Sensors and Instrumentation (EEL208)

by

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Variable inductance transducers

- Change of self-inductance
- Change of mutual inductance
- Production of eddy current

Self inductance

- Differential output configuration
- Advantages
  - Sensitivity and accuracy are increased
  - Output is less affected by the external magnetic field
  - Variation due to temperature changes is reduced
  - Effect of change in supply voltage is reduced

Mutual inductance

- ❑ Working principle
- ❑ Air-cored coils
- ❑ Iron core coils
    - ❑ Advantages: small size and less sensitive to external magnetic field

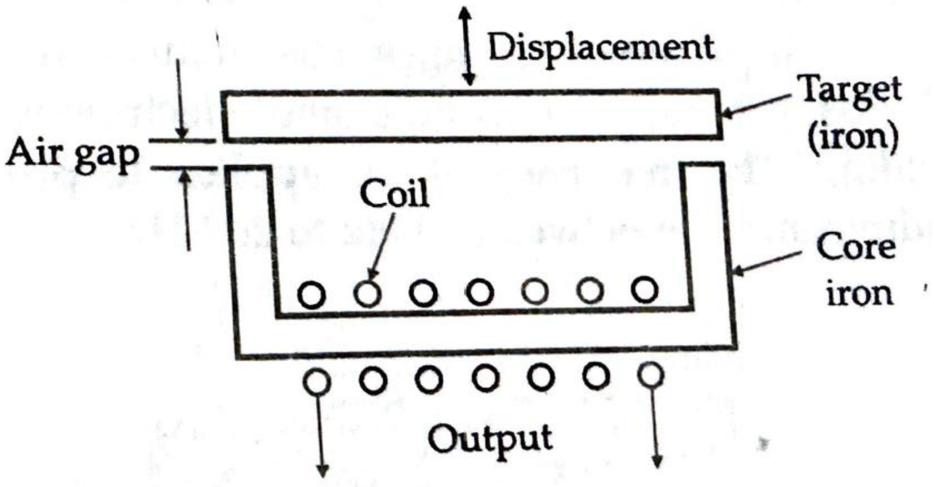
Eddy current transducers

- ❑ Working principle
- ❑ Application

Eddy current transducers

Numerical example 1:

In a variable reluctance type proximity inductive transducer shown in the Figure the coil has an inductance of 2 mH when the target made of ferromagnetic material is 1 mm away from the core. Calculate the value of inductance when a displacement of 0.02 mm is applied to the target in a direction moving it towards the core. Show that the change in inductance is linearly proportional to the displacement. Neglect the reluctance of the iron parts.



