Module 6: Computer Instrumentation

Introduction, instrumentations, measurement system, control system, Transducer and Sensor: transducers, sensors, classification of transducers, characteristics of transducers, selection criterion for transducers, temperature transducers, strain gauge, pressure transducers, force transducers, optical transducers, actuators.

Introduction:

The most dynamic, expanding and useful branch of electronics is instrumentation. The instrumentation which inherits itself to electrical and mechanical measuring devices (meters / gauges) has undergone a total change in last few decades. The developments in *semiconductor technology* introduced what can be called as electronic instrumentation, which itself has changed its face from *simple analog electronic instrumentation to digital instrumentation* and to *computerized intelligent instrumentation* in last decade.

The *intelligent instrumentation and control* systems of today, derive their intelligence from the computers used in the system. In such systems the communication links between computer, the measurement system the control system, and the computer peripheral devices play the vital role, analogous to nerves in human body.

In the present book an attempt is made to introduce these links by studying such devices and their interfacing with the computer. Chapters 1 to 6, cover the instrumentation and control devices while chapters 1 to 7 of second part deal with the computer peripheral devices.

Measurement:

The *measurement* is the natural process a human being uses in understanding the world around it. We compare the size of one object with the other to know bigness or smallness of the object. The size of room, furniture, door, utensils, trees, mountains and sky is judged by a person by observation and comparison. Thus *comparison with the predefined standards is the measurement.*

In early days the measurement was restricted to fundamental quantities like length, mass and time and derived quantities like area, volume, velocity, speed, weight, pressure etc. Later it extended to almost all the physical quantities like temperature, humidity, brightness, power, energy, electromagnetic wave radiation etc. Thus today measurement encompasses anything and everything not only in the world but in the universe.

Instruments:

The use of instruments for measurements is very common. You have been using foot – rule for measuring length, watch for measuring time and weights and balance for measuring mass. The limited ability of human being for measurement can be extended by using external physical devices (Tools, aids), known as instruments.

The instruments can increase accuracy and reliability of measurement, can extend the area of measurement which is other wise inaccessible to human being, for example measurements in hazardous conditions, at a distance, underwater etc.

Instrumentation:

The art and science of using instruments for measurement or control is known as instrumentation. A day today example of instrumentation is meter board of a car or motorcycle. It contains meters to indicate distance travelled, speed, condition of oil, cooling water, charge of battery etc. A more sophisticated instrumentation system can be seen in the control board of aircraft, in satellite control stations or in the control cabin of an automated process industry.

In its infancy, the instrumentation used mechanical devices such as dial gauges, safety values etc. in the process-parameter measurements, and/or control. The slow acting mechanical devices were then changed to electromechanical devices, to electronic devices and finally to most modern digital devices including devices including microprocessors and computers.

Measurement System:

A monitoring or measurement system is a combination (or arrangement) of different physical devices which act together as an entire unit to measure certain quantity or parameter of the plant Figure 1.1 shows the constituents of such a system. The plant represents the process that is being controlled or monitored. It has number of parameters which define characteristics of the plant or process. Some of these parameters may be vital and needs to be monitored/ measured. Such parameters are known as measurands.

The measurement system consists of three distinct devices. These are;

i. *Primary element (sensor / transducer):*

These are the devices directly in contact with the process and sense or pick up process parameter value.

ii. *Signal conditioner:*

The output available from the transducer may not be suitable for further use. It is necessary to modify it to suit the requirements of display unit and/or control system. Instrumentation amplifiers, current to voltage converters, ADC and DAC are some of the examples of signal conditioning devices. In some systems, the output of the transducer may be suitable for display unit, and / or control system in such cases this stage is absent.

iii. *The Display unit (End Device) :*

The end device gives the required information about measured quantity in the user - friendly form. The display may be in the form of audio, video or recorded form The examples are analog meters, digital meters, recorders, plotters, memory disks etc.

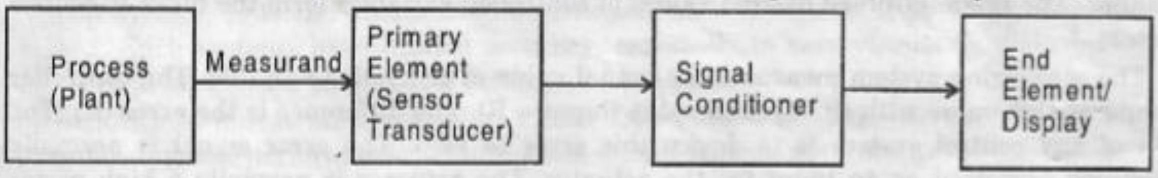


Figure 1.1 Constituents of Measurement System

Control System:

Analogous to measurement system, a control system can be defined as a combination of physical devices, connected to each other in such a way that they act as a single unit to control one or more parameters of the plant or process. We come across a large number of such control systems in day today life. The control of temperature of oven, iron, refrigerator or room is one such example in which, the temperature is sensed by the sensors and power supply is switched on or off by the relay to control the temperature. The water - level controller for overhead tank is another example, where in water level is sensed and pump is switched on or off to maintain level within certain limits. The remote control of TV and VCR is yet another example. More sophisticated control systems can be witnessed in guided misiles, satellite - control stations, in space research, in process control, in robotics, in aircrafts and in combat weapons.

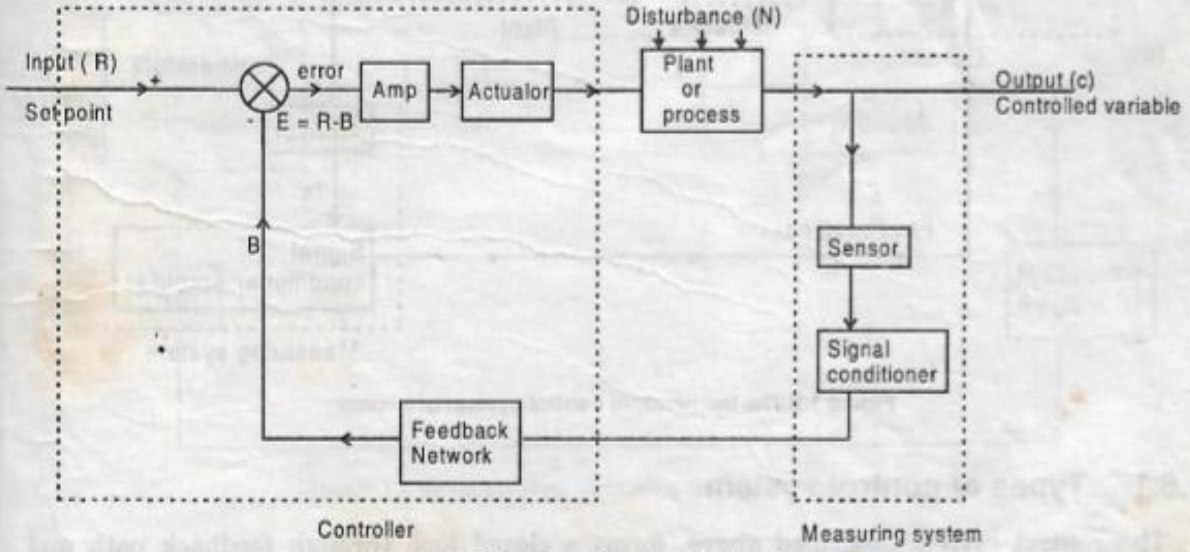


Figure 1.2 Constituents of control system

Figure 1.2 shows typical control system. The constituents of the control system are, the plant or process under control, the measuring system and the controller.

The plant is that part of the system or process which is being controlled. The plant has many physical devices connected to each other, influencing each others performance and forming a complex system. The characteristic behaviour of the plant can be controlled by controlling certain parameters called output variables or controlled variables. To get desired performance, the controlled variables must change according to predetermined manner. The predetermined desired values of controlled variables form the input to control system.

The measuring system measures the actual value of controlled variable. The controller compares this value with the desired value (input = R). The difference is the error (E). The aim of any control system is to device this error to zero. The error signal is normally amplified and used as an input to the actuator. The actuator is normally a high power device and controls input power to the plant or influences the plant – process to change the value of controlled variable.

Consider as an example, the control system for controlling the temperature of a room (Figure 1.3). Let us say the input (set value of temperature) is 50°C. The controlled variable here is temperature, the plant or process is the room with heaters. The measuring system senses the temperature (Ta), by using temperature sensor and makes it available as feedback. This value is compared with 50°C and if error is positive ($50 - T_a$), the relay, acting as actuator, switches 'ON' the heater. When error becomes negative ($E = 50 - T_a$, $T_a > 50$), the relay switches 'OFF' the heater.

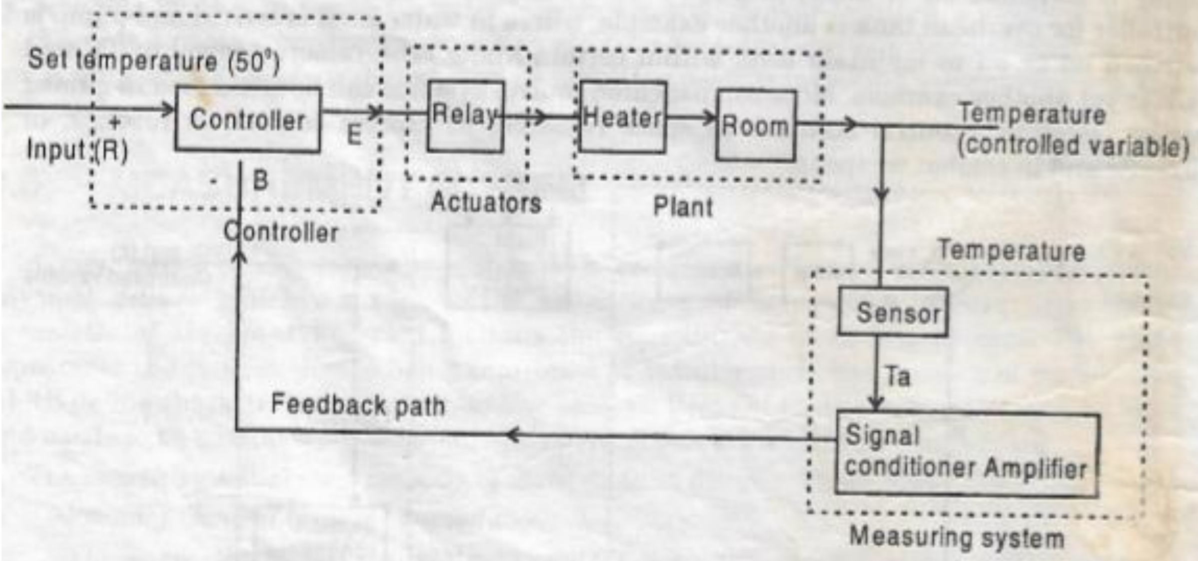


Figure 1.3 The temperature control system of a room

Types of Control System:

The control system described above, forms a closed loop through feedback path and hence known as *closed loop system or feedback system*. The feedback type control system provides continuous vigilance over the value of controlled variable. The temperature of room may get affected due to change in outside temperature, opening of doors, windows or any other such disturbances. The closed loop system will automatically account for such changes and hence is also known as *automatic control system*. It increases accuracy of the control.

