
UNIT 10 INTRODUCTION TO TRANSDUCERS AND SENSORS

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10.1 INTRODUCTION

Sensors can be broadly classified in two categories: discrete event and continuous. Discrete event, or on/off sensor, changes its state based on the occurrence of some external event. These sensors typically only give knowledge of two states based on the condition being sensed. They are based on mechanical, electrical or optical technology. Continuous sensors provide information over the continuous range of operation of the process and are commonly used in continuous control applications, where the process is being regulated based on continuously sensed attribute data. They are based on electrical, optical and acoustical technologies.

Objectives

After studying this unit, you should be able to

- describe different type of sensors and transducers, and
- understand the concepts of digital to analog conversion and vice-versa.

10.2 ACTIVE AND PASSIVE SENSORS

The sensors can be classified as active and passive. A passive sensor has no power supply and all the energy it delivers to the next stage (the signal conditioning) is drawn from the measurand. Passive sensors are also known as self-generating sensors. An active sensor is a modulator and can therefore deliver more energy to the next stage than it draws from the measurand. If the power supply is dc, the output is modulated by the measurand, and has the same frequency. If the supply is ac, the output is the carrier frequency with sidebands at \pm signal frequency.

10.3 BASIC REQUIREMENTS OF A SENSOR/TRANSDUCER

A transducer is normally designed to sense a specific measurand or to respond only to that particular measurand. A complete knowledge of the electrical and mechanical characteristics of the transducer is of great importance while choosing a transducer for a particular application. Often, it is deemed essential to get details of these characteristics during the selection of instrumentation for the experiment concerned. The basic requirements are :

- **Ruggedness**
Ability to withstand overloads, with safety stops for overload protection.
- **Linearity**
Ability to reproduce input-output characteristics symmetrically and linearly. Overall linearity is the main factor considered.
- **Repeatability**
Ability to reproduce the output signal exactly when the same measurand is applied repeatedly under same environmental conditions.
- **Convenient Instrumentation**
Sufficiently high analog output signal with high signal to noise ratio; digital output preferred in many cases.
- **High Stability and Reliability**
Minimum error in measurement, unaffected by temperature, vibrations and environmental variations.
- **Good Dynamic Response**
Output is faithful to input when taken as a function of time. This effect is analyzed as the frequency response.
- **Excellent Mechanical Characteristics**
This can affect the performance in static, quasi-static, and dynamic states. The major effects are :
 - (i) *Mechanical Hysteresis*
The dependence of the strain not only on the instantaneous value of the stress but also on the previous history of stress. Effect depends on the raw material used, aging, etc.
 - (ii) *Viscous Flow or Creep*
Effect due to viscous flow in the material of the sensing element. Magnitude increases with increasing load and temperature. Materials with low melting point show larger creep values.
 - (iii) *Elastic after Effect*
A continued deformation when the load is applied and kept constant. This effect decreases with time. Like creep, there is a similar relaxation towards the original position when the load is removed. Virtually no deformation is observed.

You will study more about these effects in Unit 2.
- **Built-in integrated device with noise, asymmetry, and other defects minimized.**

10.4 DISCRETE EVENT SENSORS

A discrete event (or on/off) sensor changes its state based on the occurrence of some external event. They may be contact type (for example, a limit switches) or non-contact type (for example, proximity switches and photoelectric sensors). These are being described in detail in this section.

10.4.1 Mechanical Limit Switches

Mechanical limit switches typically consist of a mounted actuator arm that operates a set of electrical contacts when the arm is displaced. Two examples are shown in Figure 10.1. Figure 10.1(a) illustrates the operation of a Lever-type limit switch and Figure 10.1(b) illustrates a plunger, or push-type, limit switch. In the case of the lever type, the actuator arm is a rod connected to a lever shaft, which is free to rotate when the rod is displaced. When the forces displacing the rod are removed, the lever shaft is returned to its normal position by a return spring. The lever shaft has a roller mounted on its bottom, which rotates a rocker as it changes position from right side to left side. This mechanical action operates one or more sets of contacts, which are mounted on the other side of the limit switch, as shown in the back view. The rocker shaft is connected through the housing to the contact lever assembly, the head of which moves a set of electrical contacts. The electrical contact may either be closed or open initially. The action of the actuator and lever arms takes it from its normal, or deactivated, state to the other state. Hence, a normally open limit switch will be closed when activated and a normally closed limit switch will be open when activated.

Figure 10.1(b) illustrates the more direct action of a push-type limit switch. It shows a set of contacts operated from the contact lever assembly. Contact set a-b is normally closed; set c-d is normally open. When the lever is depressed, each contact goes to its opposite state. When installed, the user wires the appropriate contact pair back to the controller, which distinguishes the state of the system by sensing the presence of voltage or current supplied through the contact.

