B.E.

Sixth Semester Examination-2010

Measurements & Instrumentation (ME-310-E)

Note : Attempt any five questions. **All questions carry equal marks.**

Q. 1. (a) Enlist functional elements of the Instruments. Give five examples of transducer elements.

Ans. There is another way in which instruments or measurement systems may be classified. This classification is based upon the functions they perform. The three main functions are explained below :

(i) Indicating Function : Instruments and systems use different kinds of methods for supplying information concerning the variable quantity under measurement. Most of the time this information is obtained as a deflection of a pointer of a measuring instrument. In this way the instrument performs a function which is commonly known as indicating function. For e g., the deflection of pointer of a speedometer indicates the speed of the automobile at that moment. A pressure gauge is used for indicating pressure.

(ii) Recording Function : In many cases the instruments makes a written record, usually on paper of the value of the quantity under measurement against time or against some other variable. Thus, the instrument performs a recording function. For e.g., a potentiometric type of recorder used for monitoring temperature records the instantaneous values of temperature on a strip chart recorder.

(iii) Controlling Function : This is one of the most important functions especially in the field of industrial control processes. In this case, the information is used by the instrument or the system to control the original measured quantity.

Thus, there are three main groups of instruments. The largest group has the indicating function. Next in line is the group of instruments which have both indicating and or recording function. The last group falls into a special category and performs all the three functions, i.e., indicating, recording and controlling.

In this text main emphasis is laid upon instruments whose functions are mainly indicating and recording especially those instruments which are used for engineering analysis purposes. The control function will be analysed in those cases where controlling enters as an integral part of the indicating and recording functions of instruments.

When the definition of transducer is confined to a device that covers the entire detector transducer stage wherein the transducer coverts a non-electrical quantity into an analogous electrical signal, the transducer may be thought of consisting of two important and closely related parts.

These two parts are :

(i) Sensing Element : A detector or sensing element is that part of a transducer which responds to a physical phenomenon or a change in a physical phenomenon. The response of the sensing element must be closely related to the physical phenomenon.

(ii) Transduction Element : A transd ction element transform the output of a sensing element to an electrical output. The transduction element in a way, acts as a secondary transducer.

The transducer can be classified :

(i) On the basis of transduction form used.

(ii) As passive and active transducer.

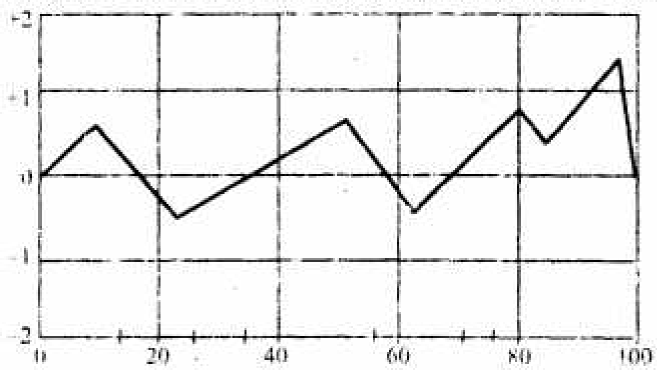
(iii) As primary and secondary transducer.

Q. 1. (b) Explain various methods of calibrations.

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 instrument is important since it affords the opportunity to check the instrument against the known standard and subsequently to find errors and accuracy. Calibration procedures involve a comparison of the particular instrument with either (i) a primary standard (ii) a secondary standard with a higher accuracy than the instrument to be calibrated or (iii) an instrument of known accuracy.

Actually all working instruments i.e., those instruments which are actually used for measurement work 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. It is essential that any measurement made must ultimately be traceable to the relevant primary standards.

Error Calibration Curve : Error calibration means that an instrument has been calibrated against a suitable standard and its static error determined at a no. of points on its scale. These data form an error curve which can be used for correcting instrument readings. A typical error curve is shown in figure.



Measured variable, percent span

Q. 2. (a) Derive the expression for overall internal uncertainty in compound quantities.

Ans. Kline & McClintock have proposed a method based upon probability and statistics which analyses the data employing uncertainty distribution. They have defined the uncertainty distribution as the error distribution the experimenter believes would exist if the situation permits multisampling.

Kline and McClintock suggests that a single sample result may be expressed in terms of a mean value and an uncertainty interval based upon stated odds.

