^n} + a_{n-1} \frac{d^{n-1} x_o}{dt^{n-1}} + \dots + a_1 \frac{dx_o}{dt} + a_0 x_o =$$

$$b_m \frac{d^m x_i}{dt^m} + \dots + b_{m-1} \frac{d^{m-1} x_i}{dt^{m-1}} + \dots + b_1 \frac{dx_i}{dt} + b_0 x_i$$

where x_o = o/p quantity

x_i = i/p

t = time

a's & b's are combination of systems physical parameters; assumed constant.

zero order: Except a_0 & b_0 all a's & b's are assumed to be zero

$a_0 x_o = b_0 x_i \Rightarrow x_o = \left(\frac{b_0}{a_0}\right) x_i$ → instrument follows this equation is zero order

First order: $a_1 \frac{dx_o}{dt} + a_0 x_o = b_0 x_i$ ⇒ other than $a_0\, a_1\, b_0$ are '0'

second order: $a_2 \frac{d^2 x_o}{dt^2} + a_1 \frac{dx_o}{dt} + a_0 x_o = b_0 x_i$

Errors in Measurement:

Lec 4 . 5

Measurement is the process of comparing an unknown quantity with an accepted standard quantity. It involves connecting a measuring instrument into the system under consideration & observing the resulting response on the instrument. The measurement thus obtained is a quantitative measure of the socalled 'true value'.

Any measurement is affected by many variables therefore the results rarely reflect the expected value. The degree to which a measurement nears the expected value is expressed in terms of the error of measurement.

Error may be expressed as absolute or as percentage of error.

Absolute error may be defined as the difference between the expected value of the variable & the measured value of the variable

$$e = Y_n - X_n$$

where e = absolute error, Y_n = expected value
X_n = measured value

Random Errors:

These are errors that remain after gross & systematic errors have been substantially reduced or atleast accounted for. Random errors are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy. such errors can be analyzed statistically.

NO specific reason can be assigned & precaution could be taken to avoid these errors.

Ex: Noise

DC Voltmeters:

Lec 6

The most commonly used dc meter is based on the fundamental principle of the motor. The motor action is produced by the flow of small amount current through a moving coil which is positioned in a permanent magnetic field. This basic moving system, often called the D'Arsonval movement, is also referred to as the basic meter.

Different instruments forms may be obtained by starting with the basic meter movement & adding various elements as follows. [DC]

i) dc current, by adding a shunt resistance, forming a micro ammeter, a milliammeter or an ammeter

ii) dc voltage by adding a multiplier resistance, forming a millivoltmeter or a voltmeter

iii) resistance, by adding a battery & resistive network, forming an ohmmeter

The basic meter movement becomes an ac instrument, measuring

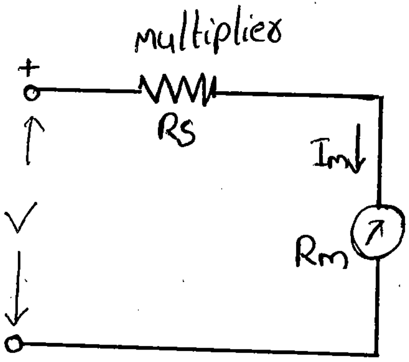
i. ac voltage or current by adding a rectifier, forming a rectifier type meter for power

ii) RF voltage or current, by adding a thermocouple type meter for RF.

To use the basic meter as a dc voltmeter, it is necessary to know the amount of current required to deflect the meter to full scale. This current is known as full scale deflection (I_{fsd}). Sensitivity = $1/I_{fsd}$

DC voltmeter:

A basic D'Arsonval movement can be converted into a dc voltmeter by adding a series resistor known as multiplier. The function of the multiplier is to limit the current through the movement so that the current does not exceed the full scale deflection value. A dc voltmeter measures the potential difference between two points in a dc circuit.



To measure the potential difference between two points in a dc circuit, a dc voltmeter is always connected across them with the proper polarity.