Limit switches come in several varieties and designs; Figure 1.1 simply shows two concepts. They are designed for heavy-duty applications in which there is physical contact between the actuator and the process being sensed. For example, limit switches are often used on machine tools to limit the travel of a machine axis. They are sometimes used in materials handling applications, e.g. to indicate the passage of a part along a conveyor. They are typically designed to handle relatively high voltages, both AC and DC. This means they cannot be directly wired to the input port of a computer without having their signal converted to TTL level.

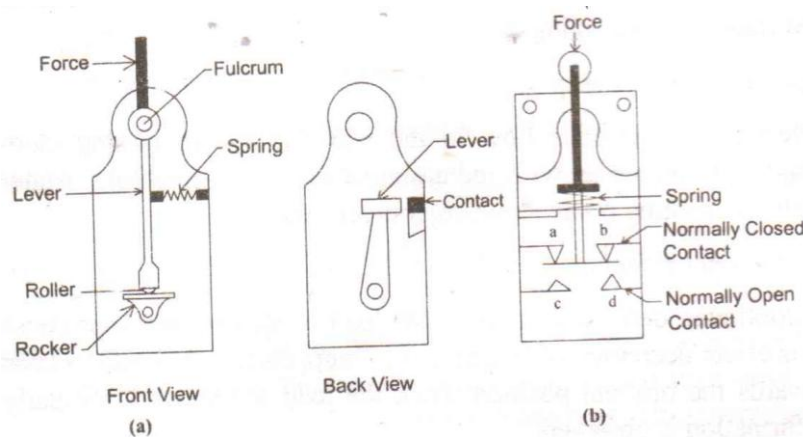


Figure 10.1 : Mechanical Limit Switches (a) Lever Type in Open Contact Position, (b) Push Type

10.4.2 Proximity Limit Switches

The term proximity switch (sometimes called proximity sensor) refers to a non-contact sensor that works on the principle of inducing changes in an electromagnetic field. The

proximity switches most commonly used in the manufacturing environment are the inductive proximity switch and the capacitive proximity switch.

Inductive proximity sensors are designed to operate by generating an electromagnetic field and detecting the eddy current losses generated when ferrous or non-ferrous metal target objects enter the field. The sensor consists of a coil on a ferrite core, an oscillator, a trigger-signal level detector and an output circuit. As a metal object advances into the field, eddy currents are introduced in the target. The result is a loss of energy and smaller amplitude of oscillation. The detector circuit then recognizes a specific change in amplitude and generates a signal, which will turn the output “ON” or “OFF”.

The active face of an inductive proximity switch is the surface where a high-frequency electromagnetic field emerges. A standard target is a mild steel, 1 mm thick, square form with side lengths equal to the diameter of the circle of the sensing surface, or 3 times the normal switching distance, if this is greater than the diameter of the sensing surface circle. The distance at which this approaching target activates (changes state of) the proximity output is called normal sensing distance. The size, shape and material affect the sensing distance in the following fashion:

- Rounded targets may reduce the sensing distance.
- Non-ferrous materials usually reduce the sensing distance.
- Targets smaller than the sensing face typically reduce the sensing distance.
- Targets larger than the sensing face may increase the sensing distance.

One of the shortcomings of the inductive proximity switch is that it can only sense metal objects. The capacitive proximity switch, on the other hand, can sense non-metallic objects as well. It uses a resistor/capacitor (RC) oscillator to generate a directed magnetic field. Introducing an object within the magnetic field causes a change in capacitance, which is detected by the control circuitry, which in turn operates an electronic switch that outputs a signal to the controller.

Proximity switches have relatively short ranges, typically from 1 to 60 mm; therefore, they must be used in situations where the target is allowed to come close to the sensor.

10.4.3 Photoelectric Sensors

Photoelectric sensors are non-contact devices that output a signal in response to the interruption of a light beam. The components of a photoelectric sensing system are shown in Figure 10.2. The two main components are the emitter and the receiver. The light source is a light emitting diode (LED). An LED is a solid state semiconductor that emits light when current flows through it. LEDs are manufactured to produce light in the visible range in the near infra-red range. The light source is paired with a receiver, which is light sensitive transistor, called a phototransistor. A transistor conducts when its base is forward biased. This is done by applying a small amount of current on the base lead. A phototransistor operates in the same fashion except that the base is biased by the energy from a light source incident on it. Phototransistors are manufactured to be sensitive to light within the spectrum of the emitter.