In certain applications, the feedback path is absent, or is assigned to human being. Such a system is known as *open – loop control system*. For example the remote control of TV is open loop system. It is the operator who gives feedback if volume is to be increased or decreased. Such systems have limited accuracy, especially in case of outside disturbance. However such system are simple, less costly and fast in operation.

In majority of industrial applications closed loop control systems are used because of their better dynamic performance, accuracy and adaptability to disturbance.

Intelligent Control System:

Majority of the modern chemical process industries, use intelligent instrumentation systems and control systems. Such systems are provided with the capability of taking their own decisions in setting inputs of controlled variables, depending upon environment and disturbance. In such systems, the intelligence is provided by the *computer or microprocessor*. The centrally controlled and distributed control, computer – controlled systems are not uncommon in large process industry. In such cases, computer assumes the role of controller as shown in figure 1.4. To communicate with the computer, the measuring system and actuating system needs ADC and DAC devices.

The use of computer in control system enables the system to handle many variables at a time, predict system behaviour before hand and actuate control and faster and more accurately. It is this multifacet aspect that has made such systems inevitable in modern control.

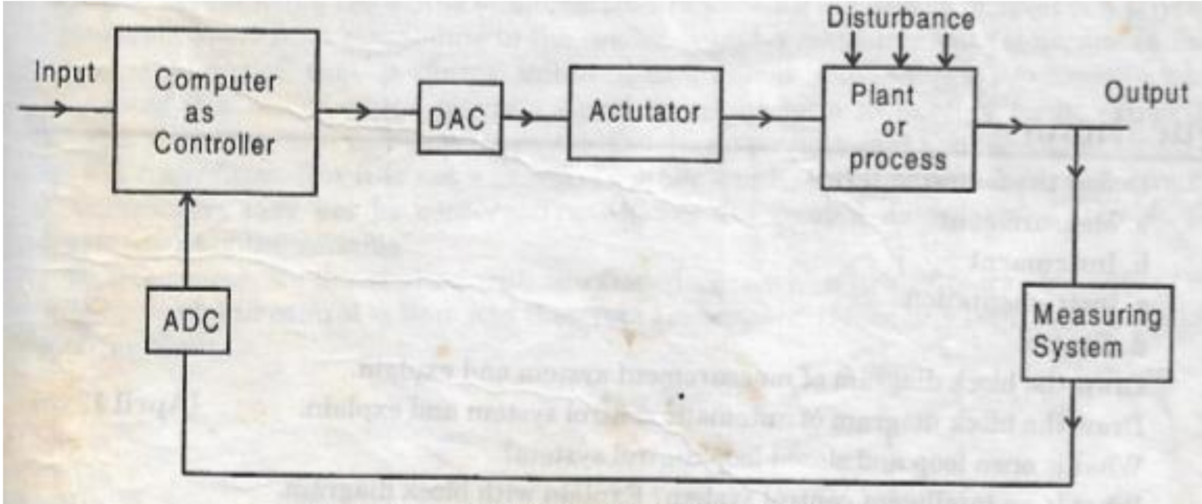


Figure: 1.4 Block diagram of Intelligent Control System

Transducer and Sensor:

In the field of instrumentation, the terms transducers and sensors are used interchangeably. Still there is a slight difference between the two. A sensor may be employed for detecting the status of the variable or sensing the degree or level of a physical. measurand, apart from responding to the condition under measurement. Thus, one can say *sensor* is a device that performs initial measurement and energy conversion, while transducer is a device which converts signal from one form to another form. Thus, for example a device which converts a current signal into proportional voltage signal would be called a *transducer*. But it is not a sensor. In other words, "all sensors are transducers but all transducers may not be sensors. Transducers are treated as sensors if they do the measurement of the variable".

In this course, we are dealing with the transducers which are primary elements of the measurement and control system and therefore are sensors. Hence any term can be used for referring them.

Classification of Transducer:

Classification of transducers is possible in several ways. Some of them are –

- The measurand they measure
- Basic phenomenon on which they work (Principal of transduction).
- Function they perform (Primary or secondary transducers)
- Energy requirement (Passive or active transducers)
- Nature of circuits (Analog or digital transducers)

1 Classification based on the Measurand

There are many types of variables required to be measured in the process control industry. Depending on the process variable or measurand one has different types of transducers. e.g. Thermocouple, RTD, thermostat are temperature transducers, while Bourdan tube, bellows, diaphragm are pressure transducers ; and so on.

2 Classification based upon the principle of Transduction

Due to change in process parameter, resistance, inductance or capacitance of the material may change. Depending on the change one has resistive, inductive or capacitive type of transducers. e.g. in thermistors – resistance of the semiconductor material changes with the temperature. In capacitor microphone, the capacitance of microphone varies with the sound pressure and so on.

3 Primary and Secondary Transducers

Sometimes, more than one transducers are required to measure the process variable e.g. As shown in figure 2.1 the Bourdon tube acting as a primary transducers senses the pressure and converts it into a displacement at its free end. The displacement moves the core of LVDT (linear variable differential transformer) and produces output voltage proportional to the movement of the core, which is proportional to the displacement of the free end which in turn is proportional to the pressure. Here, LVDT is acting as a secondary transducer, while Bourdon tube as primary transducer.

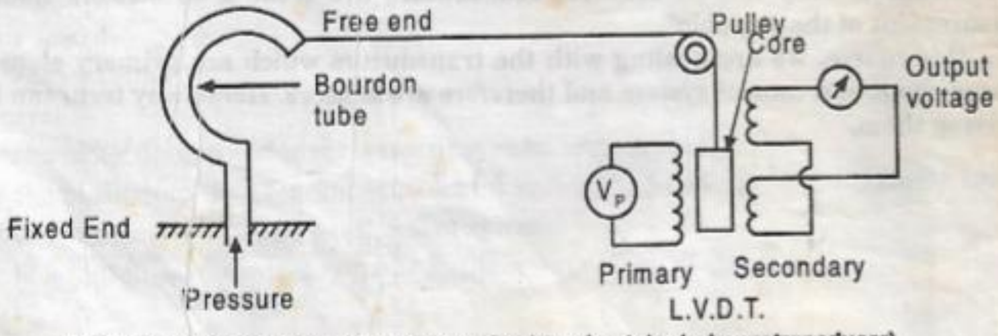


Figure 2.1 Measurement of pressure using bourdon tube (primary transducer) and L.V.D.T (Secondary transducer)

4 Active and Passive Transducer

Active transducers are self-powering devices and do not require an external power supply or excitation for the conversion of one form of signal into another form. These transducers include thermoelectric, piezoelectric, photovoltaic, electromagnetic, electrodynamic, magnetostrictive, electrokinetic, pyroelectric and galvanic sensors. In case of piezoelectric crystal, when force is applied across the crystal, an output voltage is produced. Photovoltaic devices produce voltage when illuminated by light.

Passive transducers operate under energy controlling principles. These are not self-generating type and require an external power supply or an oscillator, for the conversion of one form of signal to another form of signal. Typical examples of passive transducers are resistive, inductive and capacitive transducers. Any change in these three primary parameters can be recognized only when the element is made 'live' by electric excitation: otherwise they are in dead state. In the absence of external power, the transducer cannot work and hence is called as passive transducer. e.g, in piezoresistive transducers in the resistance of the crystal changes by the application of pressure. In photoconductive devices conductivity of the material changes with illumination.

5 Analog and Digital Transducers

Analog transducers convert the input quantity into an analog output which is a continuous function of time. e.g. a strain gauge, a L.V.D.T, a thermocouple or a thermistor may be called as "Analog transducers" as they give an output which is a continuous function of time.

Digital transducers convert the input quantity into digital form of output. e.g. shaft encoder used to measure angular position of shaft or digital tachometer used to measure the speed. Both give pulses as the output. Frequency or distance between pulses indicates the speed or angular position.

All these classifications usually overlap each other. A transducer can be classified into one or more ways. e.g. Thermistor is a passive , primary , temperature transducer which is also an analog transducer changing resistance of the semiconductor according to the temperature.

Characteristics of Transducer:

A complete knowledge of transducer is very important while choosing a transducer for a particular application. The important characteristics to be considered are as follows:

1. **Range and Span** – These are the two terms that convey the information about the lower and upper limit values of the measurand.

   The *range* of a transducer is defined as the difference between the largest and the smallest reading of the measurand. Suppose the highest value of measurand which can be measured satisfactorily is X_{max} units and the minimum value for the same is X_{min} then the transducer range is X_{min} to X_{max}.

   The *span* of a transducer is the algebraic difference between the largest and the smallest value of the measurand.

   $$\text{Span} = X_{max} - X_{min} \qquad \text{......(2.1)}$$

   X_{min} may be zero or may not be zero. If X_{min} is zero, range and span have equal values. If R-type thermocouple is used to measure temperature of 0° C to 1600°C, then range is 0 to 1600° C or simply 1600° C and span is 1600° C – 0°C = 1600°C. For PT – 100 temperature transducer, temperature range is –200°C to 600°C, while span is 600°C – (– 200°C) = 800°C.

2. **Error** – The algebraic difference between the indicated value (I) and actual or true value (T) of a measurand is defined as *error* (E). Thus

   $$E = I - T \qquad \text{......(2.2)}$$

   Error can be negative or positive depending upon the relative magnitudes of I and T. The error therefore represents the actual value of the measurand, predicted from the measurement.

