5.1. Definition and General Concept of Transducer

Definition

- The **transducer** is a device which converts one form of energy into another form.
  Examples: Mechanical transducer and Electrical transducer

Electrical Transducer

- A device which converts a physical quantity into the proportional electrical signal is called electrical transducer.

Advantages of Electrical Transducer

- Electrical output can be amplified to any desired level
- Low power requirement
- Easy transmission
- Suitable with digital control
- Low cost
- Small size
- Reduced friction effect
- The output can be modified as per requirements of the indicating or controlling equipments

Characteristics of Transducer

- High accuracy
- Rugged
- High output
- High stability and reliability
- High sensitivity
- Small size
- Fast speed of response
- Dynamic range
- Possess repeatability

Selection factor of Transducers

- Nature of measurement
- Range
- Loading effect
- Environmental considerations
- Measuring system compatibility
- Cost and availability
- Errors
- Calibration

5.2. Classification of Transducers

The following is the basic classification of the transducers. The figure 5.1 shows the classification of transducers.

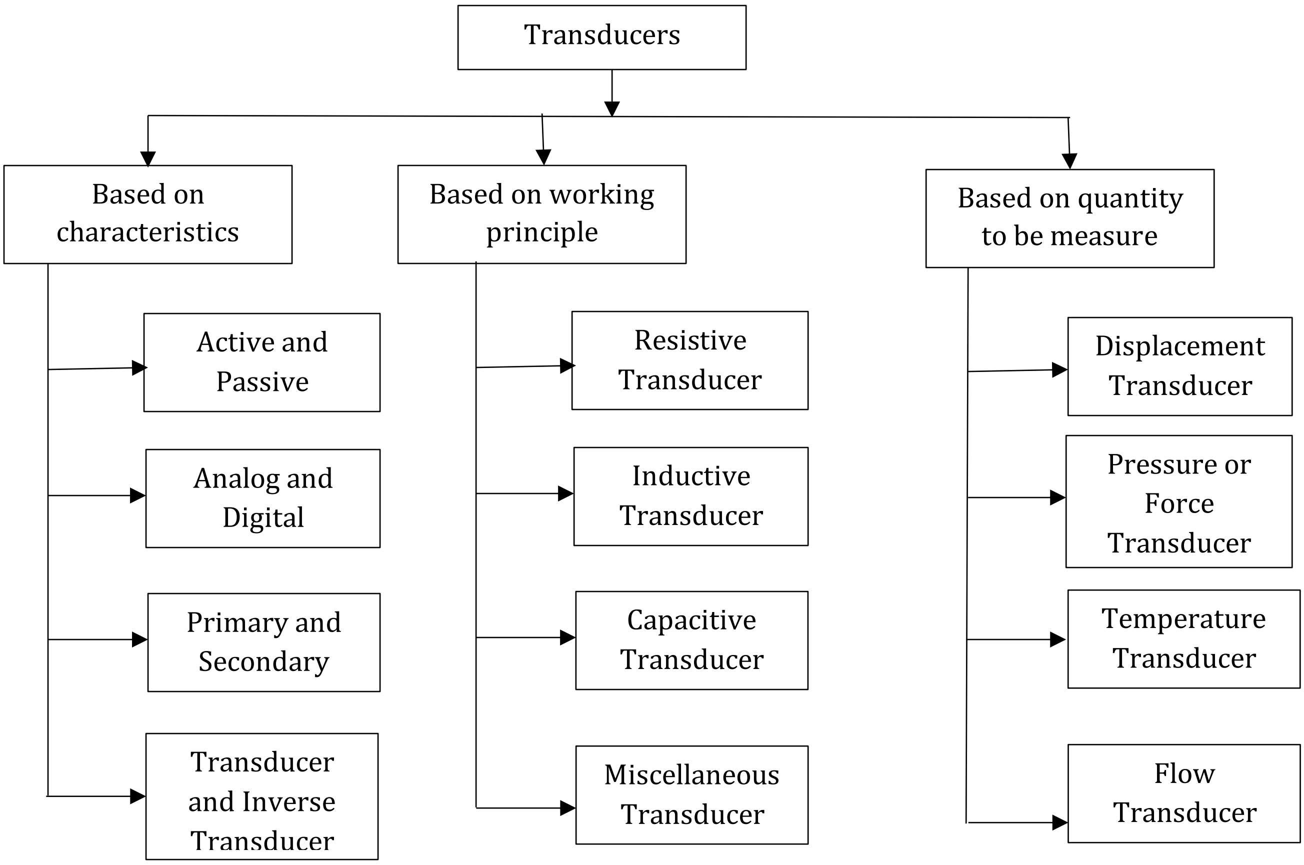

Figure 5. 1 Classification of transducers

Active Transducer

- The transducers, which develop their output in form of electrical voltage or current without any auxiliary source are known as active transducers.
- They draw energy from the system under measurement.
- They give very small output and use of amplifier is essential.
- **Examples:** Tachogenerator, Thermocouple, Piezo-electric crystals, photovoltaic cell etc.

Passive Transducer

- The transducers in which, the electrical parameters i.e. resistance, inductance and capacitance changes with change in input signal.
- They require external power source for energy conversion.
- In this, electrical parameters causes a change in voltage, current or frequency of the external power source.
- They may draw some energy from the system under measurement.
- **Examples:** Resistive, Inductive and Capacitive transducers

Analog Transducer

- Analog transducer converts input signal into output signal, which is a continuous function of time.
- **Examples:** Thermistor, Strain gauge, LVDT, Thermocouple

Digital Transducer

- Digital transducer converts input signal into output signal of the form of pulses e.g. it gives discrete output.
- These transducers are becoming more popular.
- Sometimes, analog transducer combined with ADC (Analog-to-Digital Converter) is called digital transducer.
