Electronic Measurements (1)

Transducers - Part 2

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Lecture Contents

- Revision
- Measurement of Displacement using Transducers:

Potentiometer, Linear variable differential transformer (LVDT), and Hall Transducer

Revision

Example 1- An actuator converts:

(a) electrical energy to any other form of energy
(b) electrical energy to light energy
(c) mechanical displacement into electrical signal
(d) electrical energy to mechanical form

Example - 2 Which of the following acts as an active transducer?

(a) Photo emissive cell
(b) Selsyn
(c) Strain gauge
(d) Photo voltaic cell

Example - 3- A transducer converts

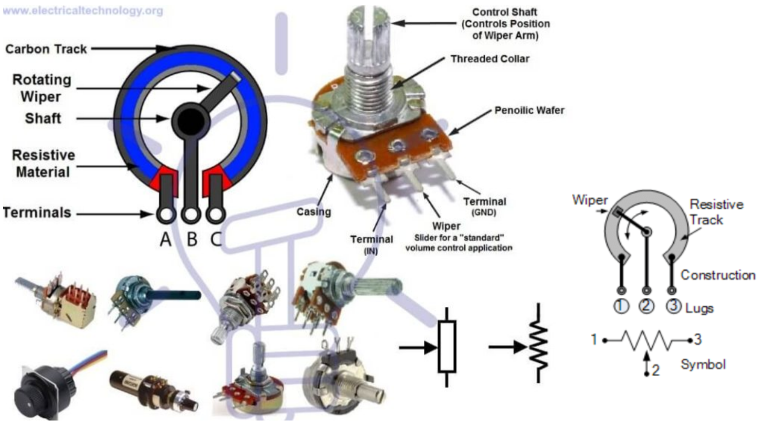
(a) mechanical energy into electrical energy.
(b) mechanical displacement into electrical signal.
(c) one form of energy into another form of energy.
(d) electrical energy into mechanical form.

Displacement Measurement Transducers

- Some of the transducers can convert the input displacement into a corresponding output electrical voltage and hence, can be used for the measurement of displacement. The transducers used for this purpose are

1. Potentiometer
2. Linear Variable Differential Transducer (LVDT)
3. Hall Transducer

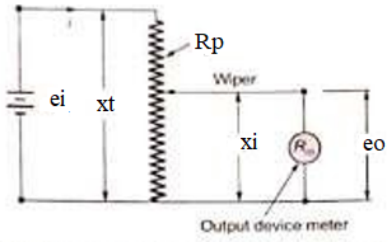
Displacement Measurement Transducers
(1) Potentiometers



Displacement Measurement Transducers (1) Potentiometers

- A resistance potentiometer is simply called "POT" .
- It consists of a resistive element provided with a sliding contact, which is called a "wiper" .
- it is a "passive transducer" , as it requires external power source for its operation.
- The resistive material "wire wound" is a 0.01 mm diameter of platinum or nickel alloy is wound on an insulated material.
- POT has four essential parts: carbon track, rotating wiper, resistive material, and conducting terminals.

Displacement Measurement Transducers
(1) Potentiometers



- The output voltage $e_o = \frac{x_i}{x_t} e_i$ or, $e_o \propto e_i \propto x_i$
  e_i and e_o are the input and output voltages (in V)
  x_t is the total length of POT (in mm)
  x_i is the wiper displacement from zero position (in mm)
  R_p is the total resistance of the POT
- The output voltage of a POT linearly varies with the displacement.

Displacement Measurement Transducers
(1) Potentiometers

Sensitivity:

$S_{POT} = \frac{\text{output voltage}}{\text{input displacement}} (V/mm)$ or $S_{POT} = \frac{e_o}{x_i}$

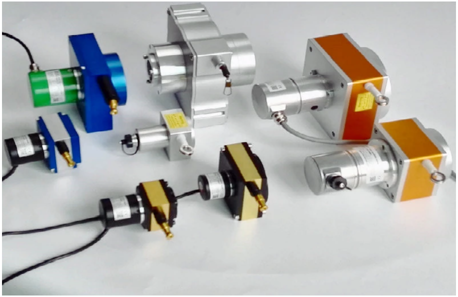
Advantages:

- They are less costly.
- Their operation is simple
- Their electrical efficiency is high.

Displacement Measurement Transducers
(1) Potentiometers

Disadvantages:

- Require a large force for wiper movement (solution: motorized POT).
- The transducer life is limited due to wear and tear problem of the wiper.



Displacement Measurement Transducers (2) LVDT

LVDT: is the most widely used inductive transducer for converting the linear motion into proportional output electrical voltage.