3. **Accuracy** – *Accuracy* is defined as the closeness with which the reading approaches an accepted standard value or true value. It is a relative term. Absolute accuracy, as such, has no significance in the measurement of a physical quantity. Usually, percentage accuracy is specified as the percentage deviation or inaccuracy of the measurement from the true value and is a ratio of the error of indicated value to the true value, expressed as a percentage.

   $$\%\ \text{Inaccuracy} = \frac{\text{Error}}{\text{True value}} \times 100 \qquad \text{......(2.3)}$$

4. **Precision** – It is a measure of the reproducibility of the measurements. *Precision* is defined as the closeness with which individual measurements are distributed about their mean value. If the same measurement is done several times, the output value should be the same for all. But in practice readings will be clustered around the mean value in a random manner. The more the number of readings falling very close to the value, the more precise the instrument is.

   Note that, high precision does not indicate high degree of accuracy.

5. **Linearity** – One of the important characteristics of transducer is *linearity* i.e. the output should be linearly proportional to the input. Most of the systems require a linear behaviour as it simplifies the design and analysis of whole system.

   Linear input – output relation can be written as $y = mx + c$, where y is the output, x is the input, m, the slope and c, the intercept (constant).

   The linearity is generally expressed as a percentage of the deviation of any point from the idealized straight line as shown in figure 2.2. The non-linearity is given by

$$\%\ \text{Non linearity} = \frac{\text{(Maximum deviation of output from the idealized straight line)}}{\text{actual reading}} \times 100 \qquad \text{......(2.4)}$$

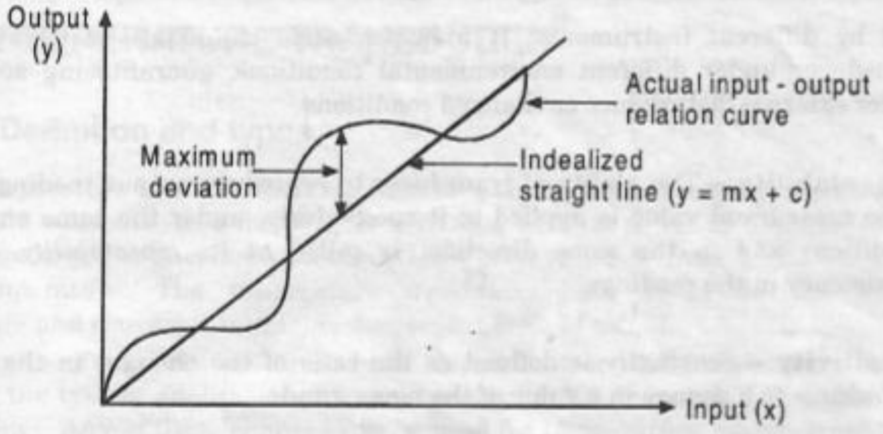


Figure 2.2 : Linearity

6. **Resolution** – If the input is very slowly increased from some arbitrary (non -zero) input value, it is found that output does not change at all until a certain increment is exceeded. This increment is called resolution. *Resolution* may be defined as the ability of a transducer to discriminate between nearly equal values. In short it is the smallest measurable input change.

   The *threshold* value of the transducer defines the smallest measurable input. It is the resolution at zero value or the minimum input required to make transducer active.

7. **Hysterisis:** – Output of the transducer depends upon past history of input. When a device is used to measure any parameter, first for increasing values of the measurand and then for decreasing values of the measurand; the two output readings obtained may be different. The difference of output readings so obtained is the *hysterisis* of the device. Hystersis is very common in electromagnetic devices. For better accuracy, hysterisis should be minimum.

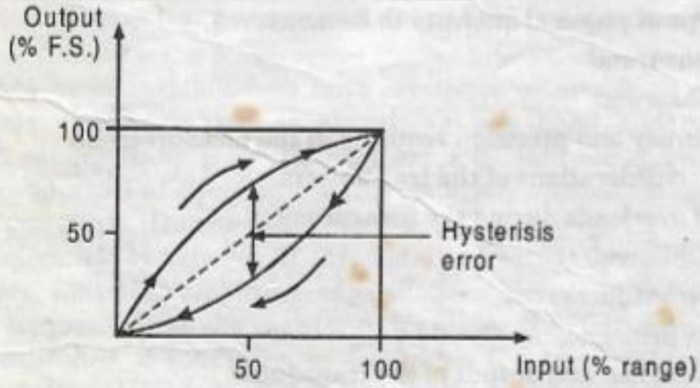


Figure 2.3 Hysterisis

8. **Reproducibility** – *Reproducibility* is the ability of transducer to produce output readings when the same input is applied at different times under different conditions and by different instruments. It indicates same characteristic behaviour of the transducer under different environmental conditions, guaranteeing accuracy even under external disturbance or changed conditions.

9. **Repeatability** – The ability of transducer to reproduce output readings, when the same measurand value is applied to it successively, under the same environmental conditions and in the same direction, is called as its *repeatability*. It indicates consistency in the readings.

10. **Sensitivity** – *Sensitivity* is defined as the ratio of the changes in the output of a transducer to a change in a value of the measurand.

11. **Drift** – *Drift* is a slow variation in the output signal of a transducer with time when the measurand is constant. Zero drift is defined as the deviation in the transducer output with time from initial value, when the measurand and conditions are constant.

12. **Dead band** – *Dead band* is defined as the largest change in the input quantity to which the transducer does not respond.

13. **Stability** – The ability of a transducer to retain its performance through out its specified operating life and storage life is defined as its *stability*.

Selection Criteria for Transducer:

To choose the transducer for specific application one should consider the following points:

a. Purpose of measurement.
b. Nature or type of physical quantity to be measured.
c. Source of measurand.
d. Range of measurand.
e. Order of accuracy and precision required in the measurement.
f. Installation considerations of the transducers.
g. Possibility of overloads during the measurement.
h. Ambient conditions.
i. Life span of transducer.
j. Transduction principle.
k. Limits on excitation and output of the transducer.
l. Availability of transducer.
m. Ease of operation.
n. Right time availability of transducer to meet installation schedules.
o. Cost.

Temperature Transducer:

2.6.1 Definition and types

The temperature is one of the fundamental parameters expressing degree of hotness or coldness of a substance or a medium. It is related with its power of communicating heat to the surrounding, i.e. thermal potential. Heat always flows from higher temperature to lower temperature. The *temperature transducers* are those devices which senses temperature and convert it into some convenient form of signal.

The choice of temperature transducer depends upon the temperature measurement range and the type of application. When a body is heated or cooled, many changes occur in the substance. Any of these changes can be used for temperature measurement. There are, in general, four types of temperature transducers based on the following temperature dependent physical properties.

i. *Mechanical transducer:* In this, physical change is used to sense the temperature. The expansion of a substance with temperature, produces change in length, volume or pressure e.g. mercury in glass or alcohol in glass.

ii. *Resistance transducer:* In this, change in electrical resistance with temperature is used . The principle is used in resistor thermometer (RTD) and in thermistor.

iii. *Thermocouple transducer:* Electrical energy is generated by bimetallic junction. This is the principle of thermocouple.

iv. *Radiant energy transducer :* In this, changes in radiant energy with the temperature is used for measurement. Optical and radiation pyrometers use this principle. Normally, pyrometers are used for high temperature measurement.

Out of these, we will study RTD and thermocouple in detail.

2.6.2 RTD (Resistance temperature detector)

RTDs are primary, passive, temperature transducers whose resistance changes with temperature.

RTD's are made up of metals which have crystal structure. If we see the energy band diagram of metals, forbidden band is absent; valance band and conduction band are overlapping each other. Many free electrons are available for conduction. So normally, metals are good conductors of electricity. When voltage is applied across the metal element, the flow of electrons starts. During conduction, the electrons collide with each other which gives rise to an electrical resistance. If the metal is heated, the mean free path between collisions decreases. Since the amplitude of oscillations increases, the electrons collide with each other more frequently, i.e. the resistance increases. The resistance thermometer uses the change in resistance of conductor to determine the temperature. RTD has positive temperature co-efficient (PTC type of device), i.e. the resistance of the material increases wth increase in the temperature.

RTD's are very accurate and sensitive devices. The range of the temperature over which these can be used is decided by temperature co-efficient of the material and the crystal structure.

Most of the metals show linear characteristic for small temperature range and the characteristic becomes slightly non-linear afterwards. In general, for narrow ranges of temperature, the resistance R_T at the temperature T can be found out by the equation,

$$R_T = Ro\,[\,1 + \alpha\,(T - To)\,] \qquad (2.5)$$

where Ro is the resistance at the temperature To, α is the temperature co-efficient of the metal used and is constant within narrow ranges of temperature.

For large temperature range non-linearity occurs and the resistance value is given by

$$R_T = Ro\,[\,1 + \alpha_1\,(T - To) + \alpha_2\,(T - To)^2 + \alpha_3\,(T - To)^3 + \cdots\,] \qquad (2.6)$$

where α_1, α_2, α_3, - - - - are constants and can be found out by finding out resistor values for standard temperature or by referring tables or graphs of Resistance v/s Temperature.

RTD Materials: Materials which can be used for RTD are Nickel, Iron, Copper, Platinum, Silver, Gold, Manganese, Tungsten, etc. Amongst these Gold and Silver are rarely used for construction of RTD because of their low resistivities. Tungsten has high resistivity, but it is used for high temperature applications, as it is extremely brittle and difficult to work with Copper, because of the low resistivity and low cost is used for temperature measurement upto 120° C. But it suffers from the oxidation problem. Nickel can be used for temperature range of 100° C to 350° C. It is reliable, having good repeatability, low cost and has high temperature co-efficient of 0.0068/°C, but it is non-linear and tends to drift with time.

Platinum is the best choice for many applications. It is accurate, sensitive, reproducible, highly stable for a wide temperature range of -190°C to 660° C. It has $\alpha = 0.0039/°$ C. It is available in pure form and is relatively unaffected by environmental conditions.

Platinium is used for precision thermometer and has a resolution of $\pm$ 0.0001°C.

RTD Construction : Resistance thermometers can be in the form of wire resistors or thin film – resistor. In wire type, RTD consists of a coil wound on a mica or ceramic former, which gives support to the coil. Such coils are available in different sizes and having resistor values ranging from 10 Ω to 25 K Ω . The actual construction depends on speed of response, environmental condition, and ability to withstand vibrations. The wire is wound in the form of a coil to achieve small size and improved thermal conductivity which also reduces the response time. The coil is protected by a protecting insulating tube made up of silica. Thus RTD is simply a length of wire whose resistance is to be monitored as a function of temperature.

