Unit - IV
4.1 Sensors and Transducers

Dr.Santhosh.T.K.

- A stick-on-the-wall, wireless TV

[Displace TV – DisplaceTV]

A sweat-monitoring wearable with a dehydration alarm

[Home - Epicore Biosystems]

Syllabus

UNIT – IV **11 Periods**

Measurements and Sensors: Introduction to measuring devices /sensors and transducers related to electrical signals - Elementary methods for the measurement of electrical quantities, impedance, power and energy in DC and AC systems and their practical application.

Electrical Wiring and Safety: Basic layout of distribution system - Types of Wiring System &Wiring Accessories –Electrical Safety - Necessity of earthing - Types of earthing.

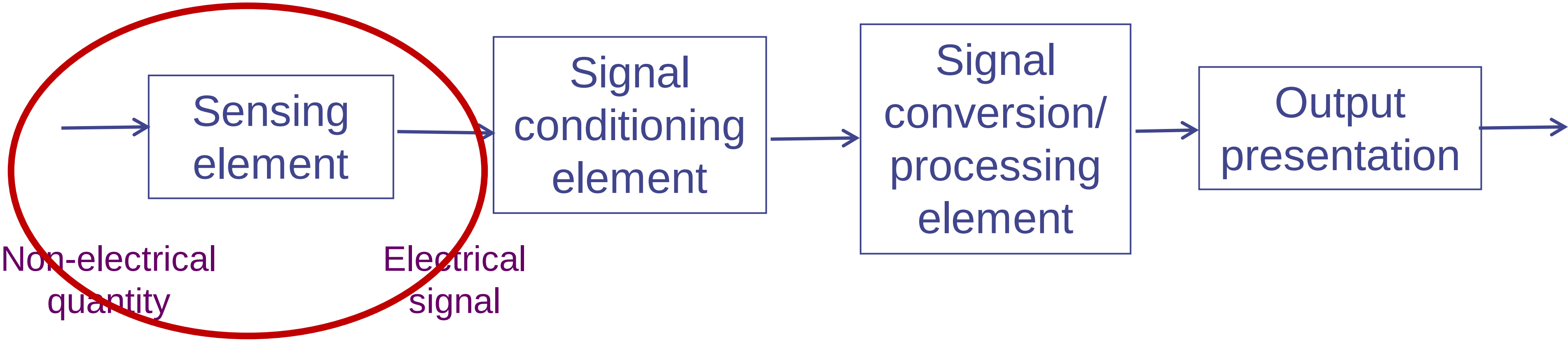
- Objective
  - Understand the basic methods for the measurement of electrical quantities.
    - Define classification of sensors and some terminologies
    - Introduce various types of sensors for measurement purpose and their applications
    - Example: Displacement, motion, level, pressure, temperature, …
  - Explore the concept of electrical Wiring and safety measures

- Learning Outcome
  - Summarize elementary methods for the measurement of electrical quantities
  - Demonstrate simple domestic wiring and understand safety measures

Overview

- Introduction
- Classification of sensors
- Passive sensors
- Active sensors

Introduction



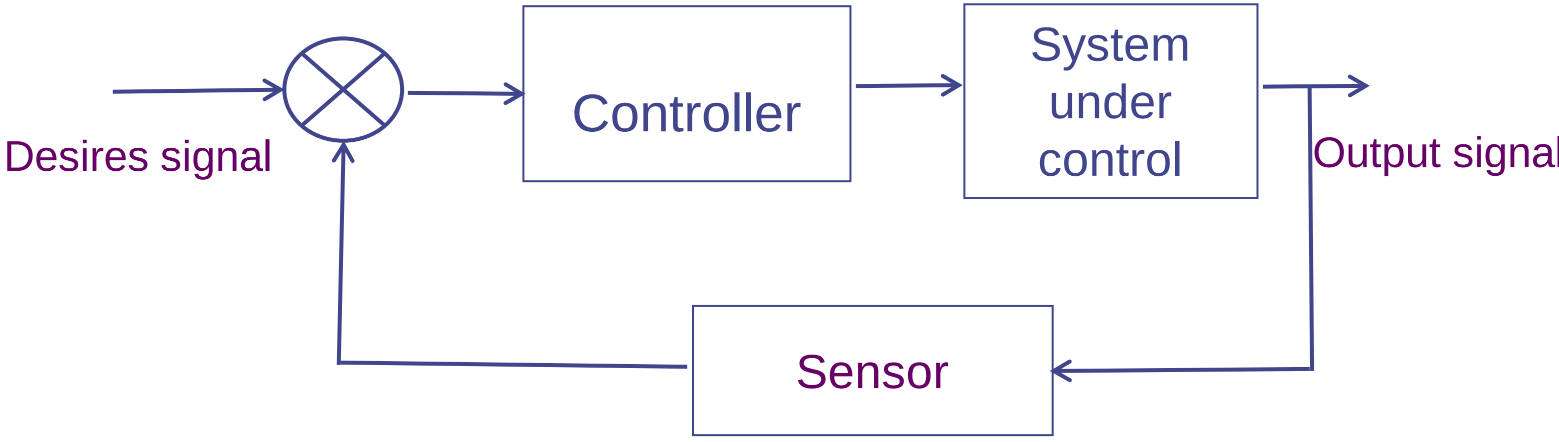
- Sensors
  - Elements which generate variation of electrical quantities (EQ) in response to variation of non-electrical quantities (NEQ)
- Examples of NEQ
  - Temperature, displacement, humidity, fluid flow, speed, pressure,…
- Sensor are sometimes called transducers

