B.E.

Sixth Semester Examination, Dec.-2009

Measurements & Instrumentation (ME-310-E)

Note : Attempt any *five* questions.

Q. 1. (a) What is static calibration? How it is done in mechanical measuring instruments?

Ans. Static Calibration : All the static performance characteristics are obtained in one form or another by a process called static calibration. The calibration of all instruments is important since it affords the opportunity to check the instrument against a known standard and subsequently to find errors and accuracy. Calibration procedures involve a comparison of the particular instrument with either (1) a primary standard (2) a secondary standard with a higher accuracy than the instruments to be calibrated (3) an instrument of known accuracy.

Actually, all working instruments i.e., those instruments which are actually used the measurement work instruments in turn must be calibrated against instrument of still higher grade of accuracy. Thus, reference instruments in turn must be calibrated against instrument of still higher grade of accuracy or against primary standard or against other standards of known accuracy.

Mechanical Instruments : These instruments are very reliable for static and stable conditions but they suffer from a very major disadvantage which is because, they are unable to respond rapidly to measurements of dynamic and transient conditions. This is due to the fact that there instruments have moving parts that are rigid, heavy and bulky and consequently have a large mass. Mass presents inertia problems and hence these instruments cannot faithfully follow the rapid changes which are involved in dynamic measurements. Thus, it would be virtually impossible to measure a 50Hz voltage by using a mechanical instruments but it is relatively easy to measure a slowly varying pressure using these instruments. Another disadvantage of mechanical instruments is that most of them are a potential source of noise and cause noise pollution.

Q. 1. (b) Describe the difference between deflection and null type of instruments with suitable examples.

Ans. *Difference Between Deflection and Null Type Instruments :*

(i) The accuracy of null type of instruments is higher than that of deflection type. This is because the opposing effects is calibrated with the help of stds which have high degree of accuracy. On the other hand, accuracy of deflection type of instruments is dependent upon their calibration which depends upon the instrument consists which are normally not known to a high degree of accuracy.

(ii) In the null type of instruments, the measured quantity is balanced out. This means the detector has to cover a small range around the balance (null) point and therefore can be made highly sensitive. Also the detector need not be calibrated since it has only to detect the presence and direction of unbalance and not the magnitude of unbalance. On the other hand, a deflection type of instrument must be larger in size, more sagged, thus less sensitive if it is to measure large magnitude of unknown quantity.

(iii) Null type of instruments require many manipulation before null conditions are obtained and hence are apparently not suitable for dynamic measurements where in the measured quantity changes with time. On the otherhand, deflection type of instruments can follow the variations of the measured quantity more rapidly and hence are more suitable for dynamic measurements on account of their faster response. However, there are commercially automatic control instruments that maintain a continuous null under rapidly changing conditions and thereby eliminate the need for manipulate operations :

(i) Null type of instruments are more accurate then deflection type instruments.

(ii) Null type instruments can be highly sensitive as compared with deflection type instruments.

(iii) Deflection type of instruments are more suited for measurements under dynamic conditions than null type of instruments whose intrinsic response is slower.

Q. 2. Derive the equations for time response of a first order system subjected to step input. Draw the response curve and find steady state error. Give some example.

Ans. Response of a First Order System to a Unit Step Input : Let a unit step input u(t) be applied to a first order system. Now,

$$r(t) = u(t)$$

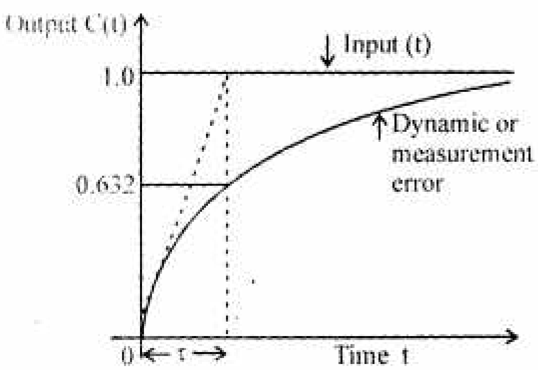
Or $$R(s) = 1/s$$

The T.F. of a first order system is

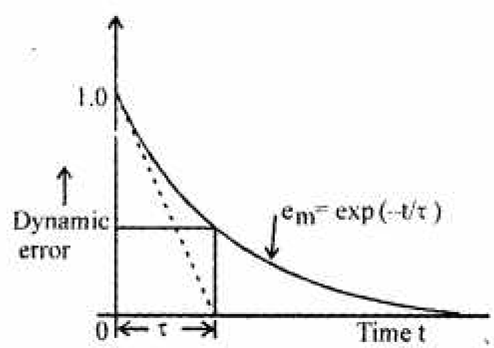
$$G(s) = \frac{1}{1+\tau s}$$

Output $$C(s) = G(s)R(s)$$

$$= \frac{1}{S(1+\tau S)} = \frac{1}{S} - \frac{\tau}{1+\tau S}$$



Response of a first order system to a step input



Dynamic error for a first order system when subjected to a step input

Taking inverse Laplace transform, the output is

$$C(t) = 1 - \exp(1 - t/\tau)$$

The output rises exponentially from zero value to the final value of unity. The initial slope of the curve is given by,