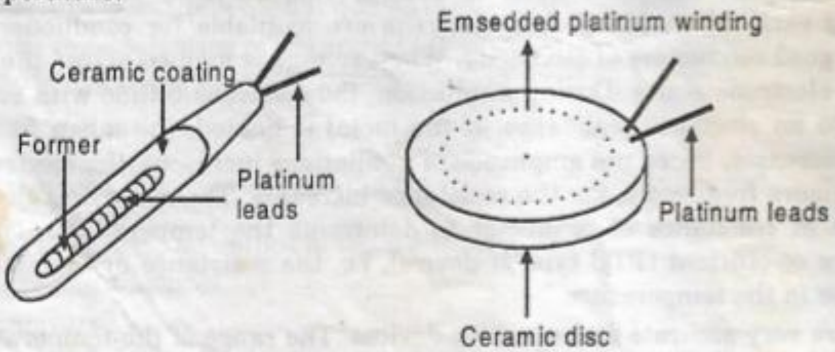


Figure 2.4 Platinum RTD construction

The RTD circuit- change in the resistance has to be converted into voltage or current for the purpose of measurement and control. The electrical power dissipated in the RTD must be limited to avoid errors due to I^2 R heating of sensor. The simplest circuit shown in figure 2.5 (a) uses a constant current source to convert the resistance change to voltage change. The output can be further amplified by an amplifier.

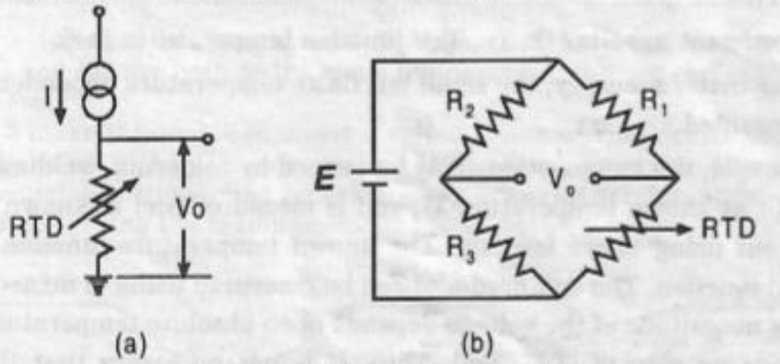


Figure 2.5 Electronic circuit for RTD

The circuit shown in fig. 2.5 (b) makes use of wheatstone's bridge in which one of the arm of the bridge uses RTD. Output produced is available as bridge output voltage proportional to change in RTD resistance and hence the temperature.

Thermocouple:

It is the most widely used temperature transducer. *It is a primary, active temperature transducer, converting the temperature change into emf.* Thus it converts thermal energy into electrical energy.

The principle of the thermocouple can be explained by considering the electrical and thermal transport properties of different metals. Thermocouple works on Seeback effect. If two different metals A and B are used to form the closed loop with the connecting junctions at temperatures T_1 and T_2, an emf is produced in the circuit which causes the current to flow. The current depends on the metals and the temperatures T_1 and T_2.

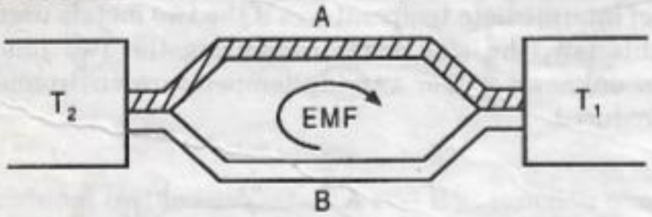


Figure 2.6 Seeback effect

The emf produced is proportional to the difference between two junction temperatures and is given by,

$$e = \int_{T_1}^{T_2} (Q_A - Q_B)\, dT \quad \text{.......... (2.7)}$$

where e = emf produced, T_1, T_2 = Junction temperatures in ^{0}K, Q_A & Q_B = Thermal transport constants of the two metals.

Thus, if the metals are same, the emf is zero. Also, if the temperatures are same, the emf is zero.

It is found that the two constants Q_A and Q_B are nearly independent of temperature and therefore a linear relationship exists.

$$e = \alpha (T_2 - T_1) \quad \text{.......... (2.8)}$$

where α = constant in volts / ^{0}k, T_1, T_2 = junction temperatures in ^{0}k.

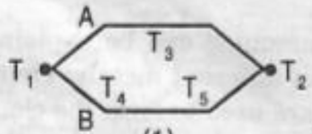
However, for better accuracy, the small but finite temperature dependence of Q_A and Q_B needs to be accounted.

In thermocouple, the two junctions may be formed by soldering, welding or brazing. One junction is kept at known temperature T_R, emf is measured and unknown temperature T_m can be found out using above formula. The known temperature junction is called as the reference / cold junction. The emf produced can be measured using a measuring instrument e.g. DMM. The magnitude of the voltage depends upon absolute temperature difference and polarity depends on sign of (T_R - T_m). Thus, it is not necessary that the measurement junction should have higher temperature than the reference junction. Sign and magnitude of the measured voltage must be noted in the measurement.

Laws of Thermocouple:

When the measuring instrument is introduced in the thermocouple circuit, two more junctions are formed in the circuit. It's effect and other important consideration in the practical application of thermocouples are defined by the following laws :

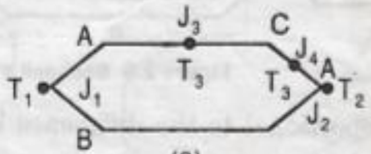
1.



(1)

The emf produced depends only on the temperatures of the two junctions and is independent of intermediate temperatures if the two metals used are homogeneous. Because of this law, the lead wires connecting the two junctions may be safely exposed to an unknown and/or varying temperature environment without affecting the voltage produced.

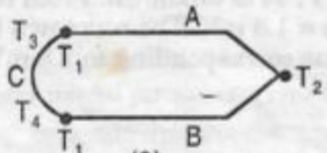
2.



(2)

If a third homogeneous metal C is inserted into either A or B, as long as the two new junctions J_3 , J_4 are at same temperature , the net emf is unaffected by introduction of metal C.

3.

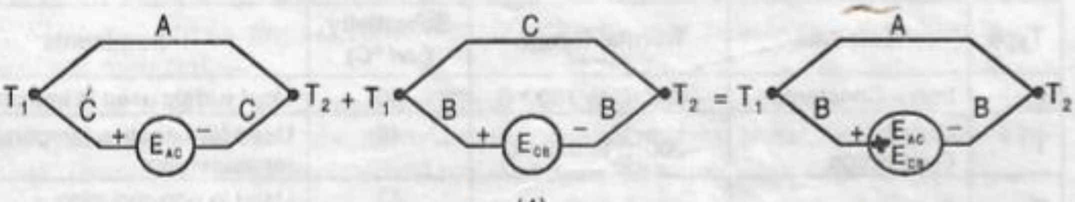


(3)

If metal C is inserted between A and B at one of the junctions, as long as the junctions AC and BC are both at the same temperature, the net emf is the same as if C was not there.

Laws 2 and 3 make it possible to insert a voltage – measuring device into the circuit to measure the emf. Metal C may represent the multimeter probe. Law 3 also shows that thermocouple junctions may be soldered or brazed (thereby introducing a third metal) without affecting the readings.

4.

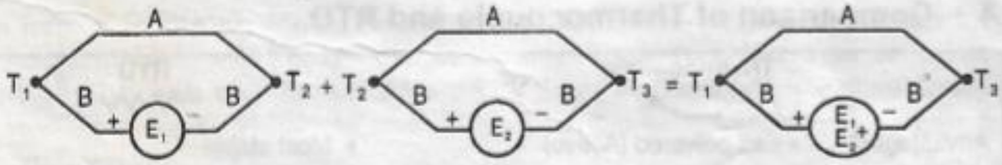


(4)

If the Seeback emf produced by the metals A and C at junction temperatures T_1 and T_2 is E_{AC} and that of metals B and C at junction temperatures T_1 and T_2 is E_{CB} , then the emf produced by metals A and B is $E_{AC} + E_{CB}$.

It shows that all possible pairs of metals need not be calibrated, metals can be paired with one standard and calibrated. Normally platinum is used as a standard. Any other combinations can then be calculated, e.g. from Copper – Platinum and Platinum – Aluminium chart, Copper – Aluminum resistance temperature relation can be found out.

5. **Law of intermediate temperature**



(5)

If Seeback emf produced by the two metals A and B at junction temperatures T_1 and T_2 is E_1 and that at junction temperatures T_2 and T_3 is E_2, then the emf of the thermocouple made up of A and B, having junction temperatures T_1 and T_3 is $E_1 + E_2$. This law is useful when the reference junction is not at 32°F. The caliberation tables are obtained by maintaining the reference junction at 32° F, varying the measured junction over the desired range of temperatures, and recording the resulting voltages. When a thermocouple is used, the reference junction may or may not be at 32° F. If it is, the caliberation table may be used directly to find the measuring –junction temperature. If it is not, the fifth law is used to calculate the desired temperature. Let the reference junction temperature be 45°F and the emf measured be 1.00 mV, then T_1 = 45°F, T_2 = 32°F, T_3 is unknown. From caliberation chart, let E_1 = 0.8 mV, E_2 = 1.00 mV; then $E_1 + E_2$ = 1.8 mV. The unknown temperature can be found by looking up the temperature value corresponding to 1.8 mV in the caliberation chart.

Thermocouple types

Several combinations of dissimilar metals can make good thermocouples for industrial use. The thermocouples along with having linear response and high sensitivity should be physically strong to withstand high temperatures, rapid temperature changes and the effect of corrosive and reducing atmosphere. Certain standard configurations of thermocouples using specific metals are given letter designations, as shown in Table 2.1. Each type has its particular features, such as range, linearity, inertness to hostile environment, sensitivity, and so on, and is chosen accordingly for specific applications.

Type	Materials	Normal Range	Sensitivity (µv/ °C)	Comments
J	Iron – Constanton	–190° C to 760 ° C	50	Most widely used in industry
T	Copper – Constanton	–200°C to 370 ° C	46	Used for negative temperature measurement
K	Chromel – alumel	–190° C to 1260 ° C	42	Used in non-reducing atmosphere.
E	Chromel – Constanta	–100°C to 1260 ° C	68	Highest sensitivity
S	90% Platinum + 10% rhodium platinum	0°C to 1500 ° C	6	Lowest sensitivity, useful for high temperature measurement
R	87% Platinum + 13% rhodium platinum	0°C to 1500 ° C	6	

TABLE 2.1 Standard Thermocouples

2.6.4 Comparison of Thermocouple and RTD

	Thermocouple	RTD
Advantages	• Self powered (Active) • Simple • Rugged • Inexpensive • Wide variety • Wide temperature range	• Most stable • Most accurate • More linear than the thermocouple
Disadvantages	• Non – linear • Low output voltage • Reference required • Less stable • Characteristic	• Expensive • Current source required • Small resistance change • Self – heating problem

Strain Gauge:

These are passive types of transducers useful for measurement of strain.