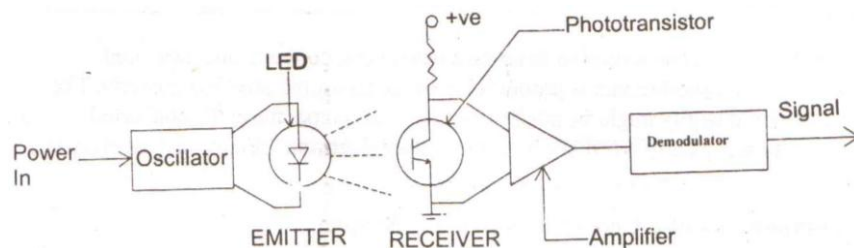


Figure 10.2 : A Photoelectric Sensor

A photoelectric sensor system comes with an oscillator that modulate, or pulses, the LED on and off at very high frequencies. The receiver is tuned to the same frequency, which allows it to differentiate between light from the emitter and ambient light.

10.4.4 Fluid Flow Switch

A discrete event sensor commonly used in process is the fluid flow switch. This device is analogous to a limit switch in mechanical systems. It is usually employed as a device to detect when a fluid travelling in a pipe is over a specified volumetric flow rate. Such a sensor can be used to govern the speed of an upstream pump, reducing it when the flow is too fast.

There are different implementations of a fluid switch. One implementation is shown in Figure 10.3. Here a float is placed in a trapped column that is in line with the fluid flow. A magnetic ring is seated on the float and, in the absence of pressure, the movable float is retained in the seated position. Water pressure raises the float proportional to the flow rate. A switch is positioned at a height where the float will be displaced when the triggering flow rate is reached. Typically the switch is a reed switch, which consists of two leaf springs sealed in a glass. These leaf springs come together when subjected to a magnetic field. This closes the circuit, providing an input signal to the controller.

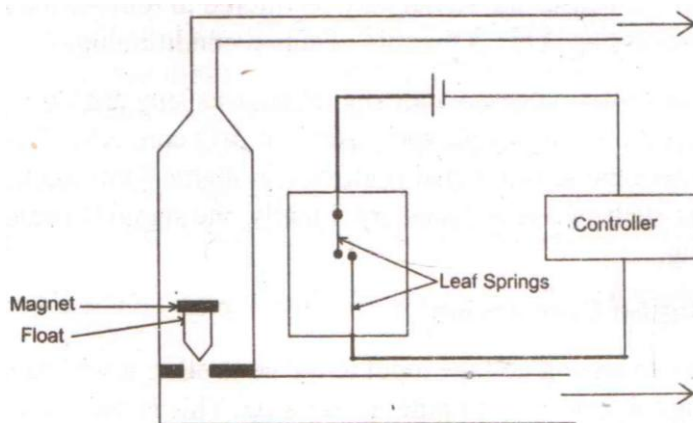


Figure 10.3 : A Flow Switch

SAQ 1

- What is the difference between active and passive sensors and continuous and discrete sensors?
- Briefly explain the principles of operation of limit switch, proximity switch and photoelectric sensors.

10.5 TRANSDUCERS

A useful way to classify transducers is on the basis of the physical property the device is intended to measure. The important properties discussed in this section are :

- Position
- Velocity
- Force or Pressure
- Temperature

10.5.1 Position Transducers

Position transducers are widely used in servomotors, linear position tables, and other applications where precise position is important. In this section we will discuss four analog position transducers (potentiometers, linear variable differential transformers, floats and resolvers) and two digital position transducers (the optical encoder and ultrasonic range sensor).

Potentiometers

An often-used position sensor is the potentiometer. The potentiometer is composed of a resistor and a contact slider that allows position to be made proportional to resistance. There are linear and rotary potentiometers depending on whether the displacement to be measured is linear or angular. An angular potentiometer is shown in Figure 10.4. Potentiometers are quite inexpensive, very rugged, and easy to use. However, they are not as accurate as some other position transducers.

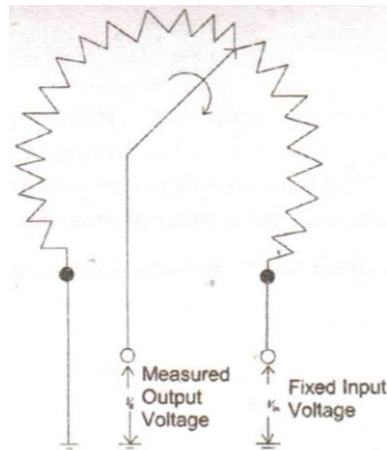


Figure 10.4 : A Rotary Potentiometer

Linear Variable Differential Transformers

The linear variable differential transformer (LVDT) is a high-resolution contact transducers. As Figure 10.5 illustrates, it is constructed with three coils, one primary and two secondary. A magnetic core sits within the coils.