The value of the multiplier required is calculated as

From circuit

$$V = I_m (R_s + R_m)$$

$$R_s = \frac{V - I_m R_m}{I_m}$$

$$R_s = \frac{V}{I_m} - R_m$$

I_m = full scale deflection current of the movement

R_m = internal resistance of movement.

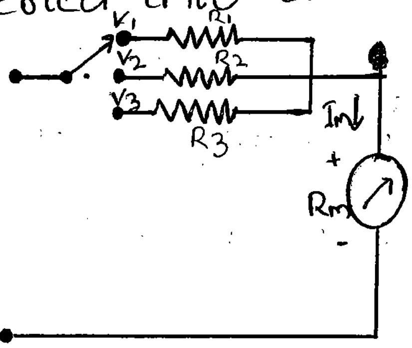
R_s = multiplier resistance

V = full range voltage of inst.

The multiplier R_s limits the current through the movement so as to not exceed the value of the full scale deflection I_{fsd}.

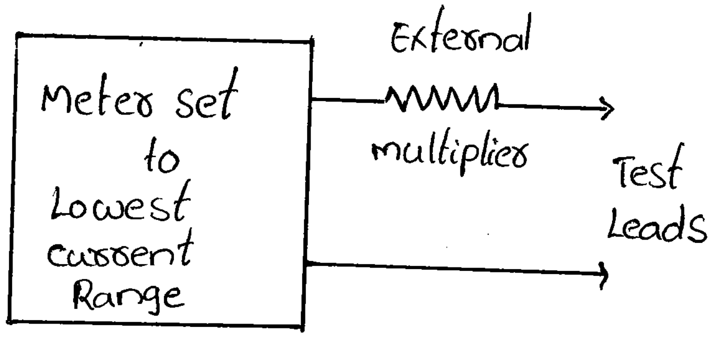
Multirange voltmeter

A DC voltmeter can be converted into a multirange voltmeter by connecting a number of multipliers along with a range switch to provide a greater number of workable ranges



Range Extension:

The range of a voltmeter can be extended to measure high voltages, by using a high voltage probe or by using an external multiplier resistor. In most meters the basic movement is used on the lowest current range.



However great care must be used not to exceed the voltage drop required for full scale deflection of the basic movement.