The measurement of strain is very common in process control industry. Many times strain gauges are used as *secondary transducers* along with the primary mechanical transducer to measure many other process variables like force, pressure, weight, acceleration etc.

Strain gauges can be classified as mechanical, optical, or electrical depending upon the principle of operation and their construction.

When force is applied to the material its dimension changes. In *Mechanical strain gauge*, the change in length Δl is magnified mechanically using levers or gears. In *Optical strain gauge* the magnification of Δl is achieved with multiple reflectors using lenses, mirrors or prisms. In *Electrical strain gauge*, change in length changes resistance, capacitance or inductance of the material.

Of these, the electrical strain gauges and that too the electrical resistance type gauges, are the most popular because of the many advantages offered by them, in the process of measurement. Therefore, here the electrical resistance strain gauges are explained.

2.7.1 Theory of operation of Resistance strain gauges

When some force is applied to a material, the dimension of the material changes. The applied force per unit area is called *stress* and the resulting deformation is called *strain*.

Let us consider a conductor of length l_o and cross – sectional area A_o. The resistance of the conductor is $R_o = \rho \frac{l_o}{A_o}$ .... (2.9)

Where ρ = specific resistance of the conductor in Ω . m .

l_o = length of the conductor in m.

Ao = Area of the conductor in m^2.

If tensile force F is (compressional force) applied, the conductor length changes by Δl. Let the new length be $l = lo + \Delta l$ (or $l_o - \Delta l$). At the same time, area decreases or increases by an amount ΔA. Let new area be $A = Ao - \Delta A$. Volume of the conductor should remain constant.

$V = loAo = (lo + \Delta l)(Ao - \Delta A)$ .... (2.10)

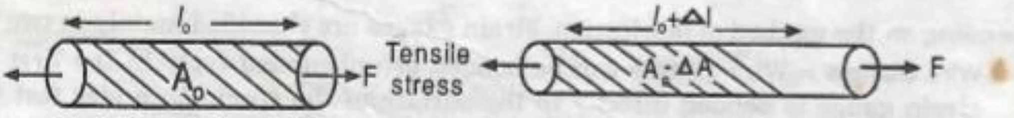


Figure 2.7 (a) Tensile stress applied to a rod

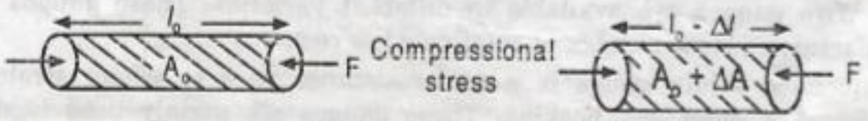


Figure 2.7 (b) Compressional stress applied to a rod

Because both length and area have changed, the resistance of the conductor changes to R.

$$R = \rho \frac{lo + \Delta l}{Ao - \Delta A} \quad \text{......} (2.11)$$

From equation 2.10 $Ao - \Delta A = \frac{loAo}{lo+\Delta l}$ .... (2.12)

$\therefore$ Equation 2.11 becomes,

$$R = \rho \frac{(lo + \Delta l)^2}{loAo}$$

$$R = \rho \frac{lo^2 + 2lo\Delta l + \Delta l^2}{loAo} \quad \text{.......... (2.13)}$$

The change in length Δl being small, Δl^2 can be neglected and

$$R \simeq \rho \frac{lo}{Ao} + 2\rho \frac{\Delta l}{Ao}$$

$$\rho \frac{lo}{Ao} \left(1 + 2\frac{\Delta l}{lo}\right)$$

$$\boxed{R \simeq Ro\left(1 + 2\frac{\Delta l}{lo}\right)} \quad \text{.......... (2.14)}$$

Therefore change in the resistance ΔR is given by

$$\Delta R \simeq 2R_o \frac{\Delta l}{l_o} \quad \text{.......... (2.15)}$$

The equation shows that, *the strain converts itself directly into a resistance change.* If one measures the new resistance R and if original dimensions of the conductor are known, strain can be found out.

The sensitivity of a strain gauge is given by a characteristic called the *gauge factor*, k, defined as the unit change in resistance per unit change in length.

$$\text{Gauge factor, } k = \frac{\Delta R/Ro}{\Delta l/lo} \quad \text{.......... (2.16)}$$

Other basic characteristics of the strain gauge are, gauge length gauge width, range of measurement, accuracy, the ambient environmental conditions it can withstand, etc. The maximum measurable strain and the achievable accuracy depends upon the type of gauge.

2.7.2 Types of electrical resistance strain gauges

Depending on the method of fabrication, strain gauges are classified mainly in two types –

1. **Wire Gauges** – Wire gauges can be bonded or unbounded type. In the first type, the strain gauge is bonded directly to the surface of the specimen under test by a thin layer of adhesive cement. It transmits the strain from the specimen to the gauge wire. Wire gauges are available in different varieties. These gauges are easy to manufacture in large number at relatively low cost.

   An unbonded strain gauge is a free resistance wire to whom strain is directly transferred without any backing. These gauges are mainly used in displacement transducers, pressure transducers, and accelerometers.

2. **Foil Gauges** – Here, instead of wire, very thin foil of the material is used. Because of foils, it has larger surface area and therefore has higher heat dissipation capability, which makes the gauges thermally stable. It has greater life. Using thick film and thin film technology, any type of complex pattern of any small size can be fabricated easily. It is useful for shear measurement and in Rosettes for two-dimensional stress analysis.

Semiconductor Strain Gauges

Nowadays, semiconductor gauges are becoming popular because of higher strain sensitivity. In the metal strain gauges, by the application of force, the dimension changes, with a very small change in the resistivity, while in semiconductor strain gauges, mainly the resistivity of the semiconductor material changes by the application of the force. The change in resistance is 40 to 100 times more than that of the conventional metal type. It's chemical inertness, low hysterisis, good fatigue life are the other advantages.

2.7.3 Temperature compensation of Strain Gauges

Basically, the element whose strain is to be measured is attached to a metal wire or foil. As stress is applied, the element deforms, the material experiences the same deformation due to which its resistance changes. The strain gauge material has some temperature coefficient. In industry, the temperature where the measurement is carried out is likely to be changed. The resistance change of a gauge is due to change in strain and change in temperature. Thus for any gauge,

$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_E + \left(\frac{\Delta R}{R}\right)_T \qquad (2.17)$$

where the subscripts E and T indicates the changes due to strain and temperature respectively. One has to compensate the effect of temperature change for accurate measurement of strain. The signal conditioning circuit can do this job. Normally, Wheatstone's bridge is used as a signal conditioner. In one arm of the bridge active strain gauge is connected and in one arm the dummy strain gauge having the same temperature co-efficient is connected and is exposed to the same temperature variation as that of the active strain gauge. Both gauge resistances change with temperature, by the same amount. Hence, the detector does not respond to this resistance – change. The gauge responds to only strain effects, which is detected by Wheatstone's bridge.

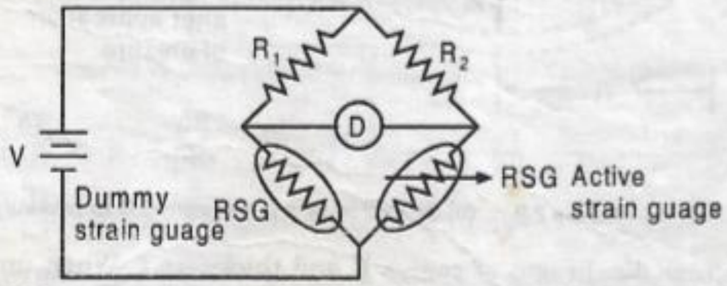


Figure 2.8 Temperature Compensation of strain gauge using Wheatstone's bridge

Pressure Transducer:

Pressure is another important process variable, which is frequently required to be monitored or controlled in process control industry. It is defined as the force acting per unit area, measured at a given point or over a surface.

Pressure transducers can be classified into *gravitational and elastic type*. In gravitational type, the manometer is the simplest device. In elastic transducers, pressure is first converted into physical displacement or strain and then it is converted into a proportional electrical signal. Many pressure sensors e.g. diaphragm, capsule, bellow, etc. are available, converting the pressure to strain. Also there are many electrical pressure transducers based on the principle of variable resistance, capacitance and inductance for converting the strain into electrical signal.

Most widely used pressure sensitive primary transducer is the elastic element. The thin plate diaphragm along with strain gauges, (acting as the secondary transducers) is used for pressure measurement. It is simple and has good dynamic response. Thin plate diaphragm is a thin circular plate stretched and fixed at its periphery. It is made up of metal alloys such as bronze, phosphor bronz, stainless steel etc. The thickness of the plate and its size depends on the range of pressure to be measured.

The arrangement to measure the pressure is shown in Figure 2.9 (a).The strain gauges are directly fixed on the diaphragm. The strain gauges may be bonded or unbonded type.

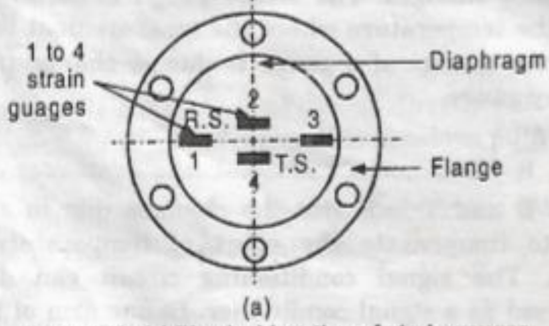


Figure 2.9 (a) Physical location of strain gauges.