Introduction …

- Advantages of using sensors include
  1. Mechanical effects such as friction is reduced to the minimum possibility
  2. Very small power is required for controlling the electrical system
  3. The electrical output can be amplified to any desired level
  4. The electrical output can be detected and recorded remotely at a distance from the sensing medium and use modern digital computers
  5. etc …

Introduction - Use of Sensors

1. Information gathering: Provide data for display purpose
   - This gives an understanding of the current status of the system parameters
   - Example: Car speed sensor and speedometer, which records the speed of a car against time
2. System control: Signal from the sensor is an input to a controller



Introduction – Sensor Requirements

- The main function of a sensor is to respond only for the measurement under specified limits for which it is designed
- Sensors should meet the following basic requirements
  1. Ruggedness: Capable of withstanding overload
     - Some safety arrangements should be provided for overload protection
  2. Linearity: Its input-output characteristics must be linear
  3. Repeatability: It should reproduce the same output signal when the same input is applied again and again
  4. High output signal quality
  5. High reliability and stability
  6. Good dynamic response
  7. No hysteresis, …

Overview

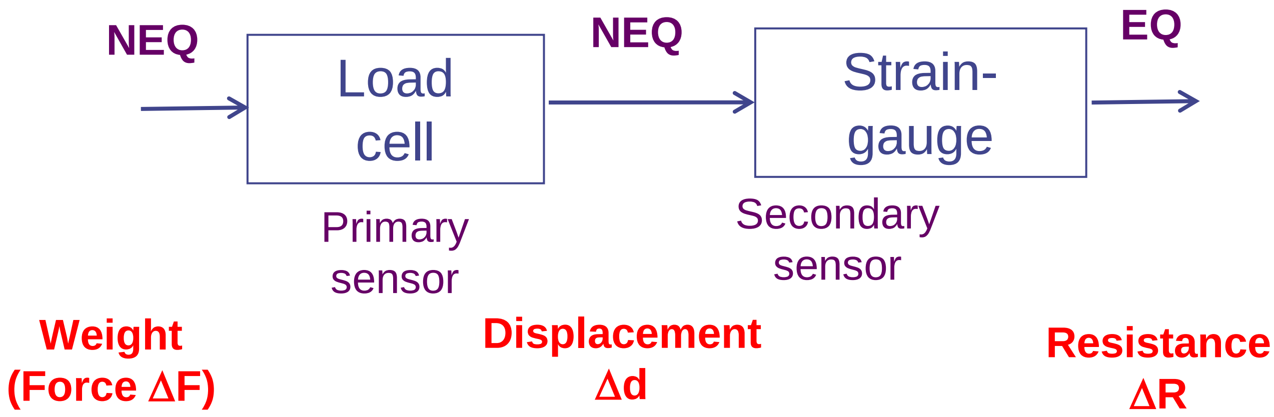
- Introduction
- Classification of sensors
- Passive sensors
- Active sensors

Classification of Sensors

- Sensors can be divided on the basis of
  - Method of applications
  - Method of energy conversion used
  - Nature of output signals
  - Electrical principle
- In general, the classification of sensors is given by
  - Primary and secondary sensors
  - Active and passive sensors
  - Analog and Digital sensors

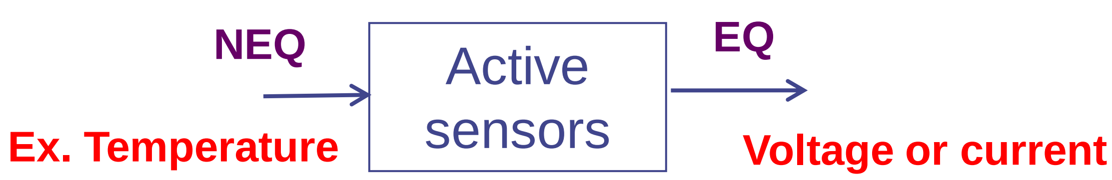
Primary and Secondary Sensors

- Classification is based on the method of application
- Primary sensor
  - The input NEQ is directly sensed by the sensor
  - The physical phenomenon is converted into another NEQ
- Secondary sensor
  - The output of the primary sensor is fed to another (secondary) sensor that converts the NEQ to EQ