The result may be written as follows :

$$X = \bar{X} \pm w\,(b \text{ to } 1)$$

X = The value if only one reading is available on the arithmetic mean of several reading

w = Uncertainty interval

h = Odds or the chance that the true value lies within the stated range, based upon the opinion of the experimenter.

The concept of uncertainty may be explained by the following example :

The results of temperature measurement may be expressed as

$$\theta = 100°C \pm 1°C$$

The means that there is an uncertainty of ±1°C in the result. In other words, the experimenter is starting in precise term the accuracy of results with which they have been made according to him. This brings about another dimension in measurements and that is how far a further specification arises. As mentioned earlier, Kline and McClintock proposed that the experimenter specify certain odd for the uncertainty. The aforesaid results may be given as

$$\theta = 100°C \pm 1°C\ (Z_0 \text{ to } 1)$$

Now the results expressed in the above form become more specific in nature. This is because the experimenter is willing to bet Z_0 to 1 odds that temperature measurement which $h_{/e}$ has made are within ±1°C of 100°C.

This approach is of a particular value is setting up an experiment, especially when it involves expenses in term of manpower, time and equipment. It provide essentials for establishing basis for predetermined estimates of reliability of results through a study of propagation of uncertainty.

Propagation of Uncertainties : The uncertainty analysis in measurement when many variants are involved is done on the same basis as is done for error analysis when the results are expressed as standard deviation or probable errors.

Suppose X is a function of several variables,

$$X = f(x_1, x_2, x_3, \ldots\ldots x_n)$$

Where, $x_1, x_2, x_3 \ldots\ldots x_n$ are independent variable with same degree of odds.

Let w_x be the resultant uncertainty and $w_{x1}, w_{x2}, w_{x3} \ldots\ldots w_{x_n}$ be the uncertainties in the independent variables $x_1, x_2, x_3 \ldots\ldots x_n$ respectively. The uncertainty in result is given by

$$w_x = \sqrt{\left(\frac{\partial X}{\partial X_1}\right)^2 w_{x_1}^2 + \left(\frac{\partial X}{\partial X_2}\right) w_{x_2}^2 + \ldots\ldots + \left(\frac{\partial X}{\partial X_n}\right)^2 w_{x_n}^2}$$

Q. 2. (b) Explain various considerations for selection of instrumentation.

Ans. The selection most appropriate instrument for a particular voltage measurement depends on the performance required in the given situation. Some important consideration in selecting a voltmeter as given below :

(i) Input Impedance : In order to avoid loading effects, the input resistance or impedance of the voltmeter should be atleast an order of magnitude higher than the impedance of the circuit under measurement.

The input impedance of the voltmeter is a function of inevitable shunt capacitance across the input terminals. The loading effect of the meter is particularly noticeable at the higher frequency, when the input shunt capacitance greatly reduces the input impedance.

In some application, a passive voltage deviation probe can be used to reduce the input capacitance at the point of measurement at specific of perhaps 20db of sensitivity. With such a probe measurements can be easily made at random point without disturbing the circuit under test.

(ii) Voltage Ranges : The voltage ranges on the meter scale may be in 1-3-10 sequence with 10db of separation or in the 1-5-5-15 sequence, or in a single scale calibrated in db. In any case the scale division should be compatible with the accuracy of instrument. For e.g., a linear meter with a 1 percent full scale accuracy should have 100 divisions on the 1.0V scale so that 1% can be easily resolved. An instrument with an accuracy of 1% or less should also have a mirror backed scale to reduce parallax and to improve accuracy.

(iii) Decibels : Use of decibel scale can be very effective in measurements that cover a wide range of voltages. A measurement of this kind is found for e.g., in the frequency response curve of an amplifier or a filter where the output voltage is measured as a function of frequency of applied input voltage. Almost all voltmeter with db scales are calibrated in db m. referenced to some particular impedance. The o-db m reference for a 600-Ω system is 0.7746V. For a 50-Ω system it is 0.2236V. In many application only a 0-db reference is needed. In this case, 0dbV can be used for any impedance system.

(iv) Sensitivity Versus Bandwidth : Noise is a function of bandwidth. A voltmeter with a broad bandwidth will pick up and generate more noise than one operating over a narrow range of frequencies. In general, an instrument with a bandwidth of 10Hz to 10MHz has a sensitivity of 1mV. A voltmeter whose bandwidth extends only to 5 MHz could have a sensitivity of 100 μV.