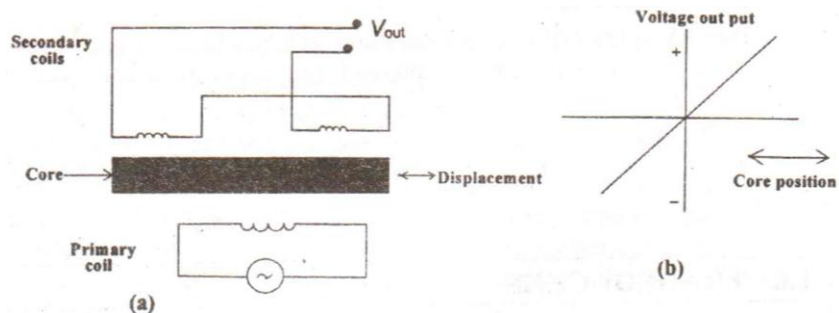


Figure 10.5 : Principle of a Linear Variable Differential Transformer (a) Operation of LVDT, (b) Core Displacement and Voltage Out

If an alternating current is imposed in the primary coil, a voltage will be induced across the secondary coil. The magnitude of that voltage is a linear function of the position of the magnetic core. Deviations from the null position of the core are translated into voltages by the equation :

$$\Delta V_o = K \Delta X \quad \dots (10.1)$$

where ΔV_o is the change in output voltage, K is a proportionality constant and ΔX is change in position.

LVDTs come in varying size. A typical limit to travel is in the range of 750 mm. The resolution of an LVDT is excellent, easily able to measure displacement below 0.25 mm. Since this is an analog devices, the limits of resolution are usually governed by the resolution of the A/D converter.

It is readily apparent that the LVDT has an advantage over the potentiometer as a position measurement device. Since its core does not touch the coil, there is no mechanical wear that would result in deterioration of performance over time. On the other hand, it is a more expensive transducer, justifiable primarily where very high and repeatable accuracy is required.

Resolvers

The resolver, shown in Figure 10.6, is a rotary transformer. The primary winding is on the rotor and the secondary windings on the stator. The secondary windings are set 90 degrees apart. An alternating current is imposed on the primary winding. As the shaft is rotated by the device where position is being monitored, the voltages on the secondary windings will vary as the sine and cosine of the angle of the rotor.

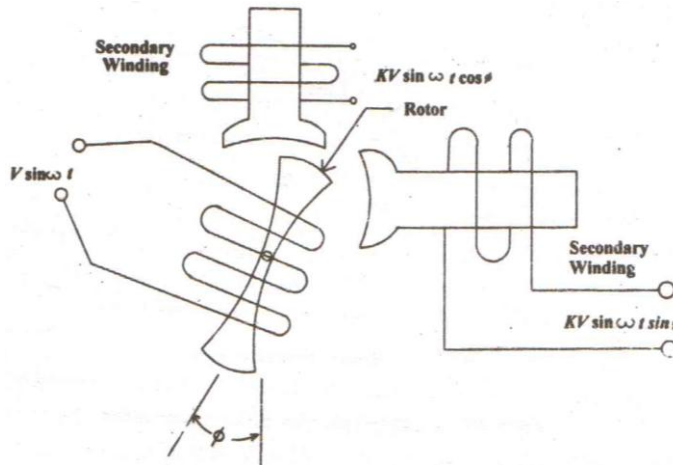


Figure 10.6 : A Resolver

The two output voltages can be converted to a binary count using a resolver-to-digital converter (RDC). This device combines the circuitry necessary to interpolate the output voltages into angular positions and the A/D circuitry required to digitize the result.

The resolver is a non-contact transducer. Unlike the rotary potentiometer, it will not lose accuracy due to wear. The high precision of the resolver is usually limited by the A/D converter, which converts the analog voltage into a digital count. Typical A/D converter incorporated in RDCs have 12- to 16-bit resolution.

Optical Encoders

An optical encoder is a digital position-measuring device. It is available in both linear and rotor construction. Figure 10.7 shows the principle of an optical encoder in rotary form. A slotted disc is rotated in between a photo emitter/detector pair. The emitter is typically a light-emitting diode and the detector is a photosensitive transistor. When light is incident on the base of the transistor, current flows from collector to emitter. As the disc rotates, the light will be alternatively blocked and allowed to pass. In the blocked state, the transistor will stop conducting. The voltage output from the detector circuit is a saw tooth. This is fed into a Schmitt trigger, which is a digital device that converts the saw tooth pattern into a square wave. The square wave, with amplitude of five volts, is digital data in a form that is readable by a digital controller. It is typical for the detector circuit to output a high signal when light is blocked and low signal when a slot is encountered.