- **Examples:** Encoders, Hall effect sensors

Primary Transducer

- When input signal is directly sensed by transducer and physical phenomenon is converted into electrical form directly then such transducer called primary transducer.
- **Examples:** Thermistor

Secondary Transducer

- When input signal is directly sensed first by some sensor and then its output being of some form other than input signal I given as input to a transducer for conversion into electrical form, then it's called secondary transducer.
- **Examples:** LVDT for used pressure measurement by using bourdon tube

Transducer (Electrical)

- It is a device that converts a non-electrical quantity into an electrical quantity.
- **Examples:** Thermocouple, Pressure gauge, Strain gauge, Photovoltaic cell

Inverse Transducer

- It is a device that converts an electrical quantity into non-electrical quantity.
- It is a precision actuator having an electrical input and low-power non-electrical output.
- A most useful application of inverse transducer is in feedback measurement systems.
- **Examples:** Piezo-electric crystal

Displacement Transducer

- A device which converts linear or angular motion into electrical output signal is known as displacement transducer.
- **Examples:** LVDT, RVDT, Gyroscope

Pressure or Force Transducer

- A device which converts pressure or force into electrical output signal is known as pressure or force transducer.
- **Examples:** Strain gauge, Piezo-electric transducer, Bourdon tube transducer

Temperature Transducer

- A device which converts transducer into electrical output signal is known as pressure or force transducer.
- **Examples:** Thermocouple, Thermistor, RTD

Flow Transducer

- A device which converts flow into electrical output signal is known as pressure or force transducer.
- **Examples:** Ultrasonic flowmeter, Hotwire anemometer

Resistive Transducer

- A transducer which works on the resistive principle is known as resistive transducer.
- **Examples:** Potentiometer, Strain gauge, RTD, Thermistor, Hotwire anemometer

Inductive Transducer

- A transducer which works on the inductive principle is known as resistive transducer.
- **Examples:** LVDT, RVDT, Synchro

Capacitive Transducer

- A transducer which works on the capacitive principle is known as resistive transducer.
- **Examples:** Capacitor microphone

5.3. List of transducers for displacement measurement

- The displacement has two type; namely, linear or translational displacement and angular or rotational displacement.
- The various transducers are used for displacement measurement listed below.

