SAT Module - III

5. *Thermoelectric Sensing element (Thermocouple)*

Seeback effect: - It states that when two different metal of different composition are joined to form two junction and if the temperature of the junction is changed then potential difference will be developed across the junction and this potential difference is called Seeback emf.

$$E_T^{AB} = a_1T_1 + a_2T_2^2 + a_3T_3^3 + ...$$

Where, a_1, a_2, a_3 →Constants which depends on the type of metals

→*Thermocouple:* - A thermo couple is constructed when two dissimilar metal of different composition are joined to form a close circuit consisting of two junction J_1 and J_2 and the two junctions are maintained at different temp. T_1 and T_2 respectively.

→*Hot Junction/ Measuring Junction:* - This junction is inserted into the system for measurement of the process temperature.

→*Cold Junction/ Reference Junction:* -This Junction is usually kept at reference temperature of 0 °C for most industrial applications.

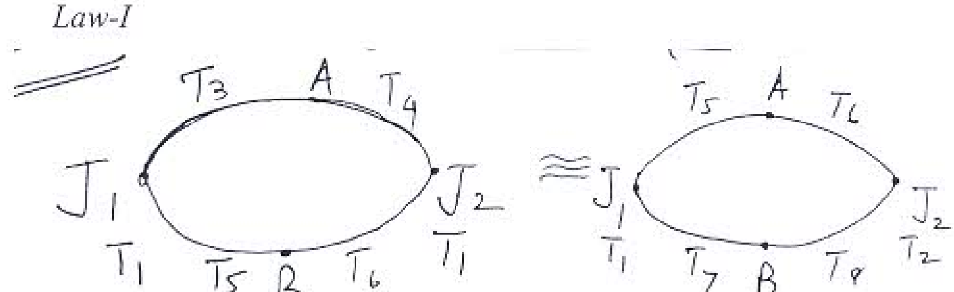
$$E_{T_1T_2}^{AB} = a_1(T_1 - T_2) + a_2(T_1^2 - T_2^2) + a_3(T_1^3 - T_2^3) + ...$$

T_1= Temperature of Measuring Junction.

T_2= Temperature of Reference Junction.

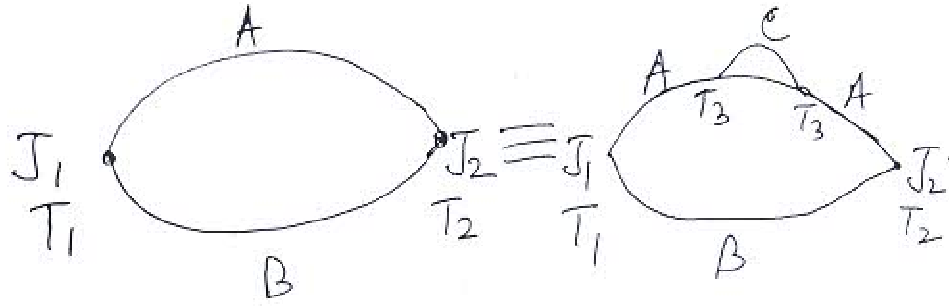
Laws of Thermocouple: -

Law-I



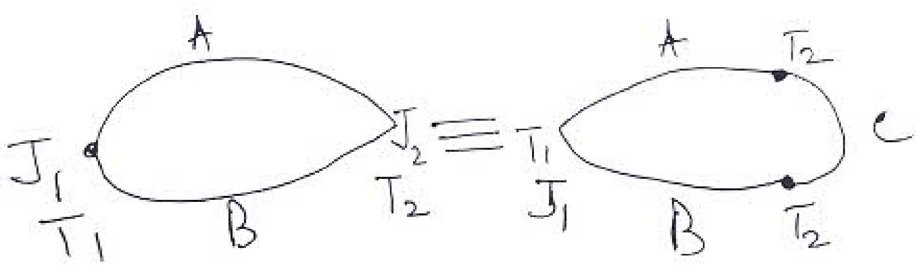
→It states that the emf of a given thermocouple depends only on the temperature of the junction and independent of the wire connecting the junction.