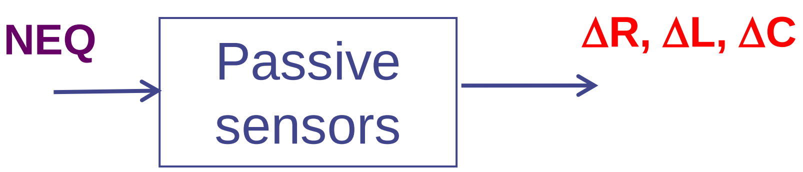
Active and Passive Sensor

- Classification based on the basis of energy conversion
- Active sensor
  - Generates voltage/current in response to NEQ variation
  - Are also called self-generating sensors
  - Normally, the output of active sensors is in μV or mV
- Examples
  - Thermocouples: A change in temperature produces output voltage
  - Photovoltaic cell: Change solar energy into voltage
  - Hall-effect sensors, …



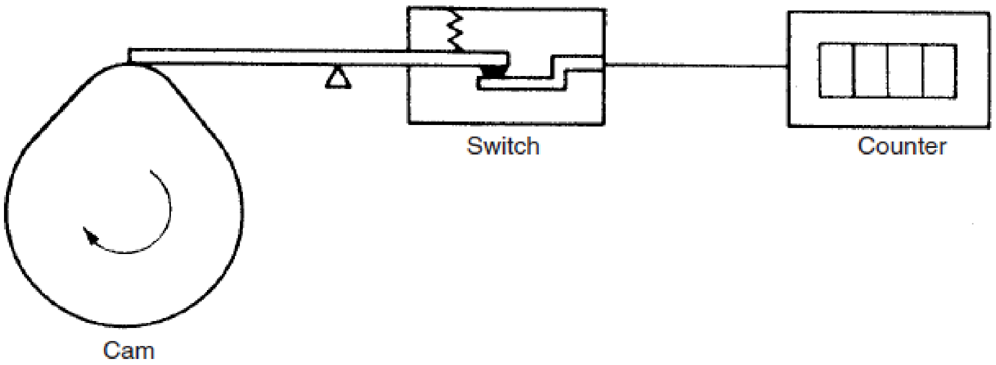
Active and Passive ….

- Passive sensors
  - Sensors that does not generate voltage or current, but produce element variation in R, L, or C
  - Need an **additional circuit** to produce voltage or current variation
- Examples
  - Thermistor: Change in temperature leads to change in resistance
  - Photo resistor: Change in light leads to change in resistance
  - Straingauge: Change in length or position into change in resistance)
  - LVDT, Mic



Analog and Digital Sensors

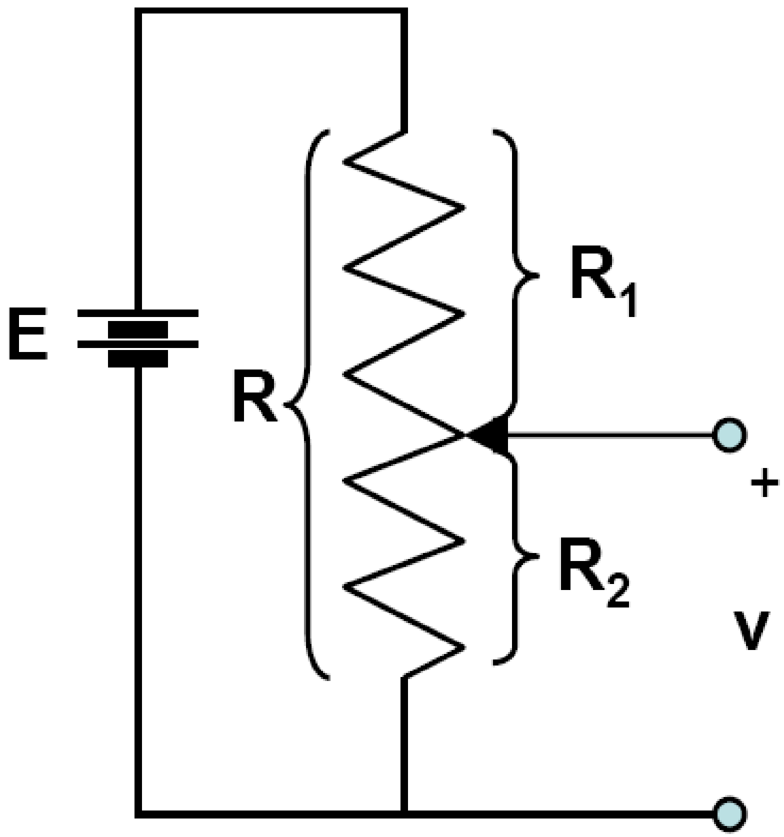
- Classification based on the nature of the output signal
- Analog sensor
  - Gives an output that varies continuously as the input changes
  - Output can have infinite number of values within the sensor's range
- Digital sensor
  - Has an output that varies in discrete steps or pulses or sampled form and so can have a finite number of values
  - E.g., Revolution counter: A cam, attached to a revolving body whose motion is being measured, opens and closes a switch
    - The switching operations are counted by an electronic counter