$$\left.\frac{dc}{dt}\right|_{t=0} = \left.\frac{1}{\tau}\exp(-t/\tau)\right|_{t=0} = \frac{1}{\tau}$$

Thus, it the initial rate of change in maintained, the system will reach its final value in time τ, the time constant.

The output at $t = \tau$ is

$$C(t) = 1 - \exp(-\tau / \tau) = 0.632$$

Thus, for a rising exponential function the time constant τ is defined as the time to reach 63.2% of its final value. It is obvious that null all first order systems will settle to their final value at $t = \infty$. For a decaying function the time constant is defined as the time taken to fall to 0.368 of its initial value.

The dynamic or measurement error is defined as,

$$e_m(t) = r(t).c(t)$$

$$= 1 - [1 - \exp(-t / \tau)]$$

$$= \exp(-t / \tau)$$

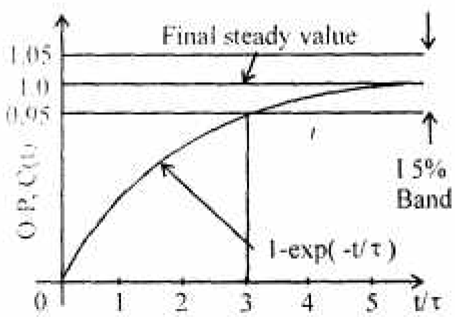
The steady state error is,

$$e_{ss} = \lim_{t \to \infty} e_m(t) = \exp_{t \to \infty}(-t / \tau) = 0$$

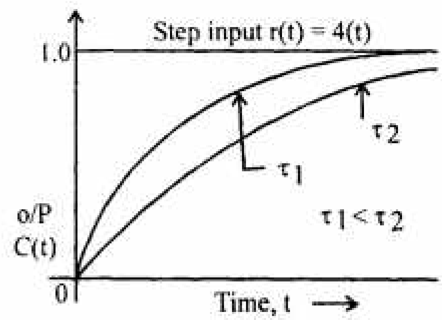
Thus, the first order system tracks the unit step input with zero static error.

Thus, if one speaks of 5% settling time, it means that the system has reached its specified value after a time which is thrice the time constant. The system reaches 0.95 of its final steady value at $t = 3\tau$.

After time interval $t = 5\tau$, the system reaches 0.993 of its final steady value and therefore it is often assumed that the instrument or system has reached its final steady or maximum value after an interval of 5τ.



Response of first order system to step input
The settilling time is 3τ for 1 5% Band



Response of first order systems of different time constants to a step input

Two curves with time constants τ_1 and τ_2 where $\tau_1 < \tau_2$. System with time constant τ_1 is faster than the system with time constant τ_2.

In some cases the initial conditions are not zero.

Let us consider the case of thermometer subjected to a step input.

θ_i = Initial temperature °C

θ_0 = Final steady temperature °C

τ = Time constant; S

The temperature at any instant is t after the application of a step input is given by,

$$\theta = \theta_0\left[1 - \exp(-t/\tau)\right] + \theta_i \exp(-t/\tau)$$

$$= \theta_0 + (\theta_i - \theta_0)\left[\exp(-t/\tau)\right]$$

Q. 3. Describe the method of measuring torque in transmission shaft under axial and bending loads.

Ans. Measuring Torque in Transmission Shaft Under Axial :

Strain Gauge Torque Meters : Two strain gauges are mounted on a shaft at an angle 45° to each other. The torque

$$T = \frac{\pi G\left(R^4 - r^4\right)}{2L}\theta \text{ Nm} \qquad \text{...(i)}$$