Linear or translational displacement transducers

- Resistive potentiometers
- Strain gauges
- Variable inductance transducers
- Linear variable differential transformers (LVDT)
- Capacitive transducers
- Piezo-electric transducers
- Hall effect transducers
- Digital transducers

Rotary or angular displacement transducers

- Resistive potentiometers
- Variable inductance transducers
- Rotary variable differential transformers (RVDT)
- Variable reluctance transducers
- Synchro
- Capacitive transducers
- Shaft encoders

5.4. Linear Variable Differential Transformer (LVDT)

- LVDT is an inductive type passive transducer.
- It measures force in terms of displacement of ferromagnetic core of a transformer.
- It converts translational or linear displacement into electrical voltage.
- It is also known as Linear Variable Differential Transducer.

Principle

- It is based on the principle of electro-magnetic induction.

Construction

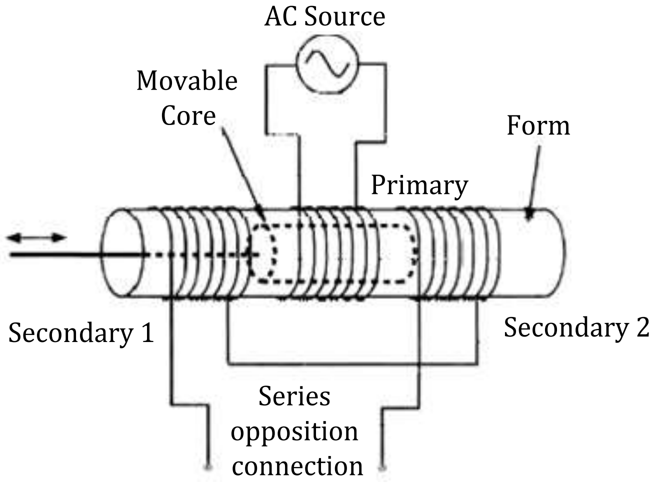

Figure 5. 2 Diagram of Linear Variable Differential Transformer (LVDT)

- LVDT consist of cylindrical transformer where it is surrounded by one primary winding in the centre of the former and two secondary windings at the sides.
- The number of turns in both the secondary windings are equal, but they are opposite to each other.
- The primary winding is connected to the ac source.
- A movable soft iron core slides within hollow former and therefore affects magnetic coupling between primary and two secondary.

Operation

- When the iron core lies at the centre of both secondary, the output differential voltage remains unaffected and have zero magnitude.
- When the core moves towards secondary-1, it induces more emf across it and less emf across secondary-2. Let's assume that it is positive displacement. Due to more flux links with the secondary-1 than secondary-2.
- When the core moves towards secondary-2, it induces more emf across it and less emf across secondary-1. Lt's assume that it is negative displacement. Due to more flux links with the secondary-2 than secondary-1.
- The output differential voltage is proportional to the displacement of the iron core.

Advantages

- High range (1.25 mm to 250 mm)
- No frictional losses
- High input and high sensitivity
- Low hysteresis
- Low power consumption
- Direct conversion to electrical signals

Dis-advantages

- LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields.
- They are affected by vibrations and temperature.

Applications

- It is used where displacements ranging from fraction of mm to few cm are to be measured. It act as primary transducer.
- They can also act as secondary transducer. E.g. the bourdon tube which acts as primary transducer and convert pressure into linear displacement then LVDT converts it into electrical signal.

5.5. Rotary Variable Differential Transformer (RVDT)

- RVDT is an inductive type passive transducer.
- It measures force in terms of displacement of ferromagnetic core of a transformer.
- It converts rotary or angular displacement into electrical voltage.
- It is also known as Rotary Variable Differential Transducer.