Lec 7

Solid State voltmeter

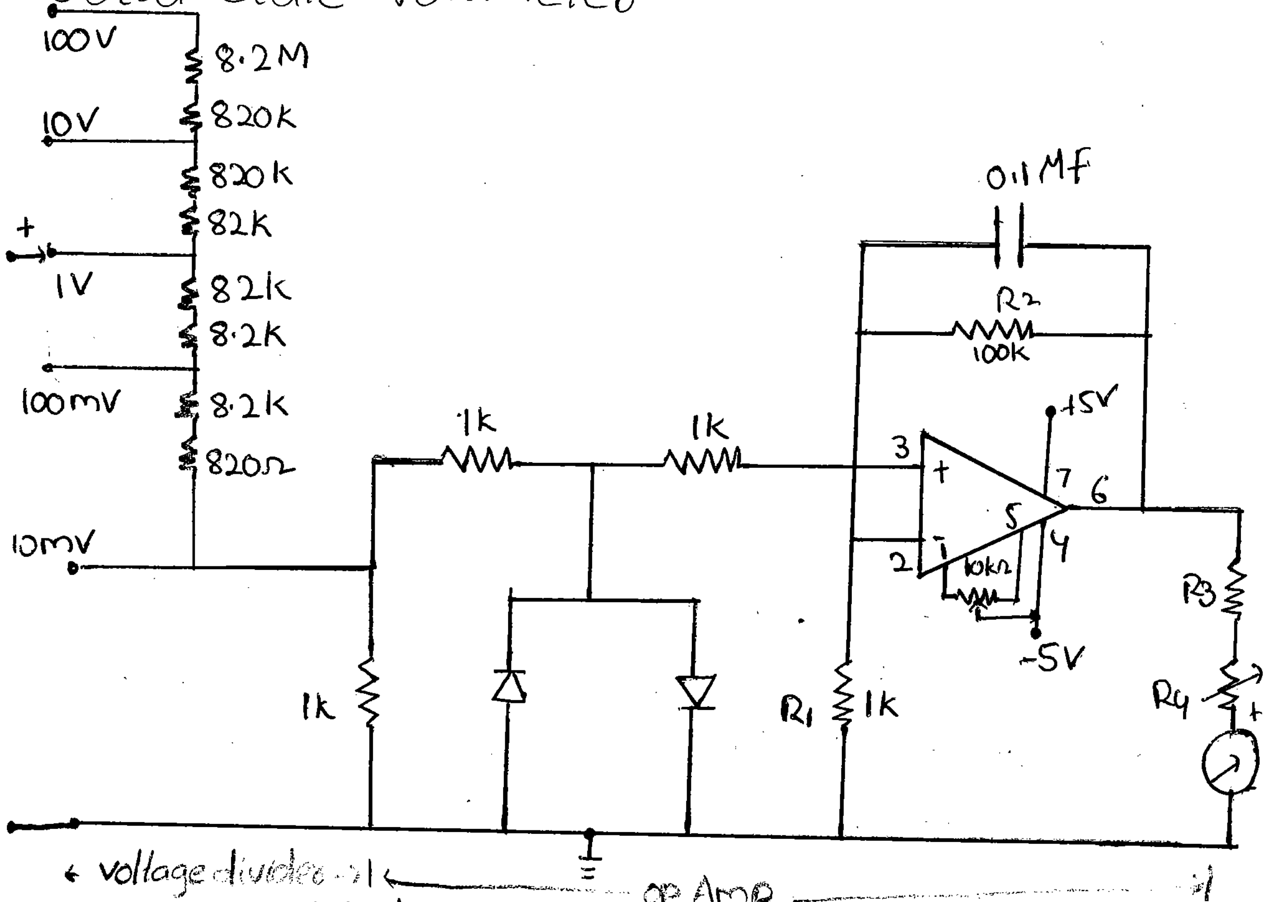


Fig: Solid state mV Voltmeter

Fig: The circuit of an electronic voltmeter using an IC opAmp 741C. This is a directly coupled very high gain amplifier. The gain of the opAmp can be adjusted to any suitable lower value by providing appropriate resistance between its output terminal, pin No6, & inverting input pin No2 to provide a negative feedback. The 0.1 MF capacitor across the 100 resistance R_2 is for stability under stray pick-ups. Terminals 1 & 5 are called offset null terminals. A 10kΩ potentiometer is connected between these two offset null terminals with its centre tap connected to a -5V supply. This potentiometer is called zero set & is used for adjusting zero output for zero input conditions.

The two diodes used for IC protection. under normal conditions, they are non-conducting, as the maximum voltage across them is 100mV. If an excessive voltage, say more than 100mV appears across, them, then depending upon the polarity of the voltage, one of the diodes conducts & protect the IC.

Differential voltmeter

The differential voltmeter technique, is one of the most common & accurate methods of measuring unknown voltages. In this technique, the voltmeter is used to indicate the difference between known & unknown voltage i.e an unknown voltage is compared to a known voltage.