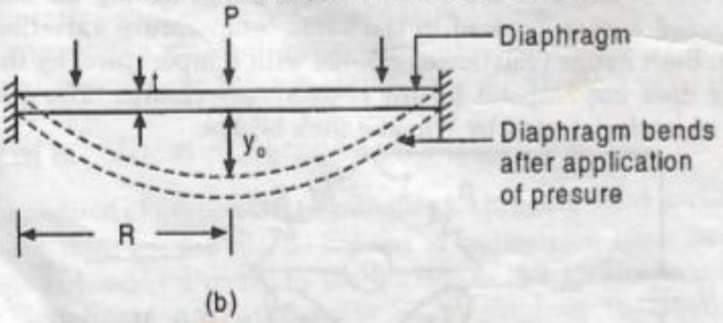


Figure 2.9 (b) Deflection in a diaphragm due to pressure

Consider a circular diaphragm of radius R and thickness t. When uniform pressure is applied on the diaphragm, it deflects as shown in Figure 2.9 (b). The diaphragm is clamped on the periphery. Therefore, the deflection 'y' is zero at the periphery and equal to y_o at the centre. The equivalent stress at the edge of the diaphragm is more than that at the centre. There are two types of stresses developed in the diaphragm – the radial and the tangential stress, σ_r and σ_t respectively.

The radial and tangential stress at the edge is $\sigma_r = \frac{3P}{4}\frac{R^2}{t^2}$ and $\sigma_t = \upsilon\,\sigma_r$ .... (2.18)

The radial strain = $\frac{\text{Radial stress}}{E} = \frac{3}{4}\frac{P}{E}\frac{R^2}{t^2}$ .... (2.19)

At the centre of the diaphragm, the stresses are

$\sigma_r = \sigma_t = \frac{-3}{8} P \frac{R^2}{t^2} [1+\upsilon]$ .... (2.20)

Tensile strain = compressional strain = $\frac{-3}{8}\frac{P}{E}\frac{R^2}{t^2} [1+\upsilon]$ .... (2.21)

where E = Young's Modulus of the material of the diaphragm.

υ = Poisson's ratio of the material of the diaphragm.

For small deflections, the stresses in the diaphragm are linearly proportional to the deflection. For very thick diaphragms $\left(\frac{R}{t} \simeq 10\right)$, the calibration would be linear. For very thin diaphragm $\left(\frac{R}{t} \simeq 100\right)$, the maximum pressure for linear operation is limited. Since both tensile and compressive stresses exist on the surface of the diaphragm, normally four strain gauges are used. Gauges 1 and 3 are mounted near the periphery. These gauges respond to radial strain to measure two types of strains. Gauges 2 and 4 are located near the centre respond to tensile strain. The four strain gauges form the four arms of the Wheatstone's bridge, which has high sensitivity and good temperature stability.

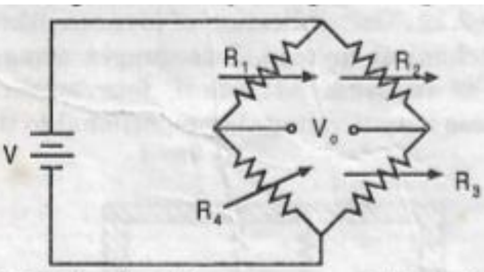


Figure 2.10 Bridge circuit for measurement of 4 strain gauges

$$Vo = \frac{a}{(1+a)^2}\left[\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right]V \quad \text{.......... (2.22)}$$

where $a = \frac{R_1}{R_2} = \frac{R_4}{R_3}$, $\Delta R_1, \Delta R_2, \Delta R_3, \Delta R_4$ are the changes in the resistor values.

To know the value of unknown pressure, the bridge is balanced initially. The bridge is said to be balanced when the output voltage is zero. Condition for the balancing of bridge is $R_1R_3 = R_4R_2$. When pressure is zero i.e. strain produced is zero, output voltage is zero. When pressure is applied to the diaphragm strain is produced because of which the resistances of four gauges change. By measuring the output voltage, one can find the unknown pressure. It is assumed that no other pressure is acting on the diaphragm other than the applied pressure.

The advantage of thin plate diaphragm is that it can be used for dynamic pressure measurements having frequency upto 10 kHz.

Another method for pressure measurement uses *Double Cantilever beam*. In this method, Cantilever beam is mechanically connected to the diaphragm by a rigid pin as shown in figure 2.11 (a). Four strain gauges are bonded near the beam. These strain gauges are thermally matched with each other to have good temperature stability. The pressure applied to the beam is measured in the same way as described above. The main advantages of this design are its rigidness, good linearity and wide range.

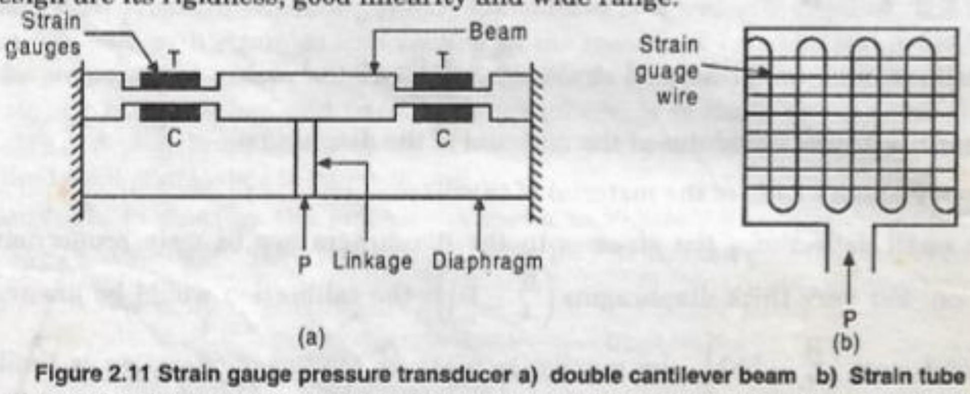


Figure 2.11 Strain gauge pressure transducer a) double cantilever beam b) Strain tube

Instead of a Cantilever deflection system, the pressure measurement can be achieved by *a strain tube*. Here the gauges are bonded on the surface of the cylinder as shown in Figure 2.11 (b).

In the case of unbonded gauge type, four bare strain gauge wires are stretched to a known initial tension and are mounted by linking the pressure sensing diaphragm and the case, as shown in Figure 2.12. On application of pressure, the elastic element displaces the armature through a mechanical linkage. Two gauges elongate while the tension in the remaining two gauges is reduced. As before, four strain gauges form four arms of Wheatstone's bridge, whose output voltage is proportional to the applied pressure.

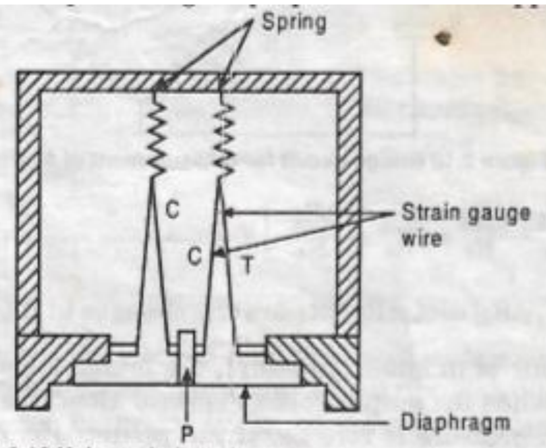


Fig. 2.12 Unbounded strain gauge pressure transducer

Force Transducer:

One important application of strain gauge is for the measurement of force or weight. These transducers are called as *Load Cells*. These basically measure deformation produced by weight or force. It is capable of measuring static or dynamic force. Through a careful choice of the material and structure, a linear relationship can be obtained between the force and the deformation i.e. strain. The materials selected should have following properties:

a) Linear stress to strain relationship upto a fairly large strain limit.

b) Low strain hysterisis over repeated loading.

Along with these, material properties such as modulus of elasticity and its variation with temperature, maximum strength, ease of fabrication needs to be considered.

There are three types of configurations of load cell:

a) Column type

b) Proving Ring type

c) Cantilever beam type

Let us study column type load cell in detail.

2.9.1 Column – Type Load Cell

To measure unidirectional force of column or rod, the simple method is by using strain gauges as shown in Figure 2.13. It is necessary that force applied to the load cell should be uniformly spread over the area of the load cell. It is also essential that there is no other force working on the column of the load cell other than the force under measurement.

In column type, the cylinder column of diameter 7cm to 30 cm and length 10 cm to 60cm is used. Cells of these dimensions measure weight and force ranging from 0.5 N to 10^4 N.

When force F is applied to the load cell, the surface of the column undergoes compressional strain along with the axis of force applied and tensile strain along with its circumference. The strains produced are measured by the four resistor type strain gauges. Out of these four, two strain gauges are fixed on the opposite sides to measure axial strains and other two for circumferential strains. The strain values can be expressed as,

$$\text{The compressional strain} = \frac{\sigma}{E} = \frac{F}{AE} \quad \text{......} (2.23)$$

$$\text{The tensile strain} = \frac{-\upsilon F}{AE} \quad \text{......} (2.24)$$

where σ is the stress developed in the column.
F is the axial force.
A is the cross – sectional area of the column.
E is the modulus of elasticity.
υ is the Poisson's ratio of the material of the rod.

The strain measurement is done with a standard four arm active Wheatstone's bridge as shown in Figure 2.10. If V is the excitation voltage applied, the output voltage Vo = 0.65 VGE, where G is the gauge factor of the strain gauges used.

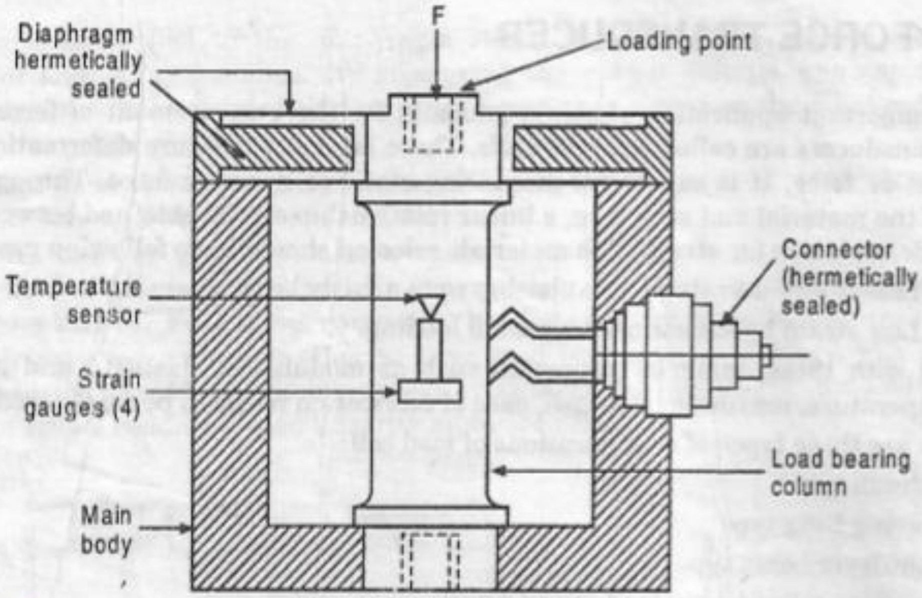


Fig. 2.13 Column type load cell

Optical Transducer:

Transducers based on the effect of physical radiation or electro-magnetic radiation of material are used frequently in instrumentation. EM radiation is a form of energy that is always in motion. It propagates through a vacuum at a speed independent of both the wavelength and frequency and is 3×10^8 m/s. The velocity is $C = \lambda f$ where λ = wavelength in meters, f = frequency in hertz.