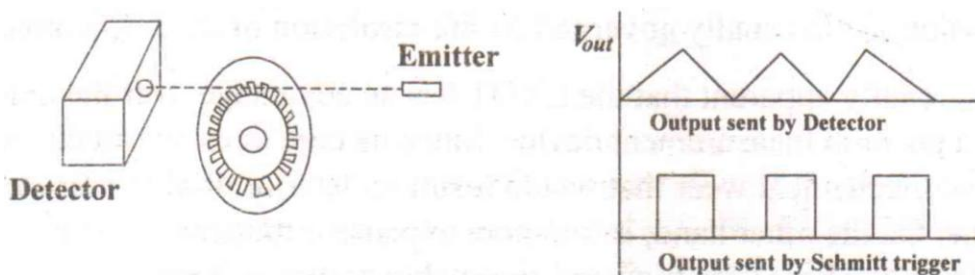


Figure 10.7 : Principle of an Optical Encoder

Float Transducers

Float transducers are the simplest method of measuring continuous position (height or level) of a liquid in a tank. Floats are widely used in process industries in which

batches of liquids are feeding production processes. There are different implementations of a float; one simple device is shown in Figure 10.8. Here a float is attached to a rod that moves the wiper of a rotary potentiometer.

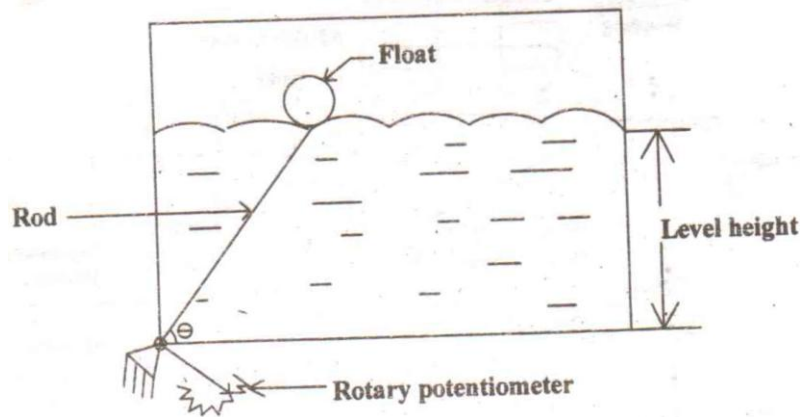


Figure 10.8 : Principle of a Float Transducer

Ultrasonic Range Sensors

For continuous measurement of a level in a tank, floats are being replaced by ultrasonic range sensors, an example of which is shown in Figure 10.9. Ultrasonic sensors use pulses of sound to measure distance. A transmitter sends out a pulse, which is reflected against the fluid whose level is being measured. When the transmitter sends out the pulse, it simultaneously initiates a timer circuit that counts clock cycles. A receiver, housed with the transmitter, receives the reflection of sound. The received signal terminates the timer and initiates the computation of distance. A microprocessor computes distance based on the speed of sound through the medium, typically air. The microprocessor may take several samples and compute and average to obtain a more accurate measurement.

The reflected signal will travel $2d$ during the period that the timer is on, Δt . If v is the velocity of sound in the medium, the distance between transducer and liquid level is

$$d = v(2\Delta t) \quad \dots (10.2)$$

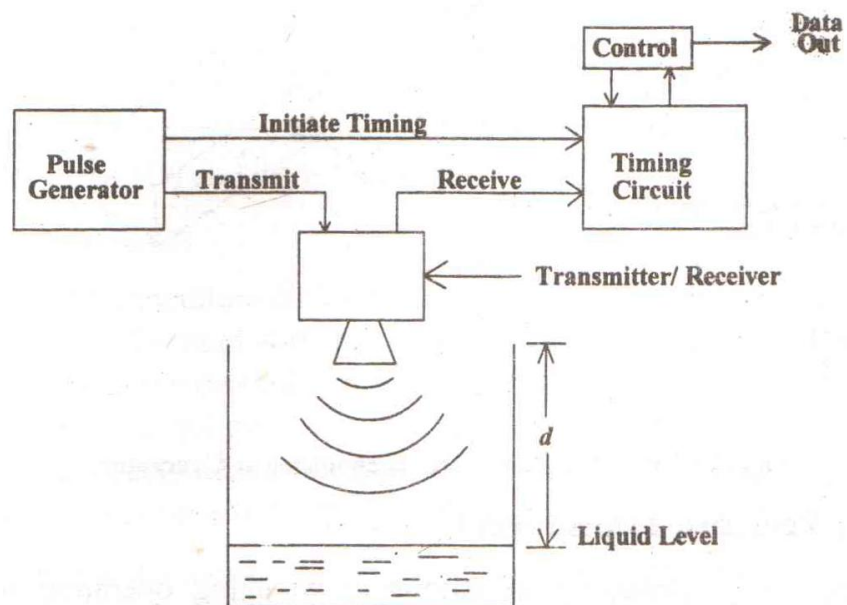


Figure 10.9 : Principle of an Ultrasonic Range Sensor

10.5.2 Velocity Transducers

Velocity transducers are used for speed control. We shall describe the digital (optical encoder) and analog (DC tachometer) velocity transducers.