(v) Battery Operation : For field work, a voltmeter powered by an internal battery is essential. If an area contains troublesome groundloops, a battery powered instrument is preferred over a mains powered voltmeter to remove the ground paths.

(vi) A.C. Current Measurement : Current measure can be made by sensitive ac voltmeter and a series resistance. In the usual case, however an ac current probe is used which enables the operator to measure an ac current without disturbing the circuit under test. The current probe simply clips around the wire carrying the unknown current and in effect makes the wire one turn primary of a transformer formed by a ferrite core and many turn secondary within the current probe body. The signal induces in the secondary winding in amplified and the output voltage of the amplifier is applied to a suitable ac voltmeter for measurement. Normally the amplifier is designed so that 1mA in the wire being measured produces 1mV at the amplifier output. The current is then read directly on the voltmeter using the same scale as for voltage measurements.

Q. 3. (a) Explain step response of a first order system.

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,

$$r(t) = u(t) \text{ or } R(s) = 1/s$$

The transfer function (dimensionless) of a first order system is

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

∴ Output $$C(s) = G(s)R(s) = \frac{1}{s(1+\tau s)} = \frac{1}{s} - \frac{\tau}{1+\tau s}$$

It is seen that the output rises exponentially from zero value to the final value of unity. The initial slope of the curve is given by :

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

Thus, if the initial rate of change is 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 rising exponential function the time constant τ is defined as the time to reach 63.2% of its final value. It is obvious that all first order system will settle to their final value at $t = \infty$.

Q. 3. (b) A voltmeter with internal resistance of 200 kΩ is connected across a resistance. It reads 250V. A milliammeter (with very small resistance) is connected in series of the same resistance reads 10mA. Determine apparent resistance, actual resistance and loading error.

Ans. Let us reduce the circuit to its Thevenin's equivalent circuit. The open circuit voltage E_o, appearing across terminals A and B is E_o

$$E_o = 100 \times 200/400$$

$$= 50\text{ V}$$

The output impedance of the source as looking into terminals A and B is :

$$Z_o = \frac{200 \times 200}{200 + 200}$$

$$= 100\text{ k}\Omega$$

The voltage across terminals A and B under loading condition is

$$E_L = \frac{E_o}{1 + Z_o/Z_L}$$

$$= \frac{50}{1 + 100/1000}$$

$$= 45.45\text{ V}$$

$$\text{Loading error} = \frac{45.45 - 50}{50} \times 100$$

$$= -9.1\%$$

$$\text{Accuracy} = 100 - \%\text{ loading error}$$

$$= 100 - 9.1 = 90.9\% \quad \textbf{Ans.}$$

Q. 4. (a) Explain the working principle of capacitive type transducer.

Ans. Working : The principle of operation of capacitive transducer is based upon the familiar equation for capacitance of parallel plate capacitor.

Capacitance, $C = \epsilon A/d = \epsilon_r \epsilon_0 A/d$

A = Overlapping area of plates; m^2

d = Distance between two plates; m

$\epsilon = \epsilon_r \epsilon_0$ = Permittivity of medium; P/m

ϵ_r = Relative permittivity

ϵ_0 = Permittivity of free space; 8.85×10^{-12} F/m

A capacitor transducer work on the principle of change of capacitance which may be caused by physical variables like displacement, force and pressure in most of the cases. The changes in capacitance may be caused by change in dielectric constant as is the case in measurement of liquid of gas levels.

The capacitance may be measured with bridge circuits. The output impedance of capacitive transducer is $X_C = 1/2\pi fC$, where C = capacitance and f = frequency of excitation in Hz.

In general the output impedance of capacitive transducer is high. This fact calls for a careful design of the output circuitry.

The capacitive transducers are commonly used for measurement of linear displacement. These transducer use the following effects :

(i) The change in capacitance due to change in overlapping area of plates.

(ii) Change in capacitance due to change in distance between the two plates.

Q. 4. (b) A first order instrument is to measure signals with frequency content up to 100 Hz with an amplitude inaccuracy of 5%. What is the maximum allowable time const. What will be the phase shift at 50Hz?