Law-II



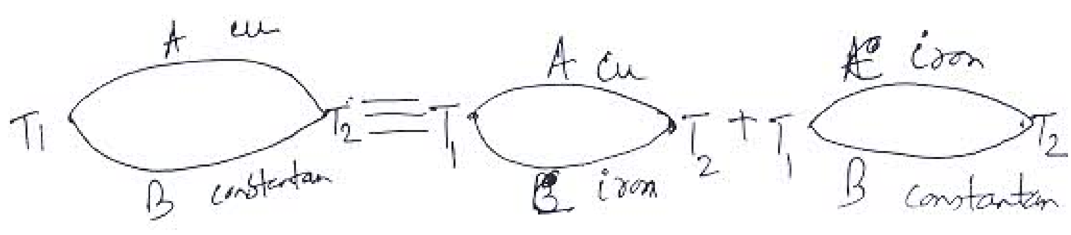
→This law states that if a 3rd metal is introduced into A (or B) and the two new junctions are at same temperature T_3, then emf of the thermocouple is unchanged.

Law-III



→This law states that if a 3rd metal 'C' is inserted between A and B at either junction. And the new junction AC or BC at the same temperature (T_1 or T_2), then the emf is unchanged.

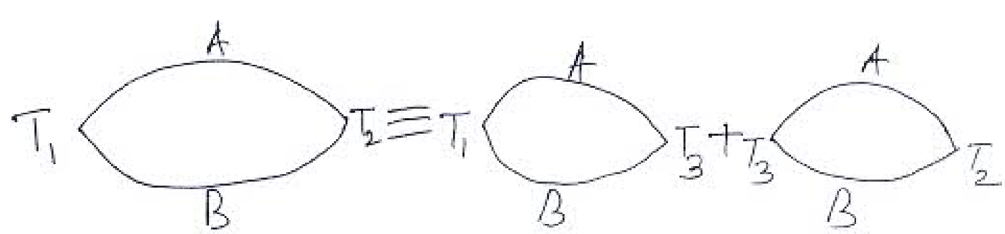
Law-IV



→Law of intermediate metal

$$E_{T_1T_2}^{AB} = E_{T_1T_2}^{AC} + E_{T_1T_2}^{CB}$$

Law-V

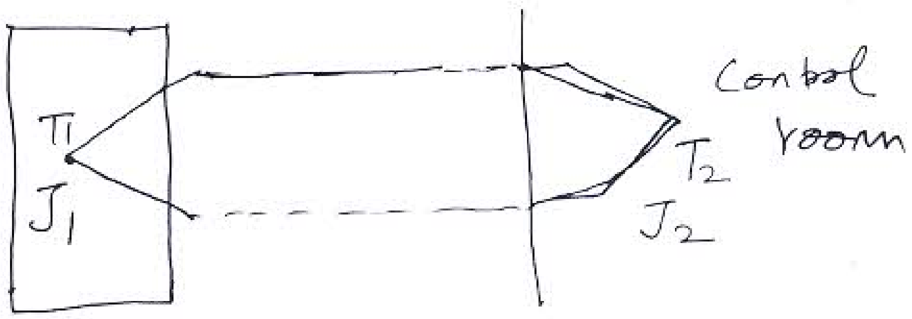


→Law of intermediate Temperature

$$E_{T_1T_2}^{AB} = E_{T_1T_2}^{AC} + E_{T_1T_2}^{CB}$$

Lead Compensation

→The use of extra lead in a thermocouple for compensating the changing output voltage of the thermocouple due to temperature variation is called lead compensation.

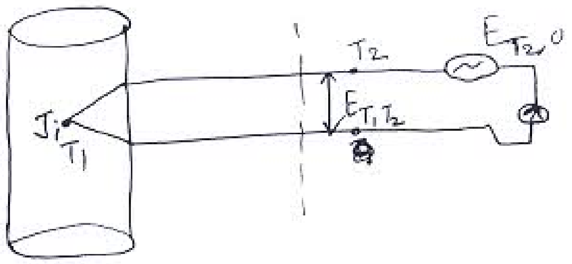


→The extra leads used for lead compensation may be of same material of thermocouple or, of different material having the same thermal conducting properties of the metal used.

Installation Problem

- Temperature indication too low with a very thin thermocouple.
- Varying temperature indication with proper operation.
- Temperature indication error increases with increasing temperature (low indication).
- Large deviations of the temperature indication from the default values.
- Temperature indication changes over the course of time.
- Temperature indicating instrument shows room temperature
- Negative temperature indication.
- Temperature indication error in the range of 20-25 °C
- Temperature indication even when thermocouple is disconnected.