Optical Encoders

Since velocity is the positional change with respect to time, any positional transducer can be used to measure velocity. If θ_1 and θ_2 are two sequential angular positions of the encoder given in radians, then

$$\omega_i = \frac{\theta_2 - \theta_1}{\Delta t} \quad \dots (10.3)$$

where ω_i is the instantaneous angular velocity in radians/sec and Δt is the increment of time between sequential position changes.

Tachometers

The basic analog velocity measurement device is the tachometer, or generator. This device can be based on the operating principle of an AC generator or a DC generator. The principle of a DC machine will be covered in detail later. As shown in Figure 10.10(a) DC tachometer consists of an armature (rotating conductor) mounted on the shaft of a device whose angular velocity is to be measured. The stator, or stationary component of the tachometer, is a permanent magnet. As the rotating conductor passes through the magnetic field, a current is induced in the conductor, resulting in a measurable voltage at V_{out} . In an ideal tachometer the relationship between speed and voltage is linear. Simply put

$$\frac{V_{out}}{V_{in}} = K \quad \dots (10.4)$$

where K is the tachometer constant. Since the tachometer is an analog device, A/D conversion is required if digital feedback is needed.

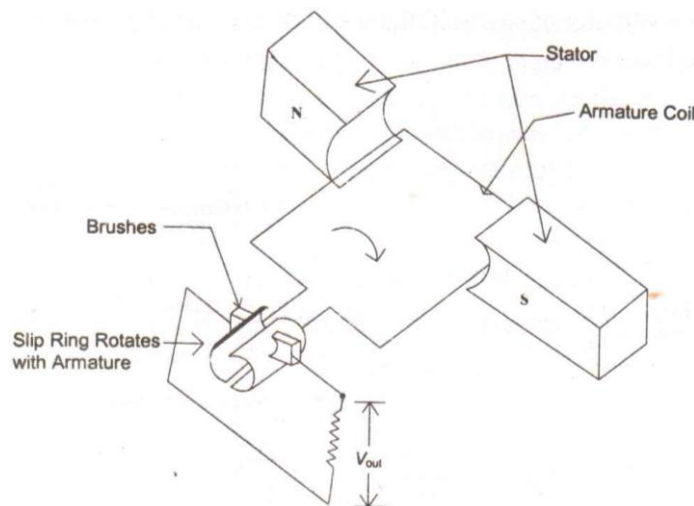


Figure 10.10 : Principle of a DC Tachometer or Generator

10.5.3 Force or Pressure Transducers

Force sensors are used extensively in automatic weighing operation in the process industries and in robotic applications when it is necessary to control gripping pressure. In this section we shall examine two analog transducers: the load cell and the strain gage.

Load Cells

A load cell is used in processes where precise weighing is required. It can be implemented using a strain gage or a LVDT. Figure 10.11 illustrates a load cell implemented by using a LVDT and a spring with linear force displacement relation. The appropriate transfer function is

$$F = K \Delta d \quad \dots (10.5)$$

where F is force, K is the spring constant and Δd is the displacement from the unloaded rest position.

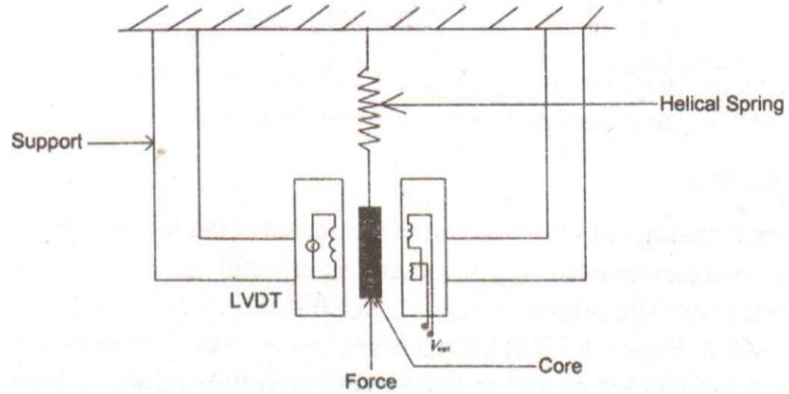


Figure 10.11 : LVDT used in Weight Measurement

Strain Gages

The most widely used pressure and force sensitive transducer is the strain gage. The principle of the strain gage is based on the resistance properties of electrical conductors. Electrical conductors possess resistance based on the relationship.