Ans. From above it is clear that the thermometer is subject to a step input of 100°C

$$\theta = \theta_0[1 - \exp(1 - t/\tau)]$$

$$= 100[1 - \exp(1 - 1.5/3.5)]$$

$$= 34.86°C$$

Time to reach equilibrium conditions = $5\tau = 10$ s

Time constant $\tau = \frac{10}{5} = 2$ s

Now we have, $\theta = \theta_0[1 - \exp(-t/\tau)]$ or $\theta/\theta_0 = 1 - [\exp(-t/\tau)]$

The time to read half of the temperature difference can be calculated as

$$0.5 = 1 - \exp(-t/2)$$

$t = 1.39$ sec. **Ans.**

Q. 5. (a) Explain the working principle of pneumatic amplifying element.

Ans. Working : Consider a simple pneumatic system. A pneumatic source is supplying air to the pressure vessel through a pipe. If the pressure drop in the pipe line is small, the flow is laminar and hence linear differential equation may be used to describe the dynamics of the system.

Let. P_i = Pressure of the air of the source under steady state conditions; N/m^2

P_o = Pressure of air in the vessel under steady state conditions; N/m^2

p_i = Small change in air pressure of the source from its steady state value; N/m^2

p_o = Small change in air pressure of the vessel from its steady state value, N/m^2

The resistance to flow (air) rate into vessel is defined as,

$$R = \frac{p_i - p_o}{q} \frac{\text{N/m}^2}{\text{m}^3/\text{s}}$$

Where. q = Rate of flow of air on account of differential pressure, m^3/s.

The volume of air at pressure P_i which gets stored in vessel to raise the pressure inside the vessel by p_o is proportional to it assuming the temperature to be constant.

∴ Volume $\quad V = Cp_o$

Constant C is defined as capacitance of the vessel,

∴ Capacitance $\quad C = \frac{V}{p_o} \frac{\text{m}^3}{\text{N/m}^2}$

From above rate of storage in the vessel

$$\frac{dV}{dt} = C\frac{dp_o}{dt}$$

Thus, we have, $\quad V = \int q\,dt = \int\left(\frac{p_i - p_o}{R}\right)dt$

∴ From above, rate of storage in the vessel

$$\frac{dV}{dt} = \frac{p_i - p_o}{R}$$

Equations (i) and (ii) we have following differential equation describing the dynamics of a pneumatic system.

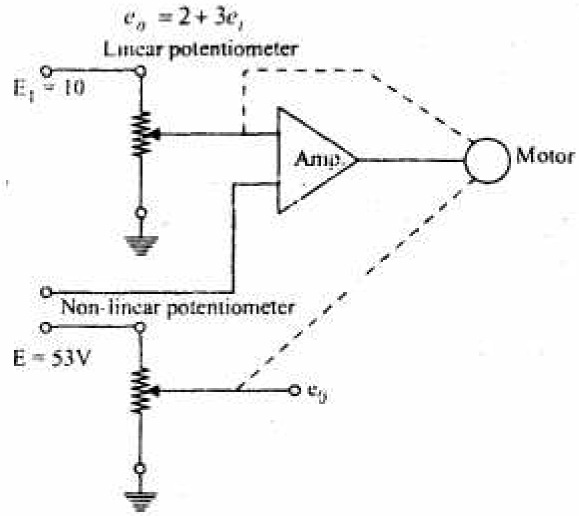
$$RC = \frac{dp_o}{dt} + p_o = p_i$$

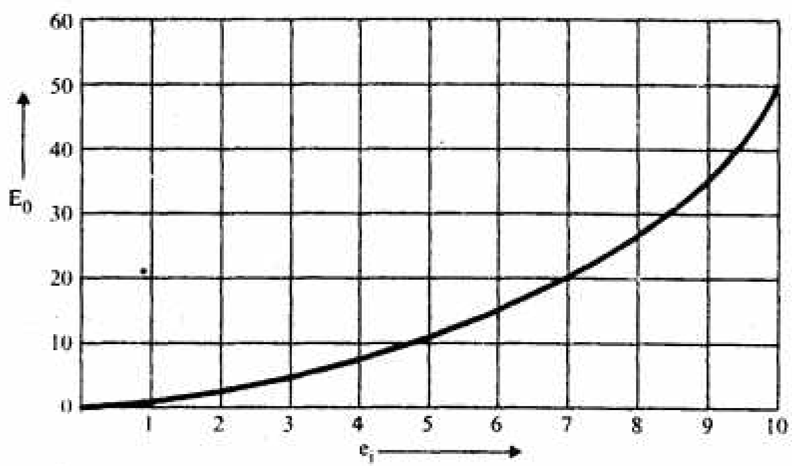
Q. 5. (b) Give an arrangement of an op amp to produce an o/p e_o such that $e_o = 2 + 3e_i$, e_i is i/p voltage.