Reference Junction Compensation of Thermocouple: -



Case-I

$T_1=100,\ T_2=0,\ a_1=4$

$E=a_1\ (T_1-T_2)=4(100-0)=400mV$

Case-II

$T_1=100,\ T_2=1,\ a_1=4$

$E=a_1\ (T_1-T_2)=4*99=396mV$

So error = 4mV

→Due to change in atmospheric temperature the reference junction temperature T_2 will be changed and there will be a corresponding change in output voltage of the thermocouple. To compensate this change in output voltage with atmospheric temperature variation is to be compensated by introducing a 2nd source of emf $E_{T_2,0}$ in series with the thermocouple output voltage (E_{T_1,T_2}).

$$E_{T_1,0} = E_{T_1,T_2} + E_{T_2,0}$$

→Metal resistance thermometer is incorporated to bridge circuit will sense the change in temperature at the reference junction and giving an output voltage signal proportional to the reference junction temperature. So output of bridge circuit should be equal to zero.

→Output of bridge circuit incorporating thermometer or, RTD is given by:

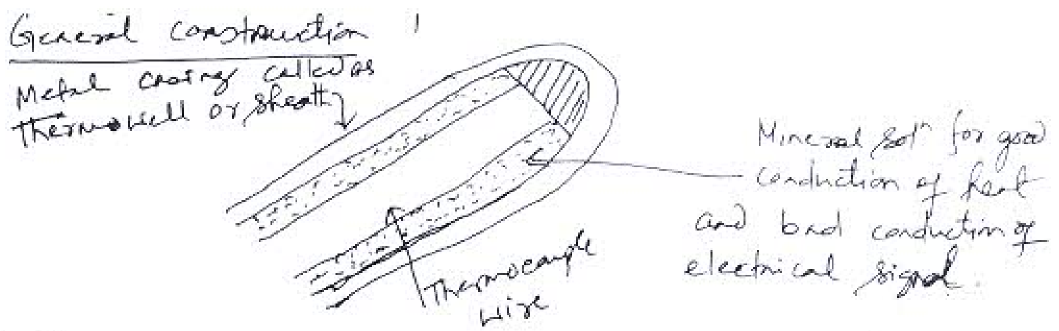
$$V_{out} = V_s \frac{R_2}{R_3} \alpha T_2$$

Where, α= resistance temperature co-efficient of RTD

Peltier Effect

→This is the reverse of see-back effect when the potential difference is applied across the two junction of thermocouple, one junction of thermocouple will be heated and junction temperature will be increased and other junction temperature will be decreased.

General Construction: -



IC Temperature Sensor

→Small size.

→No compensation circuit is required i.e. it is already present inside it.

→ These IC generate electrical output proportional to the temperature. The sensor works on the principle that the forward voltage of a silicon diode depends on its temperature.

→Voltage Temp. Characteristics:

$$V_F = \frac{KT}{e} \ln \frac{I_F}{I_S}$$

Where, T=Ambient temp in K

K=Boltzmann Constant =1.3867*10^{-23} J/k

E= Charge of electron

I_F=Forward Current

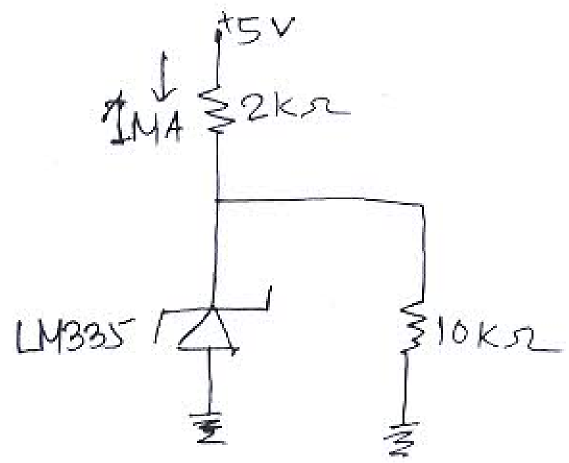
I_S=Saturation Current

→Two diodes are used to avoid saturation current.

→IC temperature sensors are available in both voltage and current output configuration.

→The current output units are usually set for an output change 1μA per Kelvin while the voltage output configuration generates 10mV per K.

LM 335



→It operates as a two terminal Zener diode with an output voltage of 10mV/K.

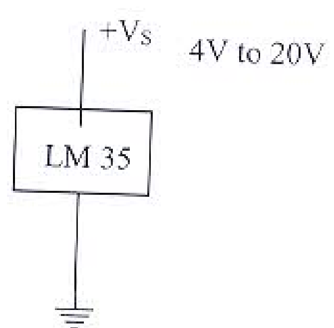
→Temperature Range is -55 °C to 125 °C.

→It gives linear output.

→Current range 400 μA< I_Z < 5mA [I_Z→Zener diode].