Principle

- It is based on the principle of electro-magnetic induction.

Construction

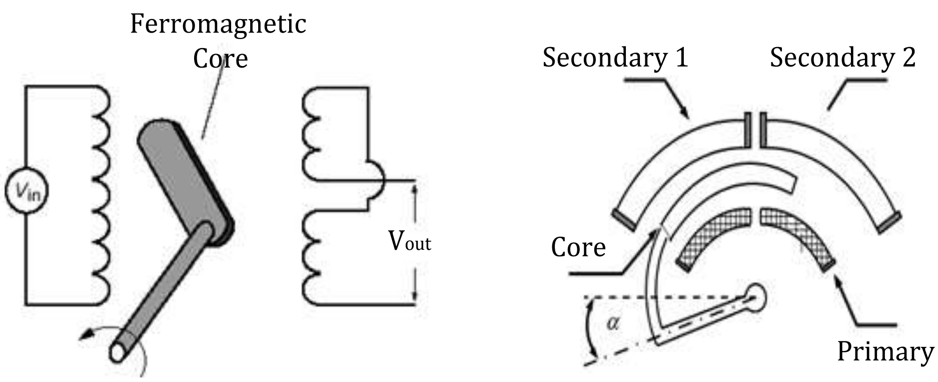

Figure 5. 3 Diagram of Rotary Variable Differential Transformer (RVDT)

- RVDT consist of rotating iron core and one primary excitation coil and two secondary output coils.

- A fixed alternating current excitation is applied to the primary stator coil that is electromagnetically coupled to the secondary coils.
- This coupling is proportional to the angle of the input shaft.
- The output pair is structured so that one coil is in-phase with the excitation coil, and the second is 180 degrees out-of-phase with the excitation coil.

Operation

- When the iron core lies at the centre of both secondary, the output differential voltage remains unaffected and have zero magnitude.
- When the core moves towards secondary-1, it induces more emf across it and less emf across secondary-2. Let’s assume that it is positive displacement. Due to more flux links with the secondary-1 than secondary-2.
- When the core moves towards secondary-2, it induces more emf across it and less emf across secondary-1. Lt’s assume that it is negative displacement. Due to more flux links with the secondary-2 than secondary-1.
- The output differential voltage is proportional to the angular motion of the iron core.
- RVDT has the accuracy of $\pm 1\%$ for rotation upto $\pm 40°$ and $\pm 4\%$ for rotation upto $\pm 60°$
- RVDT is not advisable to use If rotation is greater than $\pm 60°$, RVDT is not advisable to use.

Advantages

- Low sensitivity to temperature, primary voltages & frequency variations
- Low cost
- Small size
- Simple control

Dis-advantages

- LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields.
- They are affected by vibrations and temperature.

Applications

- It is used where rotational or angular displacements are to be measured.
- In throttle mechanism of aeroplane.

5.6. Strain Gauge

- Strain Gauge is a device used to measure strain on an object.
- As the object is deformed, the foil is deformed, causing its electrical resistance to change.
- This resistance change, usually measured using a Wheatstone bridge, is related to the strain by the quantity known as the gauge factor.

Principle

- A strain gauge is a sensor whose resistance varies with applied force.

- It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.

Construction

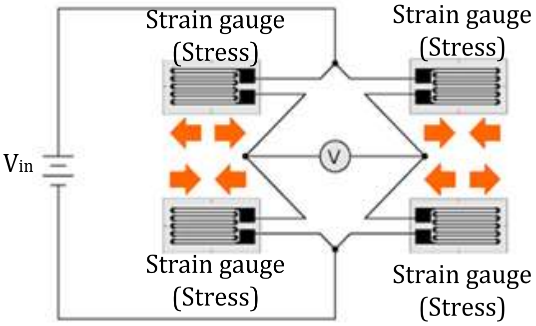

Figure 5. 4 Diagram of full-bridge strain gauge

- The strain gauge has resistive elements.
- It can be connected in half-bridge and full-bridge type.
- It has various types as following:
  - Bonded and un-bonded metal wire type
  - Wire type
  - Foil type
  - Frame type
  - Sheath type