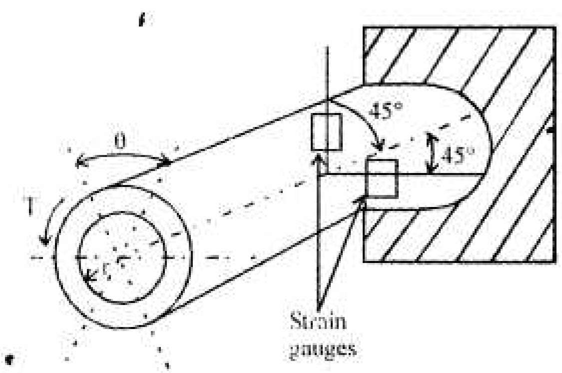
G = Modulus of rigidity; N/w^2, R = Outer radius of shaft; in

r = Inner radius of shaft; m, L = Length of shaft, m

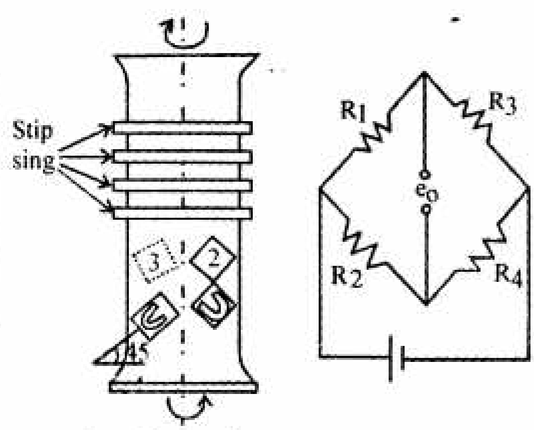
θ = Angular deflection of shaft; rad.

The strain gauge attached at 45° to the axis of the shaft indicate strains of.

$$\Sigma 45^\circ = \pm\frac{TR}{\pi G\left(R^4 - r^4\right)} \qquad \text{...(ii)}$$



Measurement of stress in a hollow shaft



(a) Shaft with strain gauges

(b) Measurement of torque of rotating shaft (bridge) using strain gauge

A strain may be measured by electrical means to indicate the torque. Multiple strain gauges may be installed and connected in a bridge circuit configuration so that any deformation due to axial or traverse loads is cancelled out in the final readout.

The arrangement has the following advantages :

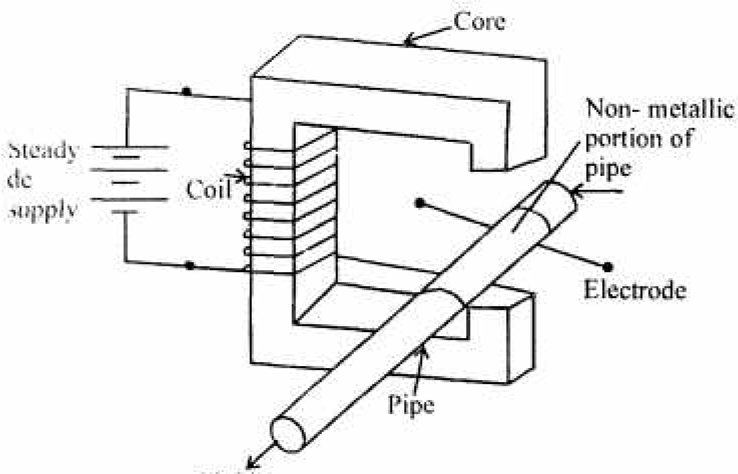
(i) It is fully temperature compensated.

(ii) It provides automatic compensation for bending and axial loads.

(iii) It gives the maximum sensitivity for a given torque. The main difficulties associated with the use of this arrangement is the connection of the bridge to its power source and display arrangement. Slip rings connected to each of the bridge terminals. Rubbing contact is made between the rings and the stationary brushes which are connected to the input and output equipment.

Q. 4. Describe construction and working of Electromagnetic flow meter. Explain the relative advantages and disadvantages of AC and DC excitations used for these meters.

Ans. Electromagnetic Flow-Meter : Electromagnetic flow meters are particularly suitable for the flow measurements of slurries, sludge and any electrically conducting liquid.



It consists basically of pair of insulated electrodes buried flush in the opposite sides of a non-conducting, non magnetic pipe carrying the liquid where flow is to be measured. The pipe is surrounded by an electromagnet which produces a magnetic field. The arrangement in analogous to a conductor moving across a magnetic field. Therefore, voltage is induced across the electrodes. This voltage is given by : $E = Blv$ volt where B = flux - density; wb/m^2,

l = length of conductor = diameter of pipe; m and v = velocity of conductor (flow); m/s.

Thus, assuming a constant magnetic field, the magnitude of the voltage appearing across the electrodes will be directly proportional to velocity. Non-conducting pipe has to be used as the output voltage gets short cipted if metallic pipes are used. This is true when liquids of low conductivity are being measured. But when liquids of high conductivity are measured the short circuiting has effect stainless steel pipes can then be used. The voltage produced are small specially at low flow rates. Therefore, the meter relies greatly on a high gain amplifier to convert the induced voltage into a usable form.