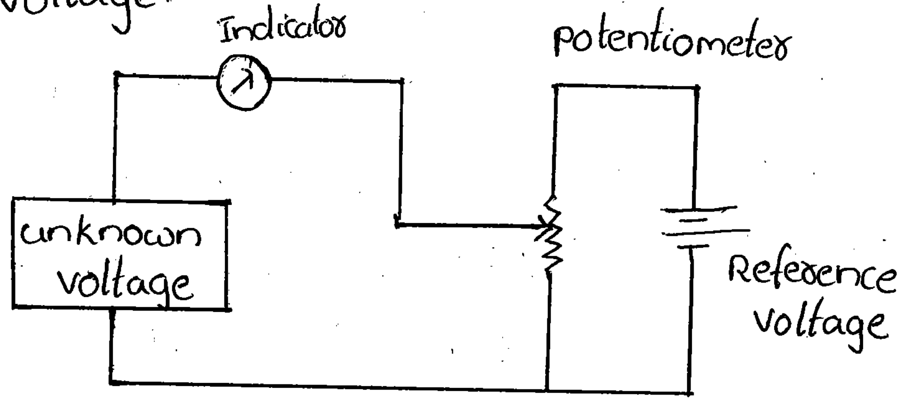


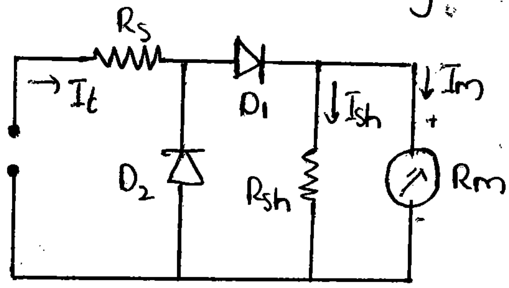
Figure shows a basic circuit of a differential voltmeter based on the potentiometric method; hence it is sometimes also called a potentiometric voltmeter. In this method, the potentiometer is varied untill the voltage across it equals the unknown voltage, which is indicated by the null indicator reading zero. under null conditions, the meter draws current from neither the reference source nor the unknown voltage source, and hence the differential voltmeter presents an infinite impedance to the unknown source.

To detect small differences the meter movement must be sensitive, but it need not be calibrated, since only zero has to be indicated.

The reference source used is usually a 1V dc standard source or a zener controlled precision supply. A high voltage reference supply is used for measuring high voltages.

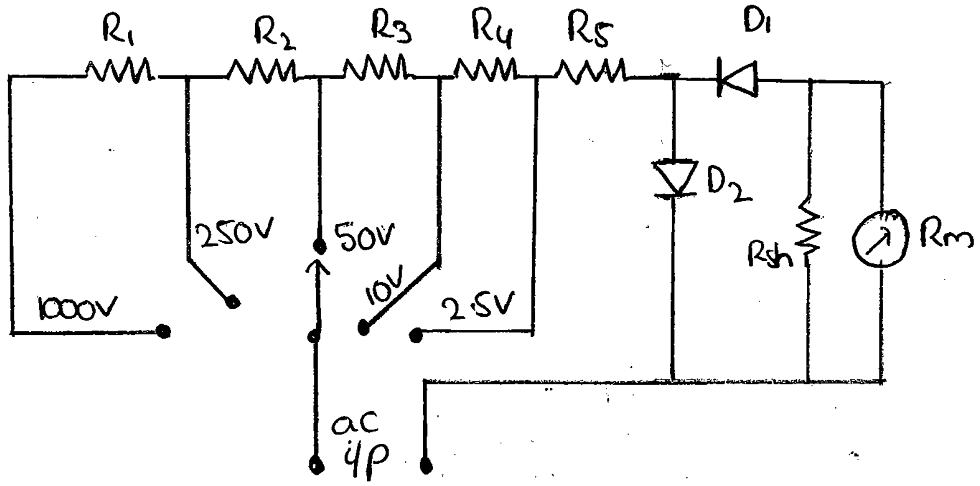
AC voltmeters: (using rectifiers)

Rectifier type instruments generally use a PMMC movement along with a rectifier arrangment. Silicon diodes are preferred because of their low reverse current & high forward current ratings.