Operation

- When the load or weight is acting on the strain gauge element, it deforms.
- The deformation in element causes the change in resistance of it. As per the balance and unbalance condition of the bridge, the voltmeter shows the output voltage.
- The output voltage is proportional to the change in resistance of the strain gauge elements and that change in resistance is proportional to the weight acting on it.
- Therefore, the output voltage vary with the weight.
- The fixed dc voltage source is required for this operation.

Advantages

- High sensitivity to input
- Low cost
- Small size
- Simple control
- Fast response
- Available in wide range

Dis-advantages

- Errors
- They are affected by external vibrations and temperature

Applications

- In weight measurement applications
- In die cutting applications
- In some medical applications
- As a Load Cell
- In torque meters
- In diaphragm pressure gauge
- In accelerometers
- In flow meters

5.7. Piezo-electric Transducer

- The Piezoelectric effect, is the ability of certain materials to generate an AC voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both.
- The most common Piezo-Electric material used is Quartz (Crystal).
- The piezoelectric transducer is used for the measurement of force, pressure, very small displacement, vibrations and sound waves.

Principle

- The main principle of a piezoelectric transducer is that a force, when applied on the quartz crystal, produces electric charges on the crystal surface.
- The Piezoelectric transducer is also known to be mechanically stiff.
- The Piezoelectric Transducer can measure pressure in the same way a force or an acceleration can be measured.

Construction

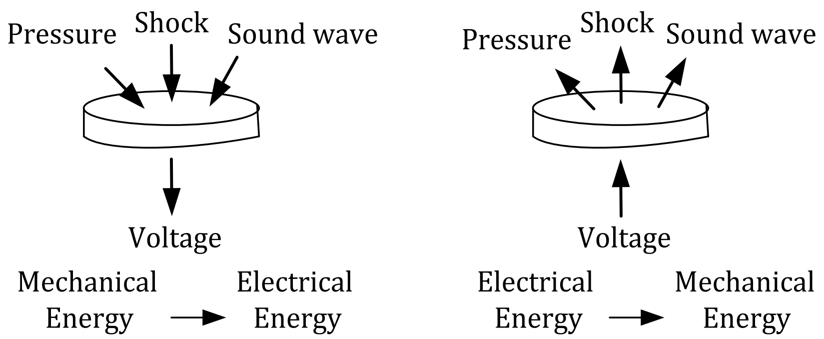

Figure 5. 5 Diagram of piezoelectric transducer

- Mainly, it has the piezoelectric crystal.
- The piezoelectric crystal attached with some force summing members.

Working

- When any pressure or force exerted on the crystal, it converts it into proportional output electrical signal.
- It is also known as inverse transducer due to its reverse inherent characteristics.
- If any electrical signal is supplied to crystal, it converts it into some physical movement.

Advantages

- Very high frequency response.

- Self-generating, so no need of external source.
- Simple to use as they have small dimensions and large measuring range.
- Barium titanate and quartz can be made in any desired shape and form. It also has a large dielectric constant. The crystal axis is selectable by orienting the direction of orientation.

Dis-advantages

- The piezoelectric transducer is used for dynamic measurement only.
- It has high temperature sensitivity.
- Some crystals are water soluble and get dissolve in high humid environment.

Applications

- Due to its excellent frequency response, it is normally used as an accelerometer, where the output is in the order of (1-30) mV per gravity of acceleration.
- The device is usually designed for use as a pre-tensional bolt so that both tensional and compression force measurements can be made.
- It can be used for measuring force, pressure and displacement in terms of voltage

5.8. Resistance Temperature Detector (RTD) (Temperature Transducer)

Principle

- A resistance temperature detector (RTD) can also be called a resistance thermometer as the temperature measurement will be a measure of the output resistance.
- RTDs are sensors used to measure temperature.
- The main principle of operation of an RTD is that when the temperature of an object increases or decreases, the resistance also increases or decreases proportionally.