Ans. In many instrumentation problems, non-linear conditions arise. They may include the effect of magnetic saturation, the non-linearity of the voltage produced by a thermocouple as a function of temperature, the air speed expressed in matched mach number as a function of wind tunnel pressures, trigonometric functions etc. One simple method of solving these non-linear functions is by the use of non-linear potentiometers.

A standard self balancing potentiometer is used to produce a displacement proportional to the input voltage e_i is shown in figure. This displacement also operates a non-linear resistance which produces an output voltage e_0 which is the desired function of the input voltage e_i. This operation is illustrated in the following example.

Let the input voltage e_i varies from 0 to 10V. The desired function of this voltage is shown in figure





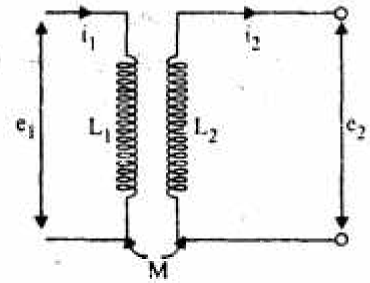
Q. 6. (a) Explain Data Acquisition System.

Ans. The field is produced by a fixed coil. This coil is divided into two sections to give a more uniform field near the centre and to allow passage of the instrument shaft. The instrument as shown in figure may be a milliammeter or may become a voltmeter by the addition of a series resistance. The fixed coils are wound with fine wire for such applications.

Fixed coils are usually wound with heavy wire carrying the main current in ammeters and wattmeters. The wire is stranded where necessary to reduce eddy current losses in conductors. The coils are usually varnished and baked to form a solid assembly. These are then clamped in place against the coils supports This makes the construction grid so that there is no shifting or change in dimensions which might effect the calibration.

The mounting supports are preferably made out of ceramic, as metal parts would weaken the field of the fixed coil on account of eddy currents.

Torque & Power Measurement Techniques : Flux linkages of coil 1



$$\psi_1 = L_1 i_1 + M i_2$$

Flux linkages of coil 2 $\psi_2 = L_2 i_2 + M i_1$

Electrical input energy $= e_1 i_1 dt + e_2 i_2 dt$

$$= i_1 d\psi_1 + i_2 d\psi_2$$

$$e_1 = \frac{d\psi_1}{dt} \text{ and } e_2 = \frac{d\psi_2}{dt}$$

$$= i_1 d(L_1 i_1 + M i_2) + i_2 d(L_2 i_2 + M i_1)$$

$$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + i_2^2 dL_2 + i_1 i_2 dM + i_2 M di_1$$

Energy stored in the magnetic field

$$= \frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M$$

Change in energy stored $= d\left(\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M\right)$

$$= i_1 L_1 di_1 + (i_1^2/2) dL_1 + i_2 L_2 di_2 + (i_2^2/2) dL_2 + i_1 M di_2 + i_2 M di_1 + i_1 i_2 dM$$

From principle of energy conversion.

Total electrical input energy = Change in energy stored + Mechanical energy

Then, mechanical energy $= \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM$

Now, the self inductances L_1 & L_2 are constant and therefore dL_1 and dL_2 are both equal to zero, then

Mechanical energy $= i_1 i_2 dM$

Suppose T_i is the instantaneous deflecting torque and $d\theta$ is the change in deflection, then

Mechanical energy = Word done $= T_i d\theta$

Thus, we have $T_i d\theta = i_1 i_2$ dM

Or $T_1 = i_1 i_2 \frac{dM}{d\theta}$ **Ans.**

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Q. 6. (b) Explain Torsion Dynamometer. Enlist various Torque and Power measurement techniques.

Ans. Pendulum dynamometers are preferably used in the best machines for testing materials with static loads. The existing designs of torsion dynamometers have as yet no substantial advantages as compared with those of the pendulum type.

Further attempts in producing low-inertia torsion-dynamometers for static machines should aim at providing torsion bars with large twist angles, of the order of 0.5-0.7 rad. **Torsion dynamometers** in combination with inertialess indicators are preferable to those of the pendulum type for use in machines intended for high-speed loading and deformations.

Function and Applications : Torsion dynamometer to measure small forces or investigate electrostatic and magnetic interactions between bodies.