Advantages and Disadvantages of D.C. and A.C. Excitation :

(i) When d.c. excitation in used for materials of very low conductivity and flowing at slow speeds, the output emf is too small to be easily read off. The accomplishers have many inherent problems especially at love levels. High amplification can be more easily cheaply and more reliably done with a.c. than with d.c.

(ii) Many hydrogen bearing or aqueous solutions exhibits polarization effects when the excitation is d.c. The positive ions migrate to the negative electrode and disassociate forming an insulating pocket of gaseous hydrogen. There is in no such action when a.c. in used.

(iii) Another phenomenon which happens with use of d.c. is that the d.c. field may distort the fluid velocity profile by magnetohydrodynamic (MHD) action.

(iv) Since the output of electromagnetic flow meters is quite small interferring voltage input due to thermocouple type of effects and galvanic action of dissimilar metals used in meter construction may be of the same order as the signal.

(v) While a.c. systems predominate, d.c. type of systems have been used for flow measurements of liquid metals like mercury. Here, no polarization problem exists.

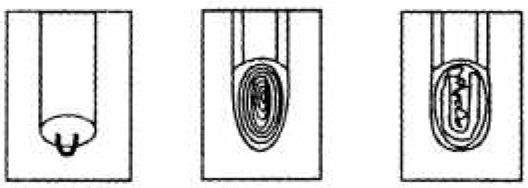
Q. 5. Explain the construction of thermocouples. Describe the different methods used for reference junction compensation fo: thermocouples.

Ans. Construction of Thermocouples : In industrial application the choice of materials used to make up a thermocouple depends upon the temperature range to be measured, the kind of atmosphere to which the material will be exposed, to output emf and its stability, mechanical strength and the accuracy required in measurements. Thermocouple materials are divided into two categories :

(i) Base metal types using platinum, rhodium etc.

(ii) Base metal type.

Several combinations of dissimilar metals make good thermocouples for industrial use. These combinations apart from having linear response and high sensitivity should be physically strong to withstand high temperatures, rapid temperature changes and the effect of corrosive and reducing atmospheres.



Exposed JW Un ground JW Grounded JW

A pair of two dissimilar metals that are in physical contact with each other form a thermocouple. These metals may be twisted, screwed, peened, clamped or ... lded together. The most commonly used method for lubricating is to weld metals together.

Thermocouples do not use back conductors except in applications where atmospheric conditions permit their use.

These conditions obtain when temperatures to be measured are line and the atmosphere is non-corrosive.

Industrial thermocouples employ protective sheathing surrounding the junction and a portion of the extension leads. The leads and the junction are internally insulated from the sheath, using various potting compounds, ceramic beads or oxides.

Thermocouples are normally met installed in pipelines, vessels and other pieces of equipment directly. They are usually placed inside protective wells so that may be easily removed or replaced without interruption or shunt down of plant. Protective wells are made of stainless steel or some other special alloy material. They are normally 12.5 mm to 25mm in diameter. The use of protective wells slows the response appreciably as they increase the mass of thermocouple. However, in applications, where response time is primary consideration, base or thin sheathed thermocouples are used.

Reference Junction Compensation : A factor which is important in the use of thermocouple in the requirement of a known reference temperature of the reference junction. This is because when the reference junction is not held at 0°C, the observed value must be corrected by adding to it a voltage that has resulted from a temperature difference equal to the amount by which the reference junction is above 0°C.

Now, $E_T = E_1 + E_0$, where E_T is the total emf at temperature T, E_t is the emf on account of temperature difference between detecting (hot) and the reference junction and E_0 is the emf due to temperature of the reference junction being above 0°C. Since, there exists a non-linear relationship between the emf and the temperature, it is important that temperatures are determined by the above process rather than converting an emf to temperature and then adding it to embient temperature.

Q. 6. (a) Explain the significance of confidence interval and confidence level in statistical analysis of data.

Ans. Significance of Confidence Internal and Confidence Level in Statistical Analysis of Data : It is possible to state through statistical analysis of the data that a range of deviation from the mean value within which a certain fraction of all values are expected to lie. This range is called the confidence interval. The probability that the value of a randomly selected observation will lie in this range is called the confidence level.