Overview

- Introduction
- Classification of sensors
- Passive sensors
  - Resistive sensors
    - Potentiometers, temperature dependent resistors, strain gauge, photoconductors (photoresistors), Piezoresistive
  - Capacitive sensors
  - Inductive sensors
- Active sensors

Variable Resistance



Linear or angular displacement = x

$$R_2 \propto x$$

$$v = \frac{R_2}{R_1 + R_2} E = \frac{R_2}{R} E$$

$$\therefore v = \frac{E}{R} x$$

Overview

- Introduction
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Inductive Sensors

- For a coil of n turns, the inductance L is given by

$$\boxed{L = \mu A \frac{N^2}{l} = \frac{N^2}{R}}$$

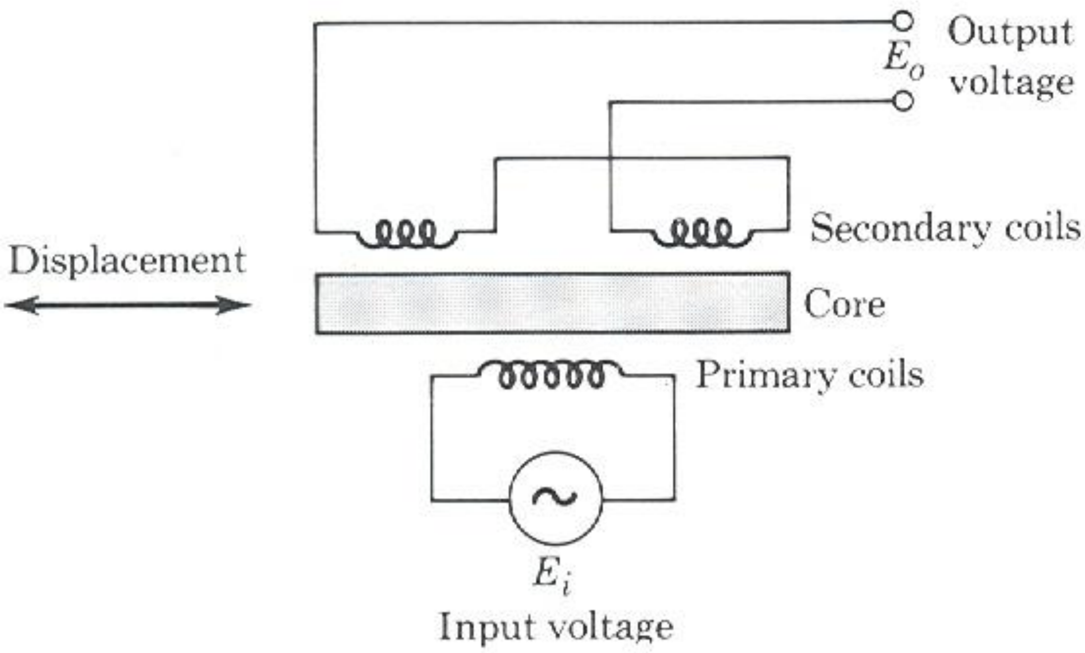
  - Where
    - N: Number: of turns of the coil
    - l: Mean length of the magnetic path
    - A: Area of the magnetic path
    - μ: Permeability of the magnetic material
    - R: Magnetic reluctance of the circuit
- Application of inductive sensors
  - Force, displacement, pressure, …
- Inductance variation can be in the form of
  - Self inductance or
  - Mutual inductance: e.g., differential transformer

Linear Variable Differential Transformer (LVDT)

- Input voltage (alternating current): One primary coil
  - There will be a magnetic coupling between the core and the coils
- Output voltage: Two secondary coils connected in series
- Operates using the principle of variation of mutual inductance