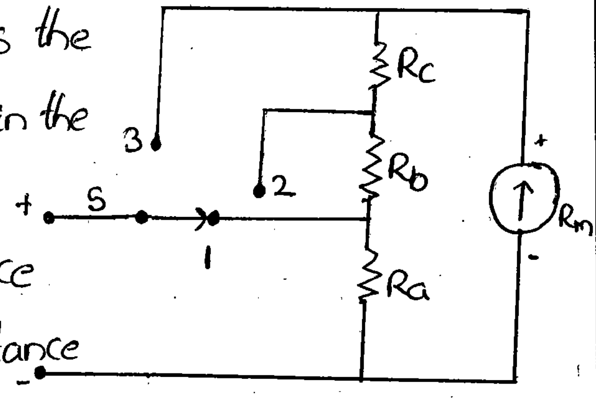
Diode D_1 conducts during the positive half of the input cycle & causes the meter to deflect according to the average value of this half cycle. The meter movement is shunted by a resistor, R_{sh}, in order to draw more current through the diode D_1 & move the operating point into the linear portion of the characteristic curve. In the negative half cycle, diode D_2 conducts & the current through the measuring circuit, which is in an opposite direction, bypasses the meter movement.

Multirange AC voltmeter



The Arylon Shunt or universal shunt

The Arylon shunt eliminates the posibility of having the meter in the circuit without a shunt. This advantage is gained at the price of slightly higher overall resistance

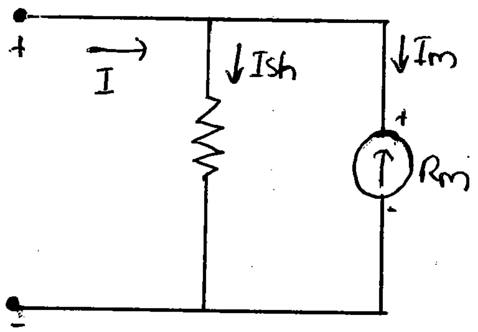


In this circuit, when the switch is in position '1' resistance Ra is in parallel with the series combination of Rb & Rc & the meter movement. Hence the current through the shunt is more than the current through the meter movement, there by protecting the meter movement & reducing its sensitivity. If the switch is connected to position '2', resistance Ra & Rb are together in parallel with the series combination of Rc & the meter movement Now the current through the meter is more than the current through the shunt resistance.

If the switch is connected to position '3' Ra, Rb & Rc are together in parallel with the meter. Hence maximum current flows through the meter movement & very little through the shunt. This increases the sensitivity.

Ammeters

The PMMC galvanometer constitutes the basic movement of a dc ammeter. Since the coil winding of a basic movement is small & light, it can carry only very small currents. When large currents are to be measured, it is necessary to bypass a major part of the current through a resistance called a shunt



The resistance of shunt can be calculated using conventional circuit analysis.

Since the shunt resistance is in parallel with the meter movement, the voltage drop across the shunt & movement must be same.

$$V_{sh} = V_m$$

$$\therefore I_{sh} R_{sh} = I_m R_m \quad \Rightarrow R_{sh} = \frac{I_m R_m}{I_{sh}}$$

But $I_{sh} = I - I_m$

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

For each required value of full scale meter current, we can determine the value of shunt resistance.

Multimeter:

A multimeter is basically a PMMC meter. To measure dc current the meter acts as an ammeter with a low series resistances

Range changing is accomplished by shunts in such a way that the current passing through the meter does not exceed the maximum rated value.

A multimeter consists of an ammeter, voltmeter & ohmmeter combined, with a function switch to connect the appropriate circuit to the D'Arsonval movement.

RF Ammeter (thermocouple)

Thermocouple consists of a junction of two dissimilar wires, so chosen that a voltage is generated by heating the junction. The output of thermocouple is delivered to a sensitive dc microammeter. Thermocouple instruments are the standard means for measuring current at radio frequencies.

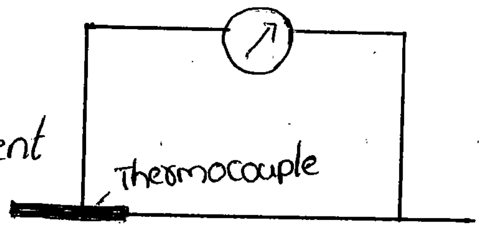
The generation of dc voltage by heating the junction is called thermoelectric action & the device is called a thermocouple.