EM radiation spectrum as shown in Figure 2.14 covers everything from very low frequency radio to x – rays and beyond that. In process – control instrumentation, spectrum concerned with the range of λ belonging to visible 400 nm and 760 nm and IR range (760 nm to 1000 nm) is of great importance. A transducer which measures radiation in the range from IR to visible and sometimes uV band is called photodetector. A transducer which measures radiation in RF range is called RF – detector.

Photodetectors use photoelectric effect which states that, when certain wavelength of light is incident on the atom, an electron is emitted and number of electrons increases if the wavelength of light decreases. Depending on how material reacts, devices are classified as

1. **Photoemissive** - These include vacuum type photocell, gas filled type photocell and photo multiplier tube.
2. **Photoconductive** - One of the most common photodectors is based on the change in conductivity of a semiconductor material with radiation intensity.
3. **Photovoltaic detectors** - An important class of photodetectors generates a voltage that is proportional to incident EM radiation intensity.

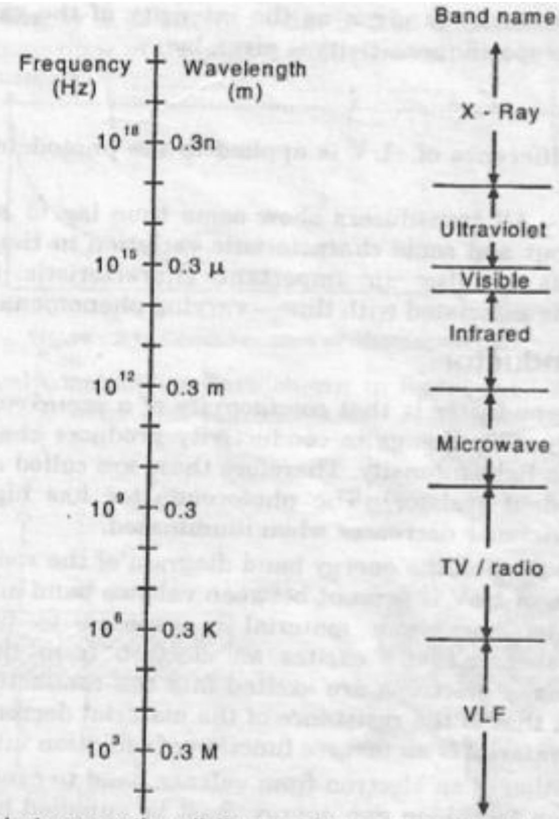


Fig. 2.14 The electromagnetic radiation spectrum covers everything from very low frequency (VLF) radio to x – rays and beyond.

2.10.1 Characteristics

Important characteristics of photodetector are:

1) **Spectral response** – The range of radiation, λ or frequency, to which the photodectors respond to, is defined by *spectral response*. Spectral response curve is different for different materials. In most cases, the response is flat within some allowed deviation within this band of radiation.

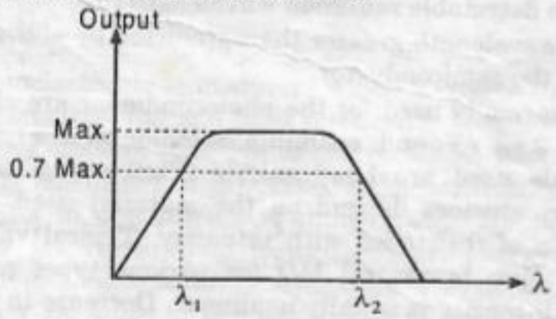


Fig. 2.15 Spectral response of photodetector

2) **Sensitivity** – *Sensitivity* is given as the intensity of the radiation at a particular wavelength λ. The specific sensitivity is given by

$$S_{\text{specific}} = \frac{\Delta I}{\Delta F} \quad \ldots\ldots (2.25)$$

when potential difference of 1 V is applied to the photodetector. It is expressed in μA/ lm.

3) **Time constant** – All transducers show some time lag to set the output after the application of input and some characteristic variation in time before settling on the final value. This is also an important characteristic because much of the instrumentation is associated with time – varying phenomena.

2.10.2 Photoconductor

Principle of a photoconductor is that *conductivity of a semiconductor material changes with radiation intensity.* The change in conductivity produces change in resistance. Thus resistor is dependent on light intensity. Therefore these are called as *photo resistive devices* or **LDR** (Light dependent resistor). The photoconductor has high resistance when not illuminated and the resistance decreases when illuminated.

Last year, you have studied the energy band diagram of the semiconductor. A forbidden energy gap of the order of 1 eV is present between valence band and conduction band. In a semiconductor photo-detector when material is exposed to light or electromagnetic radiation, photon is absorbed and excites an electron from the valence band to the conduction band. As many electrons are excited into the conduction band, conductivity of the material increases, that is the resistance of the material decreases. Thus the resistance of the semiconductor material is an inverse function of radiation intensity.

Note that for transition of an electron from valence band to conduction band, the energy equal to or greater than forbidden gap energy must be supplied by the incident light. The wavelength of the light required can be calculated using the formula,

$$E_g = \frac{hc}{\lambda max} \quad \text{.........} \quad (2.26)$$

$$\therefore \lambda max = \frac{hc}{E_g} \quad \text{.........} \quad (2.27)$$

where h = Planck's constant 6.63×10^{-34} J -S.

E_g = semiconductor energy gap (J)

λ_{Max} = maximum detectable radiation wavelength (m)

Any radiation with a wavelength greater than predicted by above equation cannot cause any resistance change in the semiconductor.

The semiconductors normally used for the photoconductor are cadmium sulphide (CdS) having a band gap of 2.42 eV and cadmium selenide (CdSe) having a band gap of 1.74 eV. Other materials used are Lead sulfide (PbS) and Lead selenide (PbSe. The characteristics of photoconductors depend on the material used. The graph or chart is provided giving variation of resistance with intensity. Typical values of dark resistance vary from hundreds of ohm to several MΩ for various types of photoconductors. The variation with radiation intensity is usually nonlinear. Decrease in resistance values as the increase in radiation intensity is as shown in figure 2.16. The resistance variation depends on the material used, dimensions of the photoconductive cell and its geometrical

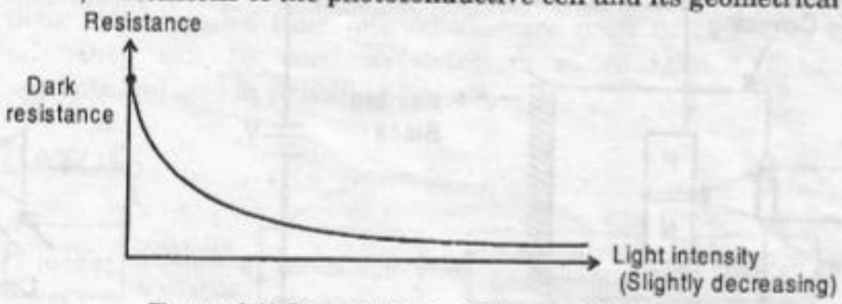


Figure : 2.16 Characteristics of Photoconductor

configuration. Two typical constructions are shown in figure 2.17 Folded photoconductive cell provides larger surface area and minimizes the resistance. Therefore it is usually preferred.

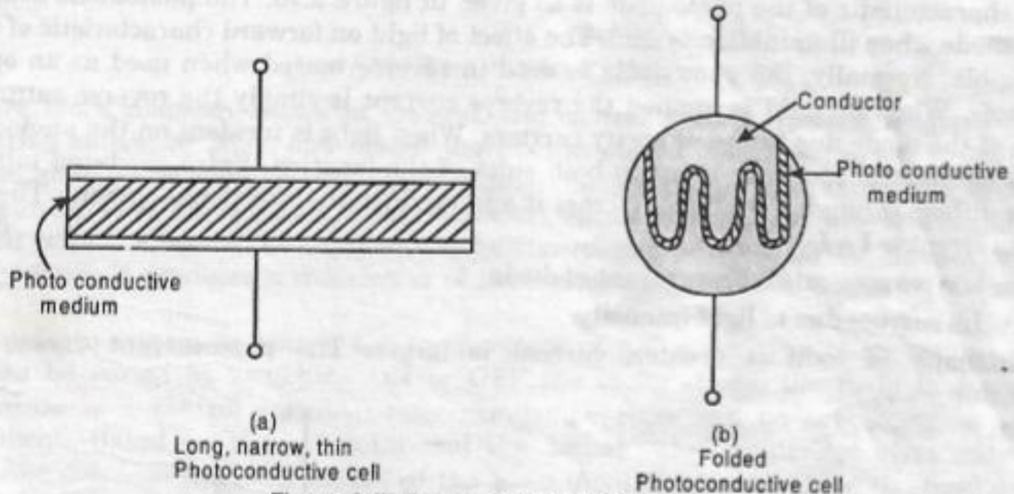


Figure: 2.17 Photoconductive Cell Structure

The main disadvantage is that the resistance of the material changes even with the temperature. Therefore it is necessary either to operate the device at a controlled temperature or to make the gap too large for thermal effects to produce conduction electrons.

2.10.3 Photodiode

Photodiode is an optoelectronic transducer, which *converts light energy into electrical energy*. Photodiodes are small in size and their response is fast.

The pn junction of any diode is sensitive to EM radiation that strikes the junction. The photodiodes are specially fabricated. It is covered in transparent plastic covering as shown in figure 2.18. Light falls on one surface of the covering. Normally the junction is very small. Therefore lenses are required to focus the light energy on the junction. While fabricating the photodiode. The capacitance associated with depletion region is made small to increase the frequency response of the diode. The other side of the plastic covering is painted black. The photodiodes available in the market has a diameter of 0.5 mm.