- The output voltage is a function of the core's displacement

- Widely used for translating linear motion into an electrical signal



Schematic diagram of a differential transformer

Overview

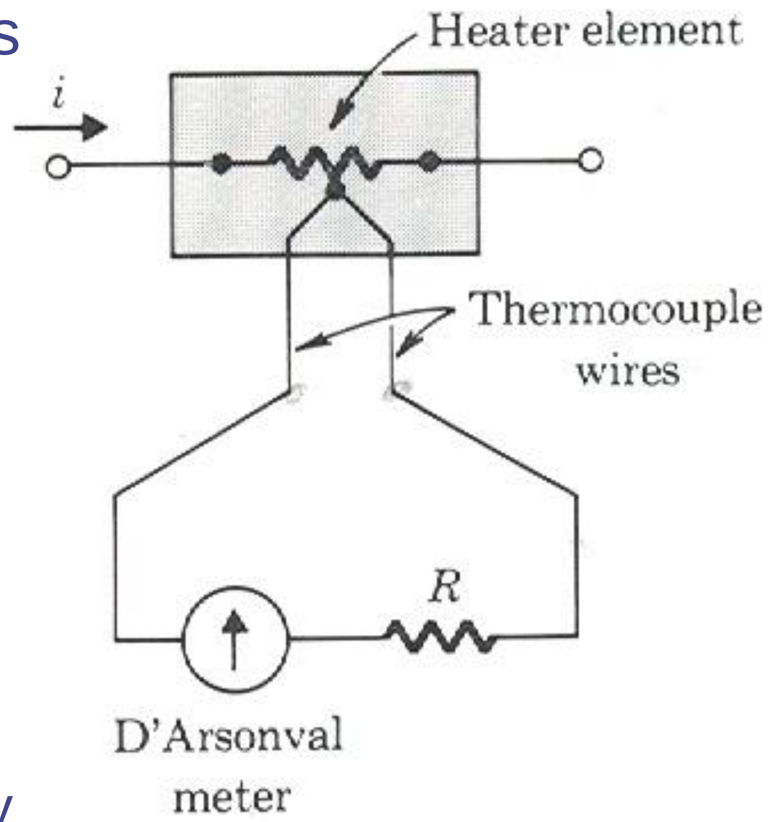
- Introduction
- Classification of sensors
- Passive sensors
- Active sensors
  - Thermoelectric transducers
  - Photoelectric transducers
  - Piezoelectric transducers
  - Hall-effect transudes
  - Tachometric generators

Active Sensors – Thermocouple …

- Applications
  - Temperature measurement
  - Voltage measurement
    - Rectifier based rms indications are waveform dependent
    - They are normally designed for sinusoidal signals
      - Hence, error for non-sinusoidal signals
    - Use thermocouple based voltmeters
      - Here, temperature of a hot junction is proportional to the true rms value of the current

Active Sensors – Thermocouple Meter

- The measured a.c. voltage signal is applied to a heater element
- A thermocouple senses the temperature of the heater due to heat generated (I_{rms}^2)
- The d.c. voltage generated in the thermocouple is applied to a moving-coil meter
  - The thermocouple will be calibrated to read current (I_{rms})
- AC with frequencies up to 100 MHz may be measured with thermocouple meters
- One may also measure high frequency current by first rectifying the signal to DC and then measuring the DC



Schematic of a thermocouple meter.