Device Name	Temp. range	Use
LM 135	-55 °C to 150 °C	Defence
LM 235	-45 °C to 125 °C	Industrial
LM 335	-45 °C to 100 °C	Commercial

LM 35



→Temperature Range is -55 °C to 150 °C

→Its output voltage of 10mV/ °C

→It gives a nearly linear output characteristics.

→It behaves as a three terminal reference rather than a two terminal Zener powered by a 4V to 20V applied to 3^{rd} terminal. But +ve and –ve supply with a pull down resistance are necessary to operate in near or below 0 °C.

AD 592

→It is a 2-terminal device that acts like a constant current element passing a constant current in µA equal to absolute temperature.

→Temperature range -25 ºC to 105 ºC.

→Output Current range 1 µA/K.

6. Elastic Sensing Element

→It converts an input force into an output displacement.

→It is commonly used for measuring torque, pressure, acceleration etc.

Burdon tube

→It is used for pressure measurement.

→These are of various types

- C-type
- Spiral type
- Helical type

→The Burdon tubes are made out of an elliptically flattered tube beat in such a way as to produce the different shape.

→One end of the tube is sealed and other is open.

→When the fluid whose pressure is to be measured enters the tube there tends to straighten out an account of the pressure applied.

→This causes a movement of free end and displacement of this end is amplified through a mechanical linkage.

→The amplified displacement of the free end may be used to move a pointer on scale calibrated in terms of applied pressure.

→Burdon tubes are made up of different materials which includes brass, alloy steel, stainless steel, bronze, phosphorous bronze, beryllium copper, monel etc.

Monel→ High pressure measurement

→Phosphorous bronze is used in low pressure application where the atmosphere is non-corrosive, while in application where corrosion and/or high pressure is a problem stainless steel or, Monel are used.

Advantages: -

→Low Cost, Simple Construction.

→Wide variety of ranges, high accuracy especially in relation to cost.

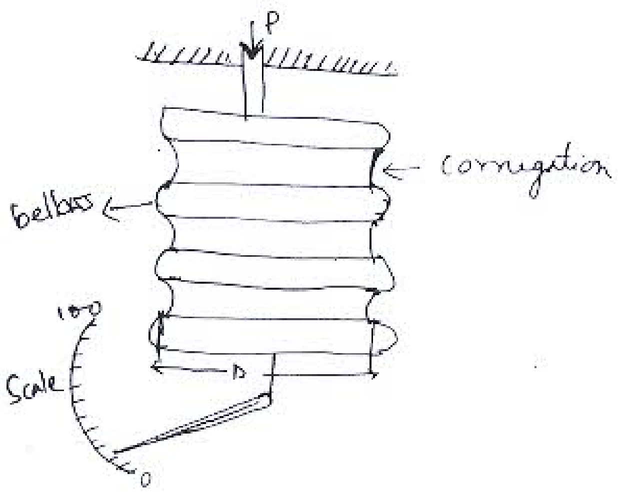
Disadvantages: -

→Low spring gradient.

→Susceptible to vibration and hysteresis.

→Susceptible to electric shock.

Bellows



→Bellow Convert pressure to displacement.

→Metallic bellows is a series of circular parts of metal welded together (Bronze or alloy)

→The bellow are made up of an alloy which is ductile, has high strength and retains its properties over long use that has very little hysteresis effect.

→Relation between the applied pressure and displacement is given by:

$$d = \frac{0.453 P b n D^2 \sqrt{1-\nu^2}}{E t^3}$$

Where, P=Pressure

b=Radius of each corrugation

n=no. of Semiconductor corrugation

t=thickness of wall

D=Mean diameter

E=Young's Modulus of Electricity

ν =Poisson's ratio

Advantages

→Cost is moderate, able to deliver high force.

→It is adaptable for absolute and differential pressure.

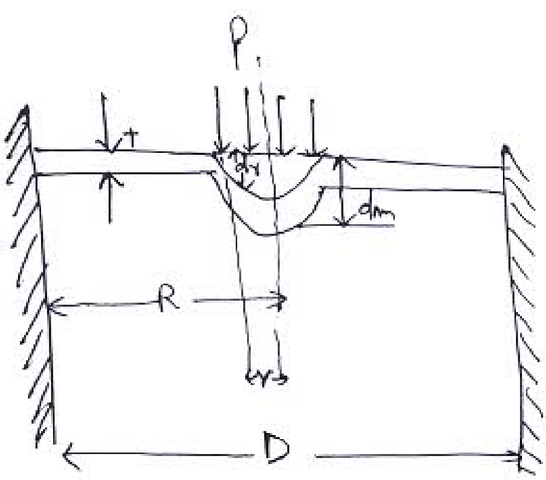
→It is good in low to moderate pressure range.