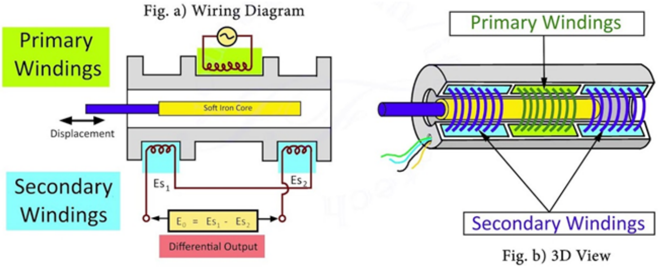
L = Linear motion (displacement)

V = Variable inductance

D = Differential, which means output is difference of two secondary outputs

T = Transformer, because it functions as the former of primary and secondary windings.

Displacement Measurement Transducers (2) LVDT



- https://www.youtube.com/watch?v=zkixSsT2p7w
https://www.youtube.com/watch?v=anCnrtjNLQM

Displacement Measurement Transducers (2) LVDT - Construction

- The transformer has one primary winding and two secondary windings (S1 and S2).
- The primary winding is connected to an alternating current (AC) source.
- A movable soft-iron core is placed inside the transformer.
- The displacement to be measured is applied to the arm attached to the soft iron core.
- In practice the core is made up of high permeability nickel-iron which is hydrogen annealed (heat treatment to eliminate hydrogen).
- The assembly is placed in a stainless-steel housing to provide electrostatic and electromagnetic shielding.
- The frequency of ac signal applied to primary winding lies between 50 Hz to 20 kHz.

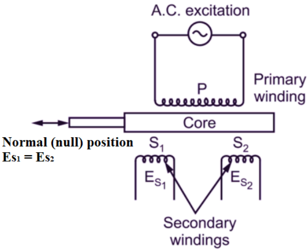
Displacement Measurement Transducers
(2) LVDT - Construction

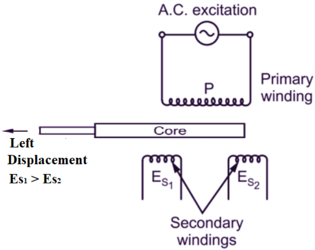
- Since the primary winding is excited by an AC source, it produces an alternating magnetic field which in turn induces alternating voltages (EMF) in the two secondary windings S_1 and S_2, due to the magnetic coupling between the primary coil and the two secondary coils.
- The percentage of magnetic coupling and hence the induced EMF in the two secondary coils depends on the iron-core position.
- The induced EMF at S_1 is E_{S1} and that at secondary S_2 is E_{S2}.
- The two secondary windings have the same number of turns and are connected in series opposition such that the differential output voltage of the transducer is $E_0 = E_{S1} - E_{S2}$..

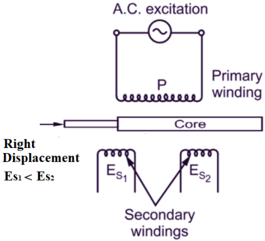
Displacement Measurement Transducers
(2) LVDT - Operation

- When the core is at its normal (NULL) position , the flux linking with both the secondary windings is equal and hence equal emfs are induced in them $E_{S1} = E_{S2}$ and the output voltage $E_0 = 0$.
- If the core is moved to the left of the null position, more flux links with S1 and less with winding $_2$. Accordingly, output voltages E_{S1} is greater than ES2. The magnitude of output voltage is thus, $E_0 = E_{S1} - E_{S2}$ and say it is in phase with primary voltage.
- Similarly, when the core is moved to the right of the null position E_{S2} will be more than E_{S1}. Thus, the output voltage is $E_0 = E_{S1} - E_{S2}$ and 180° out of phase with primary voltage.
- E_0=+ ve ($E_{S1} > E_{S2}$), When core moves to the left.
  E_0=- ve ($E_{S1} < E_{S2}$), When core moves to the right.

Displacement Measurement Transducers
(2) LVDT - Operation





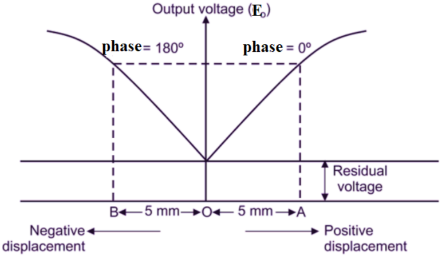


Displacement Measurement Transducers
(2) LVDT - Operation

- The amount of voltage changes in either secondary winding is proportional to the amount of movement of the core. Hence, we have an indication of amount of linear motion.
- By noticing whether output voltage is increased or decreased, we can determine the direction of motion.

Displacement Measurement Transducers (2) LVDT

- Output voltage versus (vs) displacement curve of LVDT:



- **Sensitivity of LVDT:**
  $S_{LVDT} = \frac{E_o}{l}$, where l is the displacement

Displacement Measurement Transducers (2) LVDT

Advantages:

- It is used for a very accurate measurements of displacement.
- Has a wide range for the measurement of displacement (125 mm - 250 mm)
- It is a friction less device as there is no direct contact of the windings with the core and there are no sliding contacts.
- It has high sensitivity (it gives a high output in response to the input), therefore there is frequently no need for amplification devices.
- It has low power consumption.
- It has low hysteresis.
- Is simple in construction and rugged.