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Hall-effect Transducers

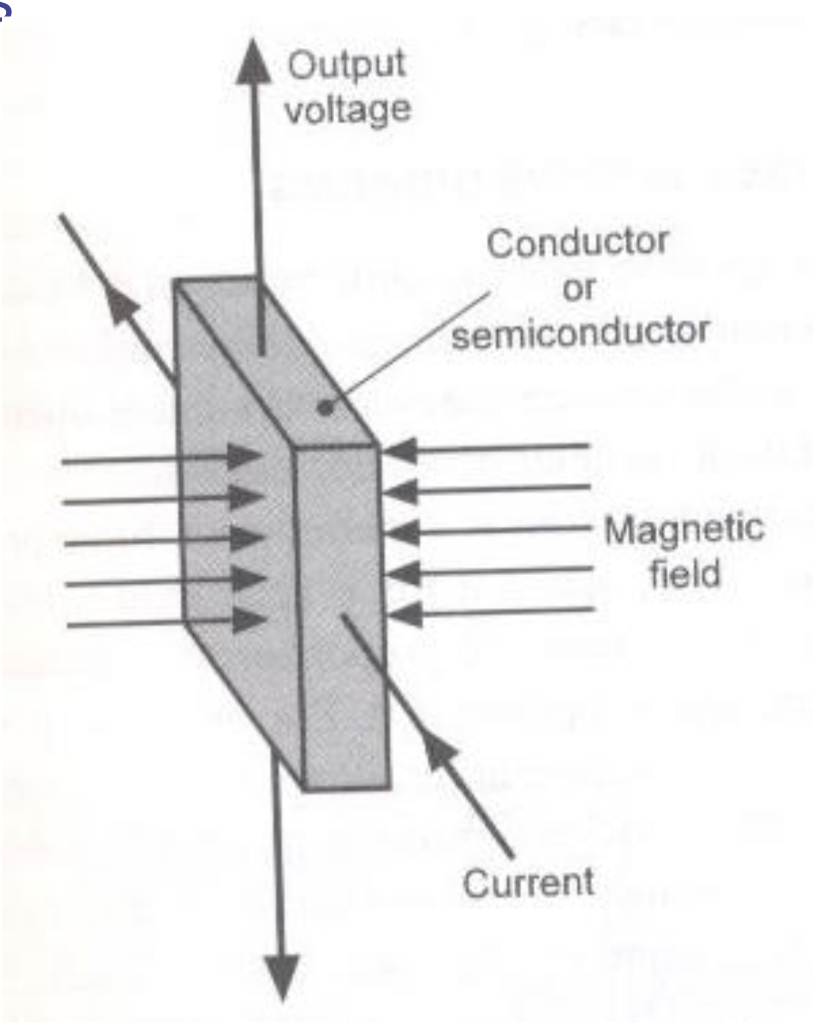
- Hall voltage is produced when a material is
  - Kept perpendicular to the magnetic field and
  - A direct current is passed through it
- The Hall-voltage is expressed as

$$\boxed{V_H = K_H \frac{I_C B}{t}}$$

- Where
  - I_C: Control current flowing through the Hall-effect sensor, in Amps
  - B: Flux density of the magnetic field applied, in Wb/m^2
  - t: Thickness of the Hall-effect sensor, in meters
  - K_H : Hall-effect coefficient
- Hall-effect sensors are used to measure flux density
  - Can detect very week magnetic fields or small change in magnetic flux density