$$R = \rho \frac{L}{A} \quad \dots (10.6)$$

where R is resistance in ohms, ρ is resistivity constant, which is a property of the specific conductor material of the wire. It is measured in the unit of ohm-cm, L is the length of the wire in cm and A is the cross-sectional area in cm^2 . Since the resistivity is a constant, a change in the length and/or area of the wire will cause a change in the resistance. This phenomenon is called ‘piezoresistivity’.

10.5.4 Temperature Transducers

Temperature transducers are used extensively in process industries such as chemical, food and pharmaceuticals, where control of temperature during manufacturing is important. Three commonly used temperature transducers are the thermocouple, the resistance temperature detector (RTD) and the thermistor.

Thermocouples

When a temperature differential exists across the length of a metal, a small voltage differential will exist due to the migration of electrons in the metal. By joining two dissimilar metal wires together at one end, a small current will be induced at the junction due to differences in the molecular structure of the metals. This is shown in Figure 10.12. Point (b), the other ends of the metal wires, is held at a reference temperature.

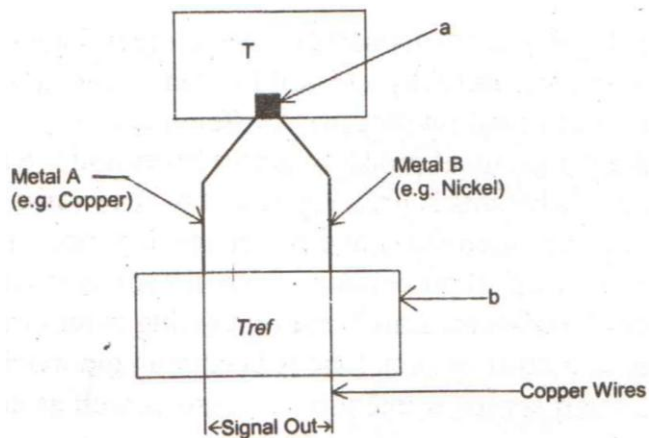


Figure 10.12 : Principle of Thermocouple

For dissimilar metals at a given temperature, the density of free electrons are different. This results in an electron migration at junction (a), causing a small current

to flow from one metal to other. This small induced electric differential, with proper signal conditioning is measured. The electric signal has the property of being linear with the temperature differential between points (a) and (b). In particular, as simplified model is of the form :

$$V_{out} = \alpha (T - T_{Ref})$$

where V_{out} is the induced voltage, α is a constant in volts/degrees K and T , T_{Ref} are the measured temperature and the reference temperature respectively.

Resistance-temperature Detectors (RTD)

The RTD temperature sensor is based on a particular property of metals wherein their electrical resistance changes with temperature. In particular, as temperature increases, so does electrical resistance. This is due to the fact that a higher temperature in a metal results in electron vibrations that impede the flow of free electrons in the metal.

When discussing strain gages, we introduced the relationship

$$R = \rho \frac{L}{A}$$

where R is resistance in ohms, ρ is resistivity constant, which is a property of the specific conductor material being in the wire. It is measured in the unit of ohm-cm, L is the length of the wire in cm and A is the cross-sectional area in cm^2 . In fact, ρ is a temperature sensitive parameter. With the knowledge of the relationship between ρ and T for a particular metal, it is possible to construct an RTD with a specific relationship between R and T .

Thermistors

A thermistor is made of a semiconductor material that exhibits a predictable and repeatable change in resistance as temperature is changed. Unlike a metal, the molecular structure of a semiconductor is such that increasing its temperature reduces its resistance. As the temperature of the material increases, electrons break free of their covalent bonds and conductivity is improved. The response function is as follows :

$$R_t = R_o e^{\beta[(1/T) - (1/T_o)]} \quad \dots (10.7)$$

where R_t and R_o are the resistances of the thermistor at temperatures T and at a reference temperature, respectively. T and T_o are the thermistor temperature and the reference temperature respectively, in degrees Kelvin, β is a property of a material used to make the thermistor. The non-linearity of the thermistor response function makes its use limited only over the most linear range of the device. Manufacturers of thermistors specify the useful range and the percent error over that range.

SAQ 3

- Differentiate between a resolver and an encoder.
- What is the difference between a thermocouple and a thermistor?