If the number of observations is large and their errors are random and follow the normal Gaussian distribution, the various confidence intervals about the mean value $\overline{X}$ are :

Confidence level	Confidence interval	Values lying Outside confidence intervals
0.500	$\overline{X} \pm 0.674\sigma$	1 in 2
0.800	$\overline{X} = 1.282\sigma$	1 in 5
0.900	$\overline{X} \pm 1.645\sigma$	1 in 10
0.950	$\overline{X} \pm 1.960\sigma$	1 in 20
0.990	$\overline{X} \pm 2.576\sigma$	1 in 100
0.999	$\overline{X} \pm 3.291\sigma$	1 in 1000

If the number of observations in small and the standard deviation is not accurately known, the confidence interval must be broadened. Here, the standard deviation is computed as,

$$S = \sqrt{\frac{\Sigma d^2}{n-1}}$$

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In order to obtain confidence intervals for mean of a group of observations from the corresponding internals for an individual observation, the later is divided by junction.

$$\text{Confidence interval of mean} = \frac{\text{Confidence interval of individual observation}}{\sqrt{n}}$$

Thus, the expectation that the mean of a group of observations will not differ by more than a certain amount from the theoretical mean of an infinite set of observations can also be expressed in terms of a confidence interval and a confidence level.

Q. 6. (b) Explain Chauvenet's criterion for the rejection of test data.

Ans. Chauvenet's Criterion : Suppose on observations are made for measurement of a quantity. We assume that n is large enough that the results will follow a normal Gaussian distribution.

This distribution may be used to computer the probability that a given reading will deviate by a certain amount from the mean. Chauvenet's criterion specifies that a reading may be rejected if the probability of obtaining the particular deviation from the mean is less than $1/2n$.

Number of readings	Ratio of maximum acceptable deviation to standard deviations d_{max}/σ.
2	1.15
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	2.29
1000	3.48

The values of the ratio of deviation to standard deviation for various values of according to this criterion.

When applying Chauvenet's criterion in order to eliminate any devious data, the man value and the standard deviation are first calculated using all data points. The deviations of individual readings are then compared with standard deviation. If the ratio of deviation of a reading to the standard deviation exceeds the limits.

Q. 7. Explain how dynamic strains can be measured with the help of a ballast circuit. Derive an expression for the sensitivity of such a circuit and obtain the condition for maximum sensitivity.

Ans. Strain Gauges and Measurement of Strain :

Strain Gauge Circuits : The theory and construction of strain gauges have already been explained. The gauge factor of a strain gauge in given,

Gauge factor $$G_f = \frac{\Delta R / R}{\varepsilon} = 1 + 2\nu + \frac{2\rho/\rho}{\varepsilon} \quad ...(i)$$

The various symbols have already been explained when we consider the sensitivity of a metallic strain gauge, we find that it is extremely versatile and reliable.

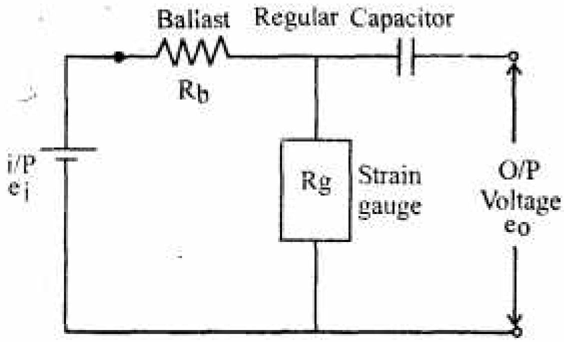
Typical values of gauge factor and resistance for commonly used strain gauges are :

$$G_f = 2 \text{ and } R = 120\Omega$$

Strain gauges are used for measurements of strains as low as 1 microstrain and therefore the corresponding change in resistance is

$$\Delta R = G_f \varepsilon R$$

$$= 2 \times 10^{-6} \times 120 = 10^6\Omega = 0.00024\Omega$$



Strain Gauge using Ballast circuit

This small change in resistance which is 0.002% of original resistance has to be measured. It is quite evident that in order to measure a change in resistance of this low order will require the use of extremely sensitive and sophistical instrumentation.

Ballest Circuit : If the R_g is the resistance of strain gauge the output voltage when the gauge is not strained is,

$$e_o = \frac{R_g}{R_b + R_g} e_i$$

∴ Change in output voltage when the gauge in strained,

$$d_{e_o} = \frac{R_b}{(R_b + R_e)^2} dR_g . e_i = \frac{R_b R_g}{(R_b + R_g)^2} \frac{dR_g}{R_g} e_i$$

$$= \frac{R_b R_g}{(R_b + R_g)^2} G_f \varepsilon e_i$$

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∴ Change in output voltage when the gauge is strained in directly proportional to the strain maximum sensitivity is obtained when the ballast resistance is equal to the strained resistance of the gauge or $R_b = R_g$. For this arrangement, change in output voltage when the gauge is strained

$$\Delta e_o = (G_f \varepsilon / 4) e_i$$

Some of the inherent limitations in the ballast circuit can be explaiend by the following example. Consider across the strain gauge when it is not strained in

$$e_0 = e_i / 2 = 4V.$$

When the strain gauge is subjected to strain, the change in output voltage is

$$\Delta e_o = 2 \times (8/4) \varepsilon = 4\varepsilon$$

Now, if a strain equal to 1 microstrain is to be measured the change in output voltage is

$$\Delta e_o = 4 \times 1 \times 10^{-6} = 4 \times 10^{-6} \mu V$$

Thus, the indicator connected to output terminals to provide indication of strain must sense a change of voltage of $4\mu V$ in a range of 4V i.e., a change 0.0001%.