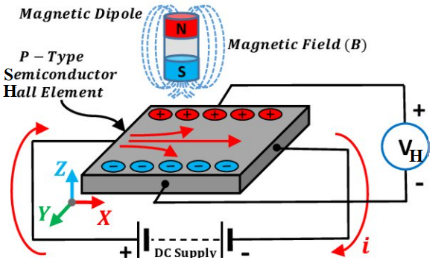
Displacement Measurement Transducers (2) LVDT

Disadvantages:

- Its performance is affected by external vibrations.
- LVDT is affected by external magnetic field (shielding is necessary).
- For dynamic displacement, the core movement is not be able to produce sufficient output due to the mass of the core.
- Significant displacement is required because the output is the difference between the secondaries voltage (Compensated using high sensitivity LVDT).

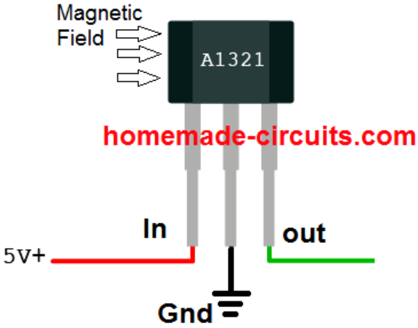
Hall effect

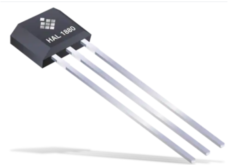
- If a metal or a semiconductor carries a current (I) placed in a magnetic field (B) (transverse magnetic field), an electric field (E_H) is developed. This is known as "Hall Effect".
- A voltage is developed due to this electric field is known as "Hall voltage".



- https://www.melexis.com/en/tech-talks/hall-effect

Hall-Effect Sensor Pin Diagram



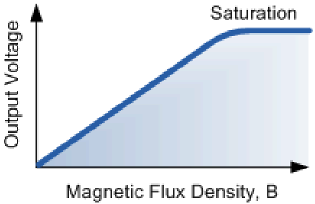


Displacement Measurement Transducers
(3) Hall Transducer

The Hall voltage is given by:

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

- B: is the magnetic flux density (Wb/m^2)
- I: current through the strip (A)
- t: thickness of the strip (m)
- K_H: Hall coefficient $(\frac{V-m}{A-Wb-m^{-2}})$
  $K_H = \frac{1}{ne}$
  - n: is the carrier concentration (m^{-3})
  - e: is the electron charge (C).
  - ne: is the charge density (C/m^3)



Displacement Measurement Transducers
(3) Hall Transducer - Applications

- Calculation of carrier concentration:
  Once the Hall coefficient K_H is measured, the carrier concentration can be obtained:
  $n = \frac{1}{e\ k_H}$ or $p = \frac{1}{e\ k_H}$
- Determination of semiconductor type:
  The sign of the Hall voltage can be used to show weather electrons or holes are the dominant carrier in the material.
- Measurements of displacement in micrometer range

Displacement Measurement Transducers
(3) Hall Transducer - Applications

- Measurement of conductivity and mobility of charge carriers:

  $$\frac{V_H}{I} = \frac{Bd}{Ane} = R$$

  As R is the resistance of the rectangular strip

  But $R = \rho \frac{d}{A}$ $\quad \therefore \rho = \frac{B}{ne}$ Where ρ is the resistivity

  And $\sigma = \frac{ne}{B}$ Where σ is the conductivity

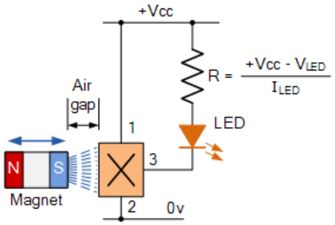
  And from this equation we can Determine the mobility of the charge carriers which given by

  $$\mu = \frac{\sigma}{ne}$$

- Detect the presence and magnitude of a magnetic field.
- Measurement of magnetic flux density B and the magnetic field intensity H:
  $H = \frac{B}{\mu_0}$, where μ_0 is the permeability of free space.

Displacement Measurement Transducers (3) Hall Transducer - Applications

Positional Detector

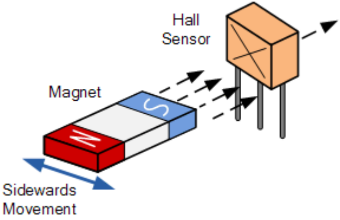


This head-on positional detector will be "OFF" when there is no magnetic field present, (0 gauss). When the permanent magnets south pole (positive gauss) is moved perpendicular towards the active area of the Hall effect sensor the device turns "ON" and lights the LED. Once switched "ON" the Hall effect sensor stays "ON".

Displacement Measurement Transducers (3) Hall Transducer - Applications

Sideways Detection

The second sensing configuration is "sideways detection". This requires moving the magnet across the face of the Hall effect element in a sideways motion.



Sideways or slide-by detection is useful for detecting the presence of a magnetic field as it moves across the face of the Hall element within a fixed air gap distance for example, counting rotational magnets or the speed of rotation of motors.