10.6 SUMMARY

In this unit, we examined the components of a sensing system, which included a sensor and a measurement circuit, and may include some form of signal processing. Sensors, their

measurement circuit and, sometimes, a signal conditioner are designed and sold by vendors as a complete package. The term ‘transducer’ is used to describe a complete and self contained sensing system. When the electrical output of a transducer is to be interfaced to a computer, an analog to digital converter is required. The functioning of A/D and D/A converters are discussed in some detail and a number of typical transducers are described for measuring position, velocity, force and temperature. Finally, a brief introduction to smart sensors is presented.

10.7 KEY WORDS

Accuracy	: The closeness of the measured value to the true value.
A/D	: Abbreviation for analog to digital converter.
Analog	: A quantity which is continuously varying as distinct from a digital quantity.
Analog to Digital Converter	: The device which converts the signal from analog to digital form.
D/A	: Abbreviation for digital to analog converters.
Digitization	: The process of converting an analog signal to digital form.
Hysteresis	: The maximum difference in output for the same measurand value within the transducer's range, one obtained by increasing from zero and the other by decreasing from a higher value of a measurand.
Measurand	: The quantity being measured.
Precision	: The closeness together of the measured values when the measurement is repeated.
Range	: The measured values over which a transducer is intended to measure, specified by upper or lower limits.
Resolution	: The smallest change in the measured which can be detected. In a analogue system, the resolution is limited by size of the least significant bit or the noise level, whichever is larger.
TTL	: Transistor-transistor logic (TTL) is a class of digital circuits built from bipolar junction transistors, diodes and resistors. All TTL circuits operate with a 5 V power supply. A TTL signal is defined as “low” when between 0 and about 0.8 V with respect to ground terminal, and “high” when between about 2 V and 5 V.

10.8 ANSWERS TO SAQs

Check your answers of all other SAQs with respective preceding text of each SAQ.

FURTHER READING

Jain R. K., 1997, *Engineering Metrology*, Khanna Publishers.

Shawne A. K., 1998, *Mechanical Measurement and Instrumentation*, Dhanpat Rai and Co. (P) Ltd.

Hazra Chowdhury, 1995, *Workshop Technology*, Media Promoters and Publishers Pvt. Ltd.

Krar Steve F, 1997, *Technology of Machine Tools*, McGraw-Hill International.

Francis T. Farago, Mark A. Kartis, 1994, *Handbook of Dimensional Measurement*, Industrial Press Inc.

Thomas G. Beckwith and John H. Lien Lard, (1984), *Mechanical Measurement*, 2nd Edition, John Willey and inc. Co., Singapore.

Holman J. P., (2004), *Experiment Methods for Engineer*. 10th Edition, Tata McGraw Hill, New Delhi.

Raghuwashi B. S., (2004), *Workshop Technology*, 15th Edition, Dhanphat Rai and Co., New Delhi.

Hazra and Choudhary, (2001), *Workshop Technology*, Volume I, Media Promoters and Publication Pvt. Ltd. Mumbai.

Jain R. K., (2201), *Engineering Metrology*, Khanna Publishers, New Delhi.

Chap Man, (1985), *Workshop Technology*, Tata McGraw Hill, New Delhi.

Kapoor A. C., (2002), *Workshop Practical Manual*, Dhanpat Rai and Co., New Delhi.

METROLOGY AND INSTRUMENTATION

Metrology is a science of measurement. Metrology may be divided, depending upon the quantity under consideration, into metrology of length, metrology of time, etc. Depending upon the field of application, it is divided into engineering metrology, medical metrology, legal metrology, etc.

Metrology is defined as the process of making extremely precise measurements of the relative positions and orientations of the different optical and mechanical components. The study of measurement involves measuring quantities, calibration of instruments, and determining the uncertainty of a measurement, and the study of weights and measures or measurements.

Engineering metrology is restricted to the measurement of length, weight, time, temperature, angles and other quantities which are expressed in linear or angular terms.

For every kind of quantity measured, there must be a unit to measure it. This will enable the quantity to be measured in number of that unit. Further, in order that this unit is followed by all; there must be a universal standard and the various units for various parameters of importance must be standardized. It is also necessary to see whether the result is given with sufficient correctness and accuracy for a particular need or not. This will depend on the method of measurement, measuring devices used, etc.

Thus, in a broader sense metrology is not limited to length and angle measurement but also concerned with numerous problems theoretical as well as practical related with measurement.

The knowledge of metrology and their applications are of vital importance in modern competitive environment.

The objective of this course is to expose the students to the fundamental of the metrology and their application in various fields.

This course comprises two blocks. The first block entitled “Principles of Measurements and Measuring Techniques” dealt with the basic concepts of measurements.