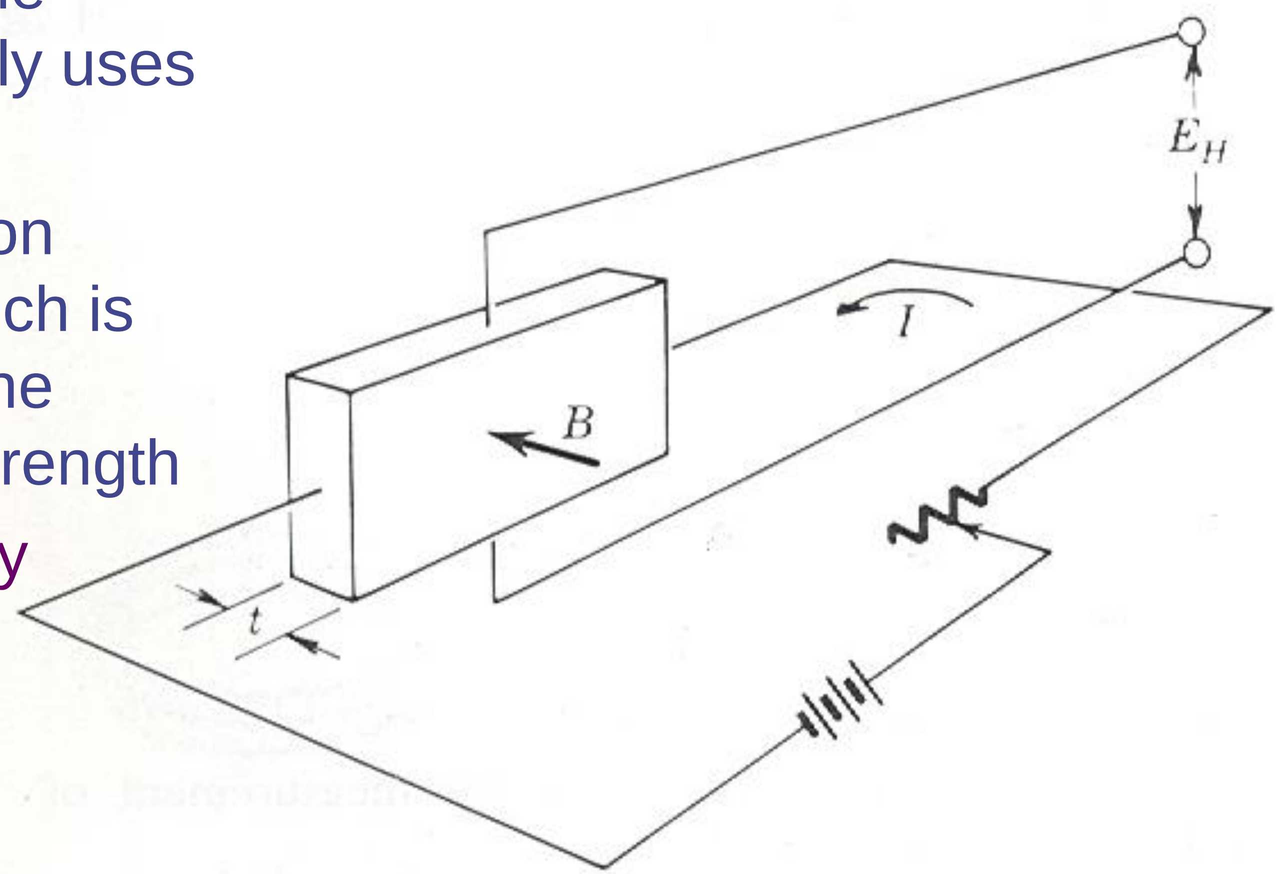
Hall-effect Transducers …

- Like active sensors, it generates voltage V_H
- It also need an external control current I_C like passive sensors
- The sensor can be used for measurement of
  - Magnetic quantitities (B, ϕ)
  - Mobility of carriers
  - Very small amount of power



Hall-effect Transducers …

- Magnetic field forces electrons to concentrate on one side of the conductor (mainly uses semiconductor)
- This accumulation creates emf, which is proportional to the magnetic field strength
- Used in proximity sensors



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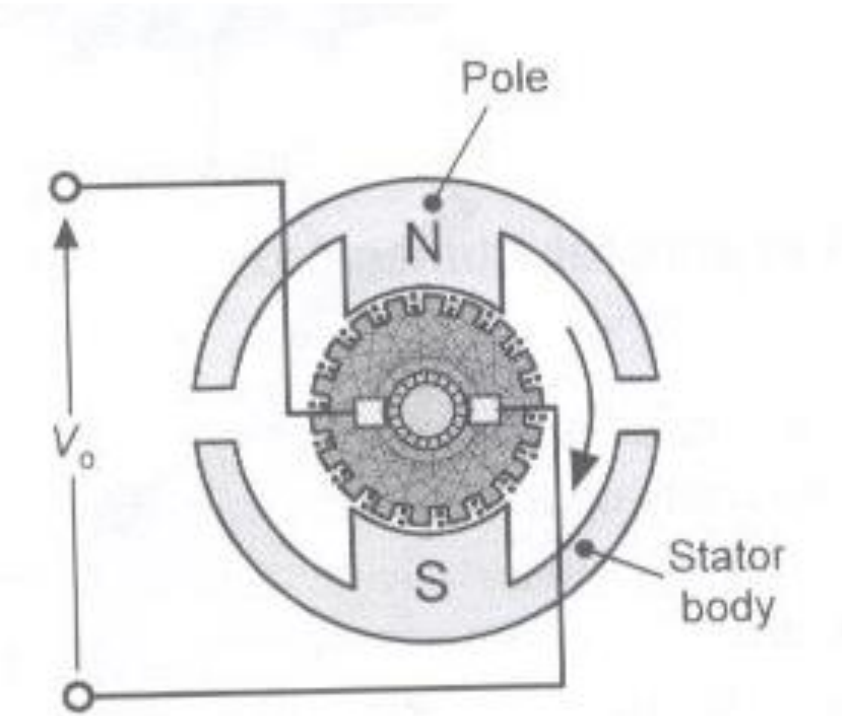
Tachometric Generators

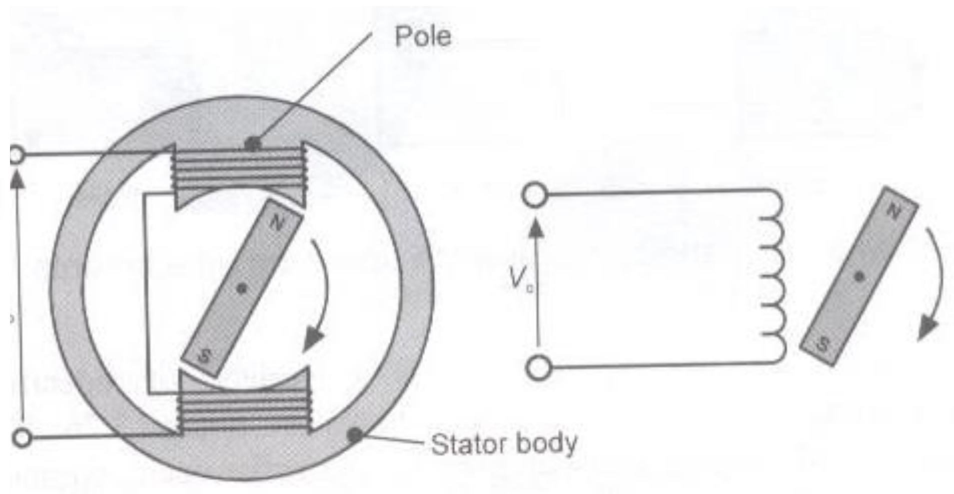
- Tachometer – any device used to measure shaft's rotation
- Tachometric generator
  - A machine, when driven by a rotating mechanical force, produces an electric output proportional to the speed of rotation
  - Essentially a small generators
- Tachometric generators connect to the rotating shaft, whose displacement is to be measured, by, e.g.,
  - Direct coupling or
  - Means of belts or gears
- They produce an output which primarily relates to speed
  - Displacement can be obtained by integrating speed
- Types of Tachometric generators: Generally a.c. or d.c.