Q. 8. Explain :

(i) A-D Converters and

(ii) Magnetic Tape Recorders.

Ans. (i) A-D Converters : They are five types :

(a) Successive approximation method (potentiometric type)

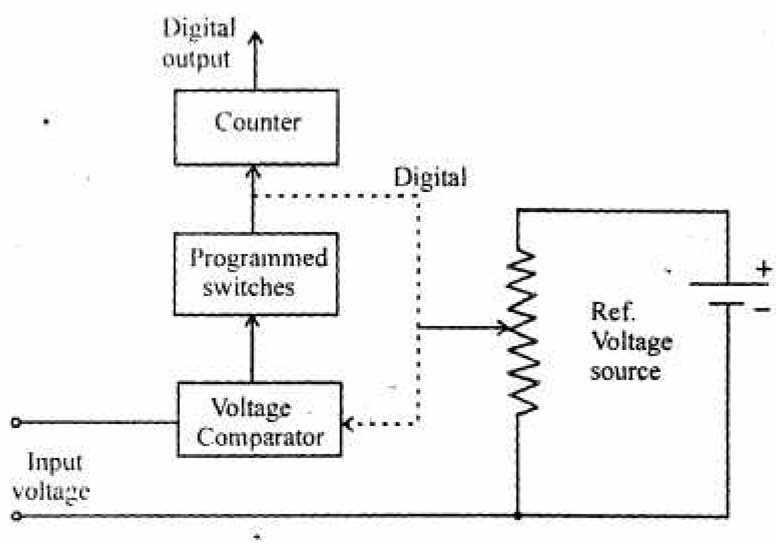
(b) Voltage to time conversion method (ramp type)

(c) Voltage to frequency conversion method (Integration type)

(d) Dual slope integration method

(e) Re-circulating remainder system

(a) Successive Approximation Method (potentiometric type) :



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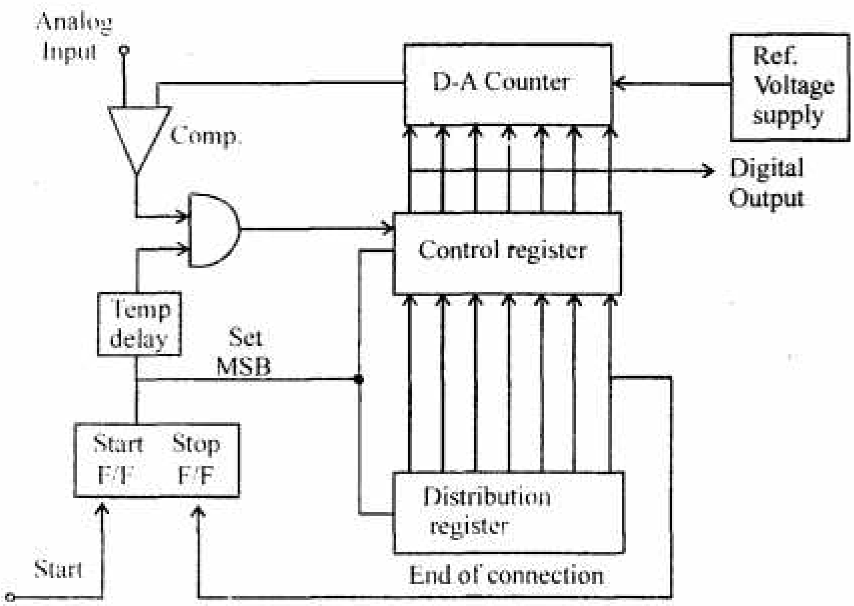
It is used on account of its high resolution and high speed. Works on successive approximation. This converter compares the analog input to a Decade Assembly Counter (DAC) reference voltage which is repeatedly divided in half. It contains the voltage divider network with coarse and time steps.