Benefits :

(i) Force compensation

(ii) Zero point adjustment

(iii) Eddy current damping element

(iv) Front and side scales

(v) Overload protection and a stem.

Equipment and Technical Data :

(i) Range front scale :	10mN
(ii) Range side scale :	±3 mN
(iii) Raw subdivision :	1mN
(iv) Fine subdivision :	0, 1 mN
(v) Maximum lever load :	0, 2N
(vi) Scale diameter :	170mm
(vii) Length of lever arm :	240mm

Torque and Power can be Measure by Power Meter :

Crankset : Crankset power meters measure the torque applied to both pedals via strain gauges positioned within the crank spider. A calculation of power is derived from the deflection of the strain gauges and pedaling cadence. These units require specific crank sets, but can be relatively simple to interchange between bikes depending on compatibility.

Bottom Bracket : Bottom bracket power meters rely on the torsional deflection in the BB shaft, this is done by the shaft having a disc at each end with perforations, these perforations are detected using non-contact photo-electric sensors that detect when torque is applied to the left pedal and then doubled. Data is sent digitally to a handle bar mounted computer unit.

Freehub : A freehub power meter uses the same strain gauges that are present in the crank power meters but are located in the rear wheel hub and measure the power after the drive chain, because of this, power should theoretically be measured less than the crank based power meters. Because these units are built into the rear wheel it is simple to interchange between bikes as long as the wheels are compatible.

Chain : At the heart of chain units is essentially a guitar pick-up that mounts to the cycle's chain stay. With this system the pick up detects the chain vibration and speed and mathematically converts it to a power output.

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Opposing Force : This method of power measurement relies on Newton's Second Law : applied minus opposing forces musts equal mass times acceleration. Crankset, bottom bracket, freehub, and chain systems measure applied forces and, therefore, require placement of sensors near the bike pedal. Opposing force power meters measure hill slope (gravity), wind speed, bike acceleration (inertia), and frictional drag. Opposing force power meters place all key sensors in the computer head, resulting in lighter weight, extreme bike-to-bike portability, and lower cost.

Direct Applied Force : This method monitors the forces applied to the pedal by the cyclist's foot Sensors in the shoe or pedal measure the forces as the cranks rotate, and calculate the power based on the magnitude and direction of the applied force, and the angular velocity of the crank. Advantages of this technique include independent measurement of power for each leg, measurement of efficiency of pedaling style, and (depending on placement of sensors) avoiding the need to replace bike components.

Q. 7. Explain any one method to measure high pressure. Derive the expression for sensitivity of hot wire pressure transducer.

Ans. The Bourdon tubes are made out of an elliptically flattened tube bent in such a way that to produce the above mentioned shapes. One end of the tube is sealed or closed. The other end is open for the fluid to entre. When the fluid whose pressure is to be measured enters the tube, the tube tends to straighten out on account of the pressure applied. This causes a movement of the free end and the displacement of this end is amplified through mechanical linkages. The amplified displacement of the free end may be used to move a pointer on a scale calibrated in terms of pressure or may be applied to a electrical displacement transducer whose output may be calibrated in terms of the pressure applied.

Bourdon tube elements have several distinct advantages and these include low cost, simple construction, high pressure range, good accuracy except at low pressures range and improved designs at the pressure for maximum safety. Their greatest advantage is that they are easily adapted for designs for obtaining electrical outputs.

The disadvantages of Bourdon tubes are : their low spring gradient which their use limits for precision measurements upto a pressure of $3MN/m^2$, are susceptible to shocks and vibrations and are subject to hysteresis.

Q. 8. Write short notes on :

(i) Thermocouple

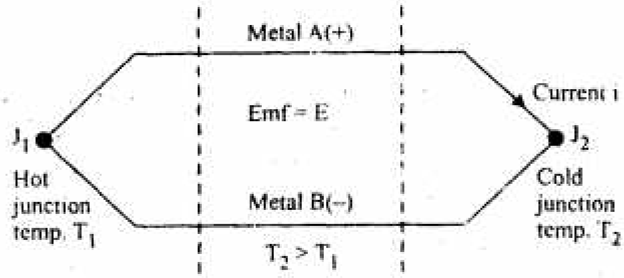
(ii) Pitot-static tube meter

(iii) Galvanometric records

(iv) Photovoltaic transducer

Ans. (i) Thermocouple : Thermocouple is the one of the simplest and most commonly used method of measuring process temperatures. The operation of a thermocouple is based upon Seeback effect. Seeback discovered that when heat is applied to junction (hot junction) of two dissimilar metals an emf is generated which can be measured at the other junction (cold junction). The two dissimilar metals form an electric circuit, and a current flows as a result of the generated emf as shown in figure.