Different Types of Thermocouples

In a thermocouple instrument, the current to be measured is used to heat the junction of two metals these two metals form a thermocouple & they have the property that when the junction is heated it produces a voltage proportional to the heating effect. this o/p voltage drives a sensitive dc microammeter, giving a reading proportional to the magnitude of the ac input.

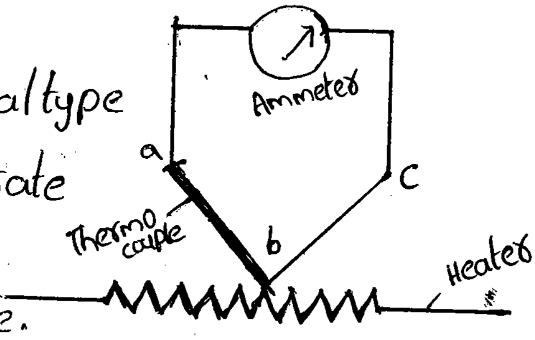
The alternating currents heat the junction the heating effect is the same for both halfcycles of the ac, because the direction of potential drop is always be the same.

Mutual Type:



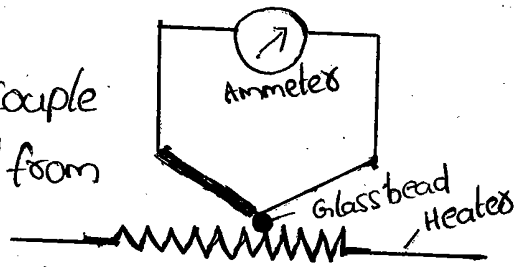
In this type, the alternating current passes through the thermocouple itself & not through a heater wire. It has the disadvantage that the meter shunts the thermocouple.

Contact type:



This is less sensitive than the mutual type. In the contact type there are separate thermocouple leads which conduct away the heat from the heater wire.

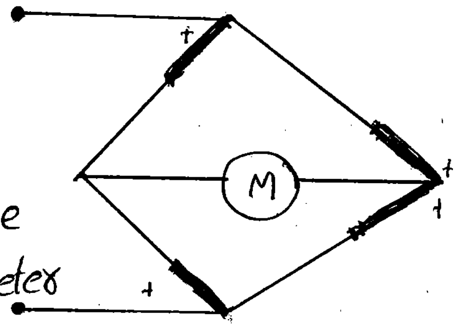
Separate Heater type:



In this arrangement the thermocouple is held near the heater, but insulated from it by a glass bead. This makes the instrument sluggish & also less sensitive because of temperature drop in the glass bead. The separate type is useful for certain applications like RF current measurement. To avoid loss of heat by radiation, the thermocouple arrangment is placed in a vaccum in order to increase the sensitivity.

Bridge Type

This has the high sensitivity of the mutual type & yet avoids the shunting effect of the microammeter



Advantages:

1. Thermocouples are cheaper than the resistance thermometers
2. Thermocouples follow the temperature changes with a small time lag & as such are suitable for recording comparatively rapid changes in temperature
3. Thermocouples are very convenient for measuring the temperature at one particular point in a piece of apparatus.
4. These instruments are not effected by stray magnetic fields.
5. These instruments are free from frequency errors
6. These instruments have a high sensitivity
7. They are very useful when used as transfer instruments to calibrate d.c instruments by potentiometer

Dis advantages:

1. They have a lower accuracy & hence they cannot be used for precision work

2. To ensure long life of thermocouples in their operating environments, they should be protected in an open or closed end metal protecting tube or well.

3. The thermocouple is placed remote from measuring devices. connections are thus made by means of wires called extension wires. the circuitry is thus complex

4. The overload capacity of thermo-couple instrument is small as compared with other instruments.