Tachometric Generators

- Voltage generated is proportional to rotation of the shaft



D.C. tachometric generator



A.C. tachometric generator

Summary

Measuring Instruments

Unit - IV

4.2 Electrical Instruments and Measurements

Dr.Santhosh.T.K.

Syllabus

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Introduction

- **Measurement:**

  It is the act or result of quantitative comparison between a predefined standard and an unknown quantity.

- **Instrument:**

  It is a device or mechanism used to determine the present value of a quantity under observation.

Principle of operation

1. *Magnetic effect*	.....	Moving-iron instruments
2. *Electrodynamic effect*	.....	(*i*) Permanent-magnet moving coil
		(*ii*) Dynamometer type
3. *Electromagnetic-induction*	.....	Induction type instruments
4. *Thermal effect*	.....	Hot-wire instruments
5. *Chemical effect*	.....	Electrolytic instruments
6. *Electrostatic effect*	.....	Electrostatic instruments

S. No.	Type	Effect	Suitable for	Instrument
1.	Moving-iron	Magnetic effect	d.c. and a.c.	Ammeter, Voltmeter
2.	Permanent-magnet moving coil	Electrodynamic effect	d.c. only	Ammeter, Voltmeter
3.	Dynamometer type	Electrodynamic effect	d.c. and a.c.	Ammeter, Voltmeter, Wattmeter
4.	Induction type	Electro-magnetic induction effect	a.c. only	Ammeter, Voltmeter, Wattmeter, Energy-meter
5.	Hot-wire	Thermal effect	d.c. and a.c.	Ammeter, Voltmeter
6.	Electrolytic meter	Chemical effect	d.c. only	Ampere-hour meter
7.	Electrostatic type	Electrostatic effect	d.c. and a.c.	Voltmeter only

Classification of Instruments

- Instruments can be classified as:

1. Absolute instruments
2. Secondary instruments

1. Absolute instruments:

- ➢ Absolute instruments indicate the value of the quantity being measured in terms of constant of instruments and its deflection.
- ➢ No comparison with standard instrument is necessary.
- ➢ Example: tangent galvanometer, Rayleigh current balance.

Continued…

2. Secondary instruments:

- The secondary instruments need calibration with respect to the absolute instruments.
- The secondary instruments determine the value of the quantity being measured from the deflection of the instruments.
- Calibration is a must for secondary instrument, without calibration the deflection obtained is meaningless.
- Example: Ammeter, voltmeter, wattmeter etc.

Continued…

- **Classification based on the nature of operation:**

➢ Secondary instruments are further classified according to the nature of operation as:

1. Indicating
2. Recording
3. Integrating instruments.

➢ **Indicating instruments** indicate the instantaneous value of quantity under measurement.

➢ **Recording instruments** give a continuous record of variation of quantity being measured (such as voltage, frequency, power etc.). Recorders are commonly used in power plants, process industries.

➢ **An integrating instrument** is one which takes into consideration the period or the time over which the quantity is supplied. e.g. ampere-hour meter, energy meter.

Continued…

- **Analog or Digital instruments:**

➢ One more way of classifying instrument is:

1. Analog instruments
2. Digital instruments.

➢ Analog information is continuous and stepless function of time. Analog instruments are easy to understand, calibrate and maintain.

➢ Digital information is in form of discrete pulses or steps. Digital instruments have higher resolution, high readability.

Continued…

- **Various instruments used in practice:**

➢ Following instruments used in day to day life in order to measure different quantity.

Sr. No.	Name of the instruments	Quantity measured
1.	Voltmeter	AC or DC voltage
2.	Ammeter	AC or DC current
3.	Wattmeter	AC power (Watt)
4.	Energy meter	Energy (Watt hour)