Ans: Change in inductance = 40 uH

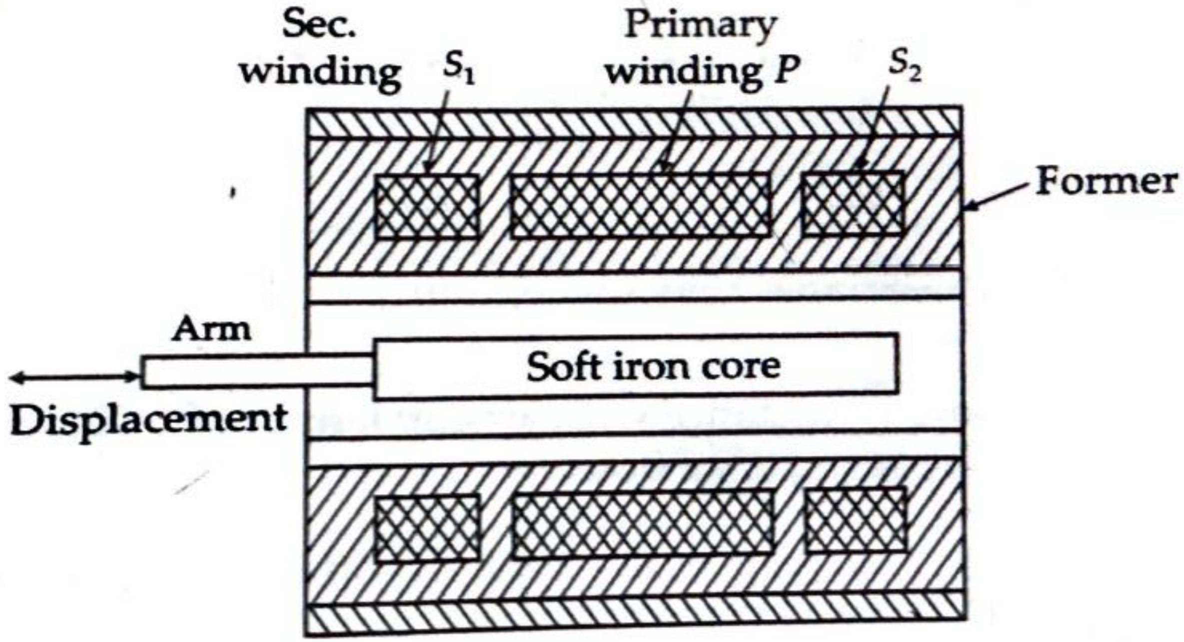
Eddy current transducers

Why iron core inductors are not used for high-frequency applications?

- **Eddy current loss**
- **Hysteresis loss**
- Saturation of core
- Poor permeability

LVDT

- ❑ Core: nickel and iron alloy
- ❑ Working principle
- ❑ Input frequency = 50 Hz to 20 kHz
- ❑ Connected in series opposition
- ❑ Phase difference
- ❑ Residual voltage



Advantages of using LVDT

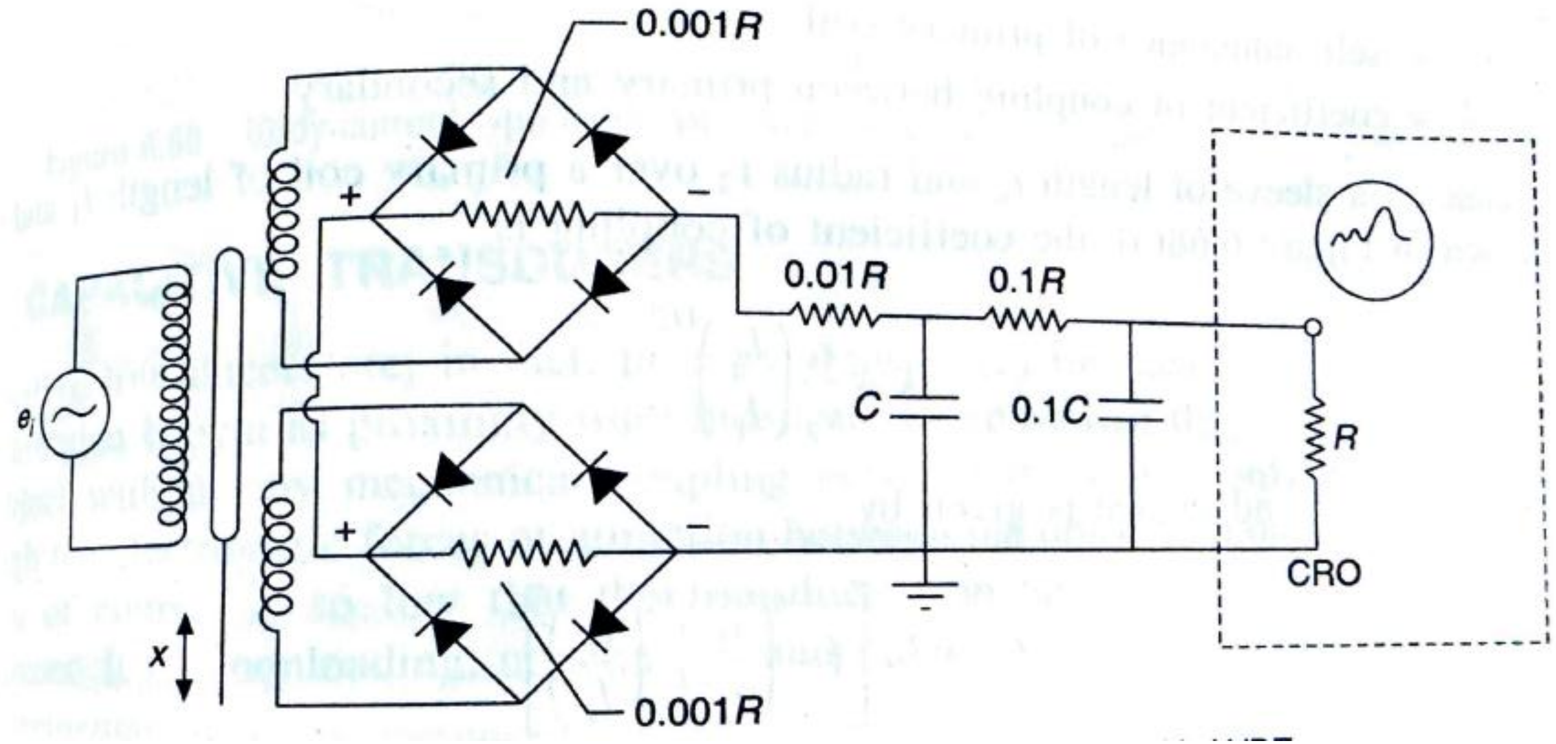
- ❑ Linearity
- ❑ High resolution
- ❑ High output
- ❑ High sensitivity
- ❑ Ruggedness
- ❑ Less friction
- ❑ Low hysteresis
- ❑ Low power consumption