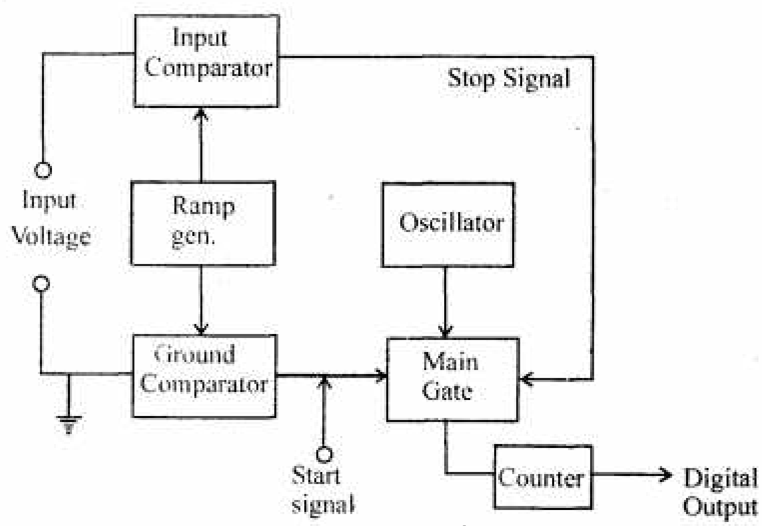


Simplified blockdiagram of succes. ve approximate method

The converter uses a digital control register with gateful binary input of 1 and 0, a D/A converter with a reference voltage supply, a comparison circuit, a control timing loop, and a distribution register.

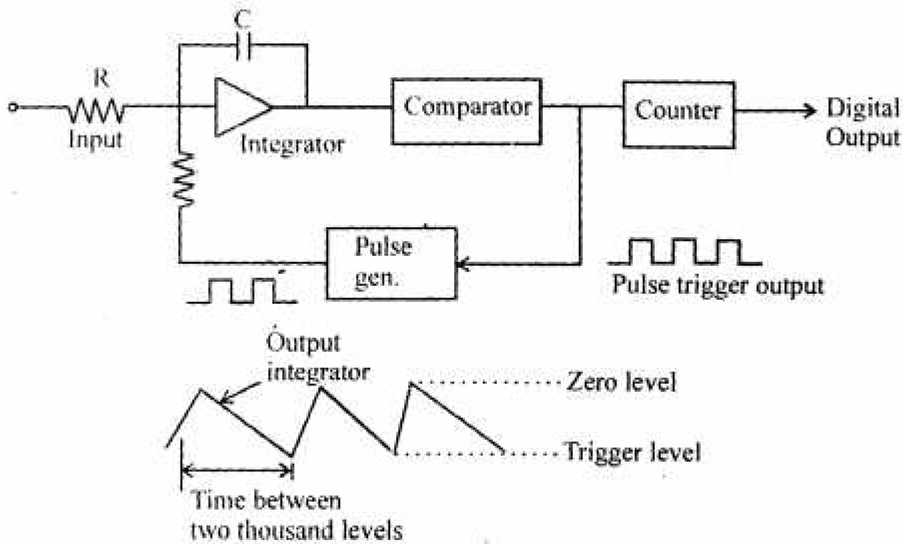
At the start of conversion cycle, both the control register and the distribution register are set with a/in the MSB and a 0 in all bits of less significance.

(b) Ramp Type :



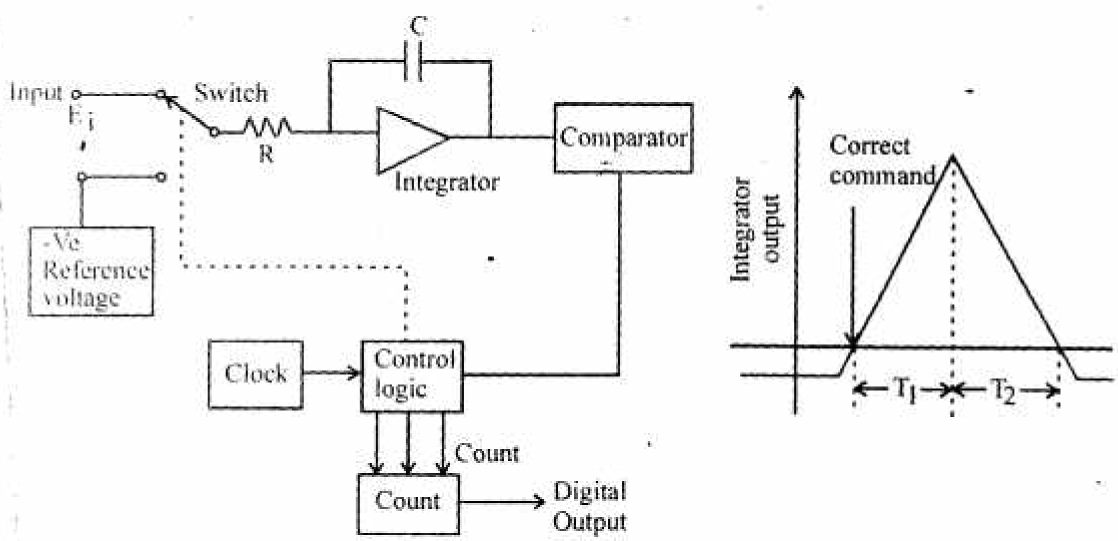
It fed to two voltage comparators. The ramp voltage may have either a negative or a positive going slope let us consider a ramp voltage with a positive going slope. When the input voltage is equal to the ground voltage the ground comparator emits a start signal to a gate which opens and permits the passage of pulses of a clock from a crystal oscillator to a digital counter.