Construction

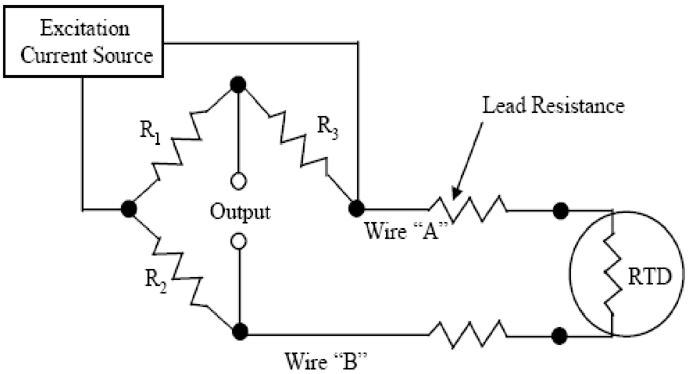

Figure 5. 6 Circuit diagram of two wire RTD bridge circuit

- RTD act as variable resistor, when heat or temperature works on it.
- The figure 5.6 shows the RTD connected in the bridge arm as variable resistor.

Advantage

- Very stable output
- Linear and predictable
- Easy to verify and recalibrate
- High accuracy
- No special wire required for installation

Dis-advantage

- More limited temperature range (-200°C to 500°C)
- High initial price
- Slower response time than a thermocouple

Applications

- More Air conditioning and refrigeration servicing
- Air, gas and liquid temperature measurement
- Exhaust gas temperature measurement
- Food Processing
- Stoves and grills
- Textile production
- Plastics processing
- Petrochemical processing
- Micro electronics

5.9. Thermistor (Temperature Transducer)

Principle

- A thermistor is a type of resistor whose resistance strongly depends on temperature.
- The word thermistor is a combination of word **'thermal'** and **'resistor'**.

Construction

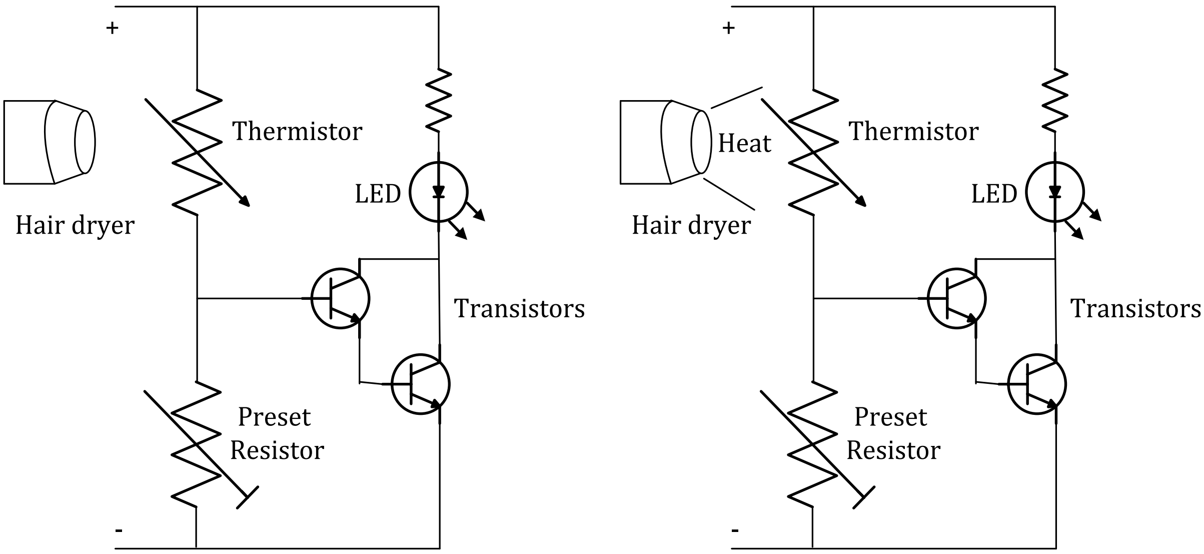

Figure 5. 7 Application circuit of Thermistor

- Thermistors are generally composed of mixture of metallic oxides.
- The resistance of the thermistor is such that it vary with the thermal effect acting on it.
- When the thermistor gets heat, its resistance decreases and when it cools, its resistance increases.