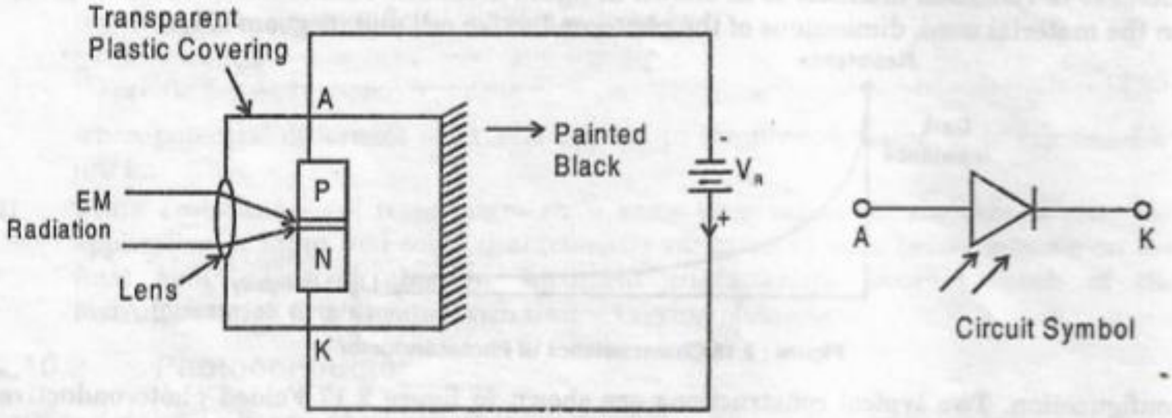


Figure: 2.18 Photodiode

The characteristic of the photodiode is as given in figure 2.19. The photodiode acts as a normal diode when illumination is zero. The effect of light on forward characteristic of diode is negligible. Normally, the photodiode is used in reverse biased when used as an optical transducer. When no light is applied the reverse current is simply the reverse saturation current of the diode due to the minority carriers. When light is incident on the photodiode, photons create electron -hole pairs on both sides of the junction. Extra produced minority carriers diffuse through the junction, cross it and produce the additional current. The total reverse current is $I = I_0 + I_\lambda$ ....(2.28) where I_0 = reverse saturation current of diode

I_λ = current due to light intensity.

If intensity of light is greater, current is larger. The photocurrent versus light relationship

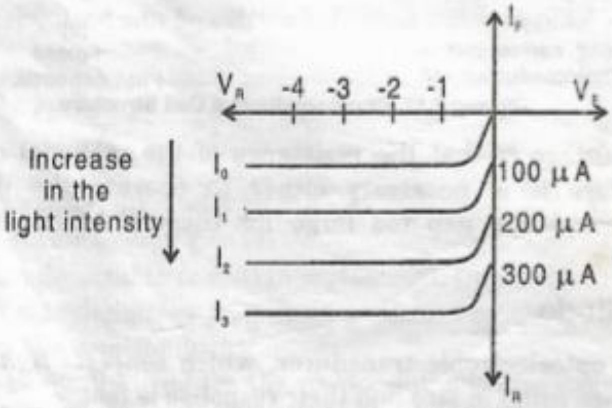


Figure: 2.19 Characteristics of Photodiode

is linear over a wide range. In order to maintain the linearity the bias voltage should be kept constant.

Comparing photodiodes with photoconductors, *the photodiode possesses considerably better frequency response, linearity, spectral response and lower noise.* The disadvantages of photodiodes include small active area, rapid increase in dark current with temperature bias voltage requirement, and the necessity of amplification at low illumination level.

Because of their fast response time, photodiodes are used as cine film sound track readers. Similarly they can be used as detectors of modulated light in optical communication systems and also in switching circuits.

Actuator:

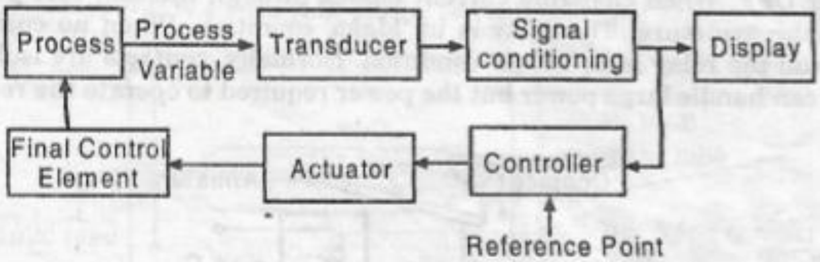


Figure 2.20 Block diagram of process – control

Above block diagram shows in general, the control system. Controller gives output considering reference point and actual process variable. This output when given to an *actuator*, actuates or operates a mechanism that changes the process value. The operation of actuator involves the steps necessary to convert the control signal in the form required by the final control element. In many cases the control signal is converted into an entirely different form. It produces a translation of the converted signal into action on the control element.

Consider a system to control the temperature of A/C room. The temperature of this room can be varied by switching ON or OFF the cooler. Here, the room is a process, temperature is a control variable, reference temperature can be set according to our requirement. Based on the set point and the actual value, controller gives output to increase or decrease the temperature of the room. Actually, the cooler is the final control element which actually changes the room temperature. To switch ON or OFF the cooler, relay is required. It is called as 'actuator', in this particular example.

In water – control or pressure control system a valve (final control element) is to be operated. The device that converts the control signal into physical action of opening or closing the valve, is actuator.

Depending on the mechanism used there are following types of actuators.

1. *Electrical:* - In the following a short description of common types of electrical actuators is given.
2. *Pneumatic:* - Translates a control signal into a large force or torque.
3. *Hydraulic:* - Used when very large force is required. It uses an incompressible fluid to provide the high pressure.

2.11.1 Relay

The switching action may be obtained as a result of the mechanical action of an actuator, electromechanically by a current in a solenoid or in a relay or by means of a solid state device.

Relay is basically an automatic switch operated under a control signal. It can make or break connection in electrical circuit. Electromechanical switch is more common. The basic principle of such a switch is that when coil of relay is energized or de-energised its contacts are set ON or OFF. When changing current passes through the coil, core gets magnetized and attracts the armature. The relay is in 'Make' condition. When no current is flowing through the coil the relay is in 'Break' condition. Normally, contacts are isolated from coil. The contacts can handle large power but the power required to operate the relay is small.

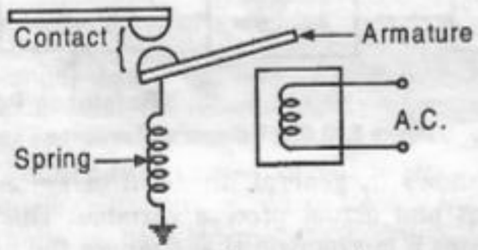


Fig. 2.21 General purpose relay

Relays are cheap, reliable and have long life. They are available in different shapes sizes and types. Different types are A.C. relays, telephone relay, polarised relay, stepping relay, differential relay, reed relay, etc.

Reed Relay – Reed type relays are used for high speed operation. Depending on the construction there are two types of reed relays.

i. Dry reed relay
ii. Ferrite reed relay

i. Dry reed relay – Two reeds/ rods of iron – nickel composition are sealed in a glass capsule, filled with inert gas. Normally, contacts are gold plated, gold being good conductor. The sealing also provides complete protection from atmospheric constituents.

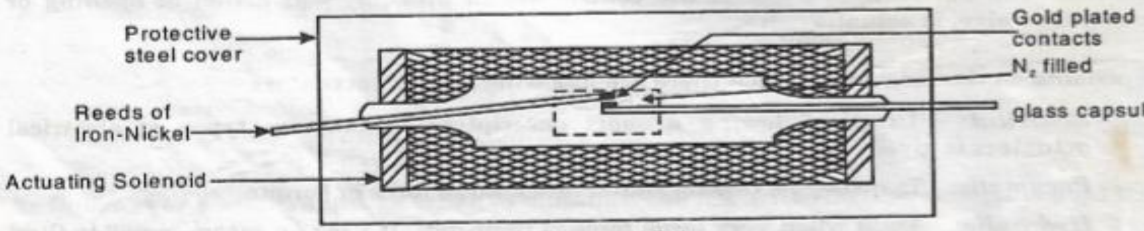


Fig. 2.22 Dry Reed Relay

In reed relay types the contacts like open, close or change over types are available. To operate the contacts, two solenoid coils are placed in glass tube of relays. If coils are connected in series and in same direction, then normally open contacts are operated. If coils are connected in opposite direction, then normally closed contacts are operated. Using three reeds in the glass tube a change over position is possible.

These relays can be used upto 500 mA in sophisticated instruments like microprocessor or computer. If one uses normal relay in such systems, the data will be lost by the time the relay operates. The speed of reed relay is high because mechanical arrangement of spring is avoided. Another advantage is that very weak magnetic field is required for operation of the relay.

iii. **Ferrite Reed Relay** – It is a reed relay using ferrite element.

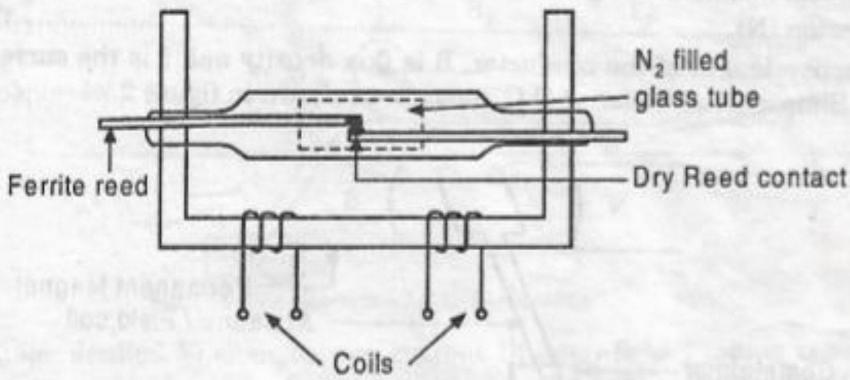


Figure 2.23 Ferrite Reed Relay

In case of ferrite reed relay, contacts can be operated by controlling pulses of current through two coils. If two coils are pulsed in series, the contacts are closed and relay is in 'Make' condition. Contacts are released when single coil is reverse pulsed. The permanent core magnetization provides automatic action. The relay is very fast – operating. A current pulse of very short duration, normally in µs or ns, is sufficient to operate the relay. These types of relays are used in modern telephone exchanges and in computers.