(c) Integrating Type :



The integrator produces a ramp signal whose slope is proportional to the input voltage signal level. When this ramp signal reaches a preset threshold level, a trigger pulse is produced. Also a current pulse is produced which discharges the capacitor of the integrator, after which a hence ramp in initiated.

(d) Dual Slope Integration A/D Converter :



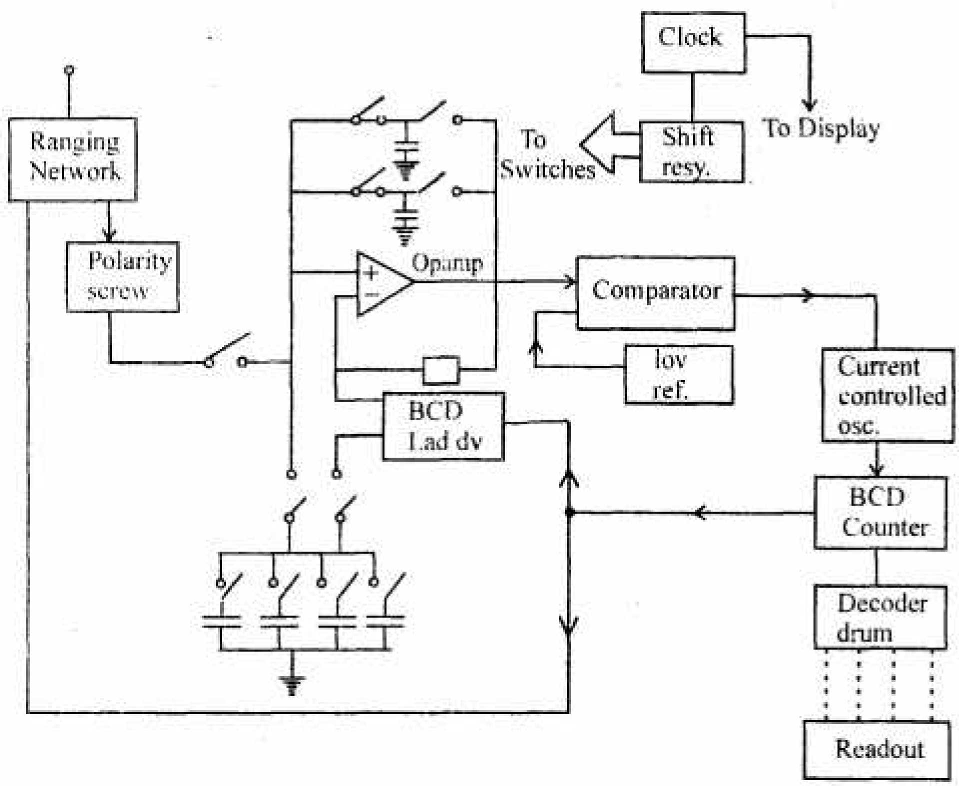
The reference voltage and the input analog voltage are sequentially connected to the integrator with the help of a switch. The output from the integration during a conversion cycle. The difference in the slopes of the curve is due to difference in voltage level of input voltage E_i and reference voltage E_r.

T_1 = Counts when the input voltage is applied

T_2 = Counts when the reference voltage in applied.

$$E_i = (T_2 / T_1) \times E_r$$

(e) Recirculating Remainder System : The counters found in the methods of conversion so for described have been fairly conventional. that is a complete circuit had been used for each decode of display.



This system, which reduces the number of component parts of the instrument, is made possible by a sequence of operations as follows :

(i) Sample the unknown voltage

(ii) Determination of the most significant digit of the unknown

(iii) Storing the difference between the first digits worth and the unknown is a capacitor

(iv) Amplifying this remainder by a factor often

(v) Determine the next most significant digit

(vi) Storing the remainder.