This current will continue to flow as long as $T_1 > T_2$. Metal B is described as –ve with respect to metal A if current flows into it at the cold junction.



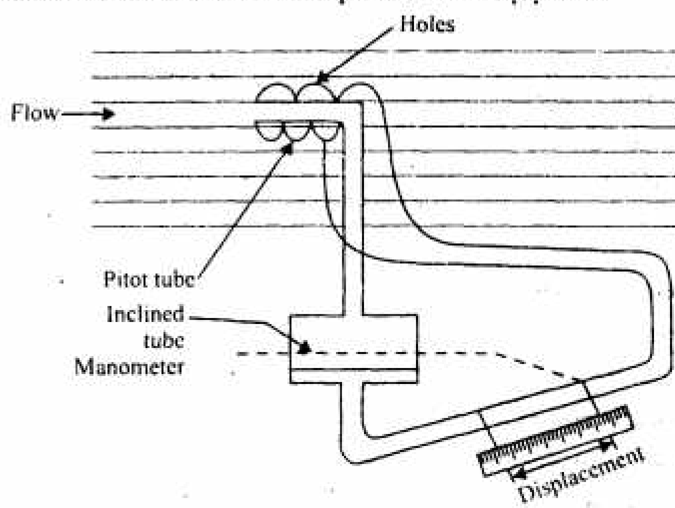
The emf produced is function of the difference in temperature of hot and cold junctions and is given by

$$E = \alpha\Delta\theta$$

Where $\Delta\theta$ = Difference between temperatures of hot and cold junctions.

***(ii)* Pitot-Static Tube Meter** : Pitot tubes are one of the most common forms of flow rate measuring devices which works on the principle of converting kinetic energy of the fluid being metered into a static head. Pitot tubes are essentially laboratory type of instruments are not normally used for industrial applications. Figure shows a pitot tube installed in a pipe line for measurement of flow rates The tube actually consists of two concentric tubes.

The open end of the inner tube faces the incoming flow. The outer tube has a closed end, but this has a number of holes in its walls. Both the tubes contains the same fluid as is flowing in the main pipeline. The pressure in the outer tube is the static pressure in the pipeline.



The total pressure in the inner tube, however is greater than this static pressure. The additional pressure on the inner tube is on account of the impact of the fluid stream on stationary inner tube.

Application of Bernoulli's theorem shows that the velocity at this point in the cross-section is :

$$V = \sqrt{\left(\frac{2(P - P_0}{\rho}\right)}$$

P_0 = Static pressure; N/m^2

P = Pressure at the entrance of tube; N/m^2

ρ = Density of liquid; kg/m^3

& thus, the velocity at a particular point may be determined from the pressure differential from the pressure differential generated by the pitot tube which is measured by an inclined tube manometer.

(iii) Galvanometric Records : These recorders use a d'Arsonval galvanometer. The pointer is equipped with a recording pen mechanism (stylus). A cut away view of the moving coil element. As current flows through the coil, it deflects. The greater the amplitude of the incoming signal (which is proportional to the quantity being measured), the greater is the deflection. When the pointer comes to rest on account of controlling torque exerted by springs the stylus also comes to rest. Thus, the value of quantity is recorded. This is necessitated by the fact that in recorders the movement of the large moving coil situated in a strong magnetic field.

(iv) Photovoltaic Transducer : Photovoltaic transducer or solar transducer as it is sometimes called produces an electrical current when connected to a load. Both silicon (Si) and selenium types are used. It may be used in no of applications. Multiple unit silicon voltaic devices may used for sensing light as a means of reading punched cards in the data processing industry. Gold doped germanium cells with controlled spectral responses act as photovoltaic devices in the infra red region of the spectrum and may be used as infra red detector.

Application of Photovoltaic Cell : The characteristic of a photovoltaic cell is logarithmic in nature. A logarithmic charactersitics may have useful application in practice. When the transducer is remote from the amplifier, any noise picked up or connecting leads may be attenuated by using high CMRR (common mode rejection ratio) of the amplifier. The input impedance assuming R is small in comparison with R_f, is R since junction R and R_f is a virtual earth. The voltage gain is R_f/R.