Disadvantages

→It needs ambient temperature compensation

→It is unsuitable for high Pressure.

Diaphragm



→Diaphragm is pneumatic sensor which convert pressure to displacement.

→Diaphragm is nothing but an elastic membrane on which pressure is applied and the corresponding displacement is measured.

→For this type of diaphragm, the relationship between the applied pressure and displacement is given by:

$$P = \frac{256 E t^3 d_m}{3(1-v^2)D^4} \ N/m^2$$

Where, E=Young's Modulus

t=thickness of diaphragm

d=diameter of the diaphragm

R=Radius of the diaphragm

V =Poisson's Ratio

d_m=deflection at centre of diaphragm corrugated environment, we can also use rubber.

Practical Elastic Sensor

1) Cantilever load cell

$$e = \frac{b(l-x)F}{wt^2\varepsilon}$$

Where, e→Total force induced on applying force

→ The applied force causes the cantilever to bend so that top surface experiences a tensile strain and the strain gauge one and there will experience an increase in resistance.

$$R_1 = R_3 = R_0 + \Delta R$$

Where, R_0=initial resistance at t (-0)

→ Strain gauge 2 and 4 experience compressive strain and there will be decrease in resistance $R_2 = R_4 = R_0 - \Delta R$

$$G = \frac{\left(\Delta R / R_0\right)}{e}$$

$$\Delta R = G e R_0$$

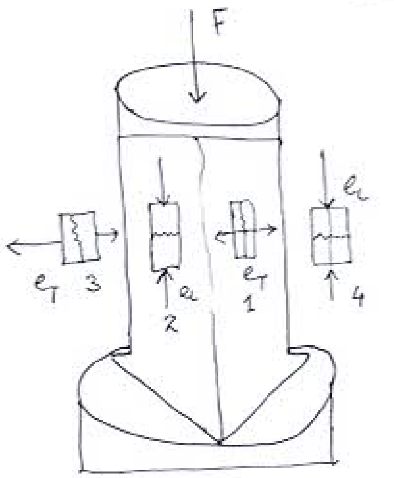
$$R_1 = R_3 = R_0 + R_0 Ge$$

$$= R_0(1 + Ge)$$

$$R_2 = R_4 = R_0(1 - Ge)$$

$$E_{th} = V_S Ge \rightarrow \text{Output voltage of bridge ckt.}$$

2) Pillar Load cell



$$E = \frac{Stress}{Strain} = \frac{F/A}{-e_L}$$

$$e_L = -F/AE$$

$$e_T = -\nu e_L = \frac{F\nu}{AE}$$

$$R_1 = R_3 = R_0 + \Delta R$$

$$R_2 = R_4 = R_0 + \Delta R$$

$$\Delta R = GeR_0$$

$$R_1 = R_3 = R_0 + R_0 Ge_T$$

$$= R_0(1 + Ge_T)$$

$$R_2 = R_4 = R_0 + R_0 Ge_L$$

$$= R_0(1 + Ge_L)$$

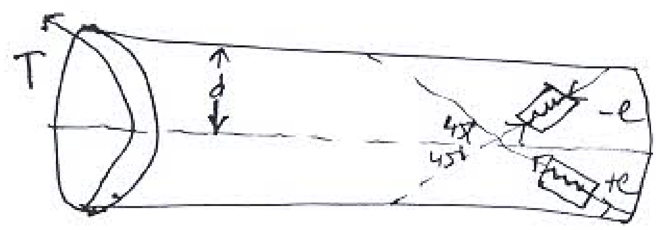
$$R_1 = R_3 = R_0\left(1+\frac{GF\nu}{AE}\right)$$

$$R_2 = R_4 = R_0\left(1-\frac{GF}{AE}\right)$$

$$E_{th} = \frac{V_S}{2}\left(\frac{GF}{AE}\right)(1+\nu) \rightarrow Output\ of\ the\ bridge\ ckt$$

Torque Sensor

→Torque Sensor is a 2nd order dynamic element.



$$Total\ e = \frac{T}{\pi S a^3}$$

Where, S= shear Modulus

T= Applied Torque

a=Radius of cylinder

$$R_1 = R_3 = R_0(1+Ge)$$

$$R_2 = R_4 = R_0(1-Ge)$$

$$E_{th} = V_S Ge$$