Properties of Thermistor

- They have **negative** thermal coefficient. i.e. resistance of the thermistor decreases with increase in temperature.

- They are made up of the **semiconductor** materials.
- They are made **sensitive** than RTD and Thermocouples.
- Their **resistance** lie between 0.5Ω to 0.75 MΩ.
- They are generally used in applications where measurement range of temperature -60°C to 15°C.

Advantages

- High sensitivity
- Can be used at normal room temperature
- High sensitivity
- Small size
- Low cost
- Fast response
- Simple conditioning circuit

Dis-advantages

- Non-linear
- High sensitivity allows the thermistor to work at low temperature range
- Not suitable for wide temperature change
- Shielded cable have to be used

Applications

- Applications include temperature measurements , compensation and control
- Used in air conditioners
- Used In detection of fire alarms

5.10. List of Pressure Transducers

List of pressure transducers

- Strain gauge
- Capacitance type transducer
- Piezoelectric type transducer
- Optical type transducer
- Fibre-optic type transducer
- Surface acoustic wave type transducer
- Bridgeman type transducer
- Bourdon tube type transducer
- Diaphragm type transducer
- Bellows type transducer

List of pressure elements (pressure actuator)

- U-tube manometer
- Well type manometer
- Inclined manometer
- Diaphragms
- Capsule

- Bourdon tube
- Bellows

5.11. Hall Effect Transducers

- When a conductor is kept perpendicular to the magnetic field and a direct current is passed through it, it results in an electric field perpendicular to the directions of both the magnetic field and current with a magnitude proportional to the product of the magnetic field strength and current.

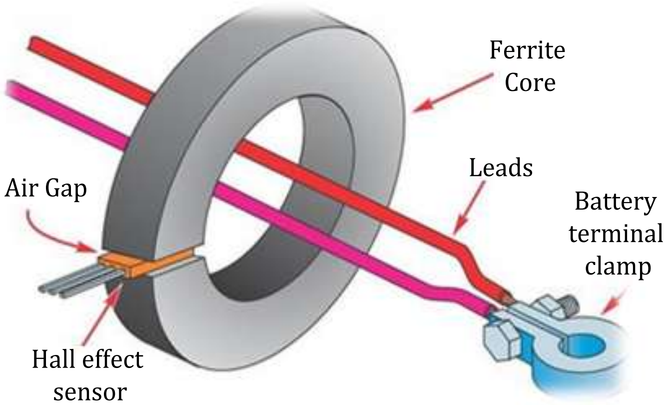

Figure 5. 8 Typical arrangement of Hall Effect sensor

- The voltage so developed is very small and it is difficult to detect it. But in some semiconductors such as germanium, this voltage is enough for measurement with a sensitive moving coil instrument. This phenomenon is called the **Hall Effect.**
- Commercial hall effect transducers are made from germanium or other semiconductor materials. They find application in instruments that measure magnetic field with small flux densities.
- Hall effect element can be used for measurement of current by the magnetic field produced due to flow of current.
- Hall effect element may be used for measuring a linear displacement or location of a structural element in case where it is possible to change the magnetic field strength by variation in the geometry of a magnetic structure.

Advantages

- Non-contact device
- Small size
- High resolution

Dis-advantages

- High sensitivity to temperature changes
- Variation of hall coefficient from plate to plate, hence requires individual calibration in each case

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