Disadvantages of using LVDT

- ❑ Sensitive to stray magnetic field
- ❑ Sensitive to temperature change
- ❑ Limited to frequency application below 20 kHz

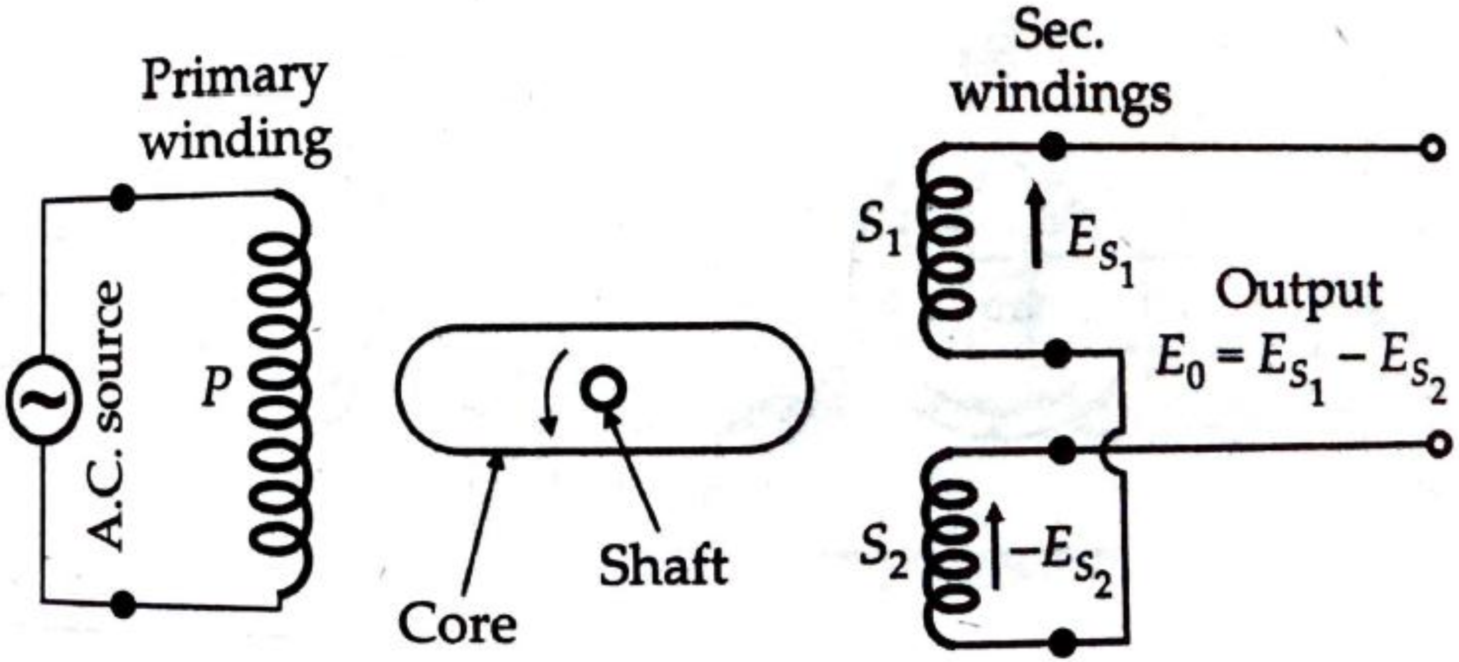
LVDT

- Polarity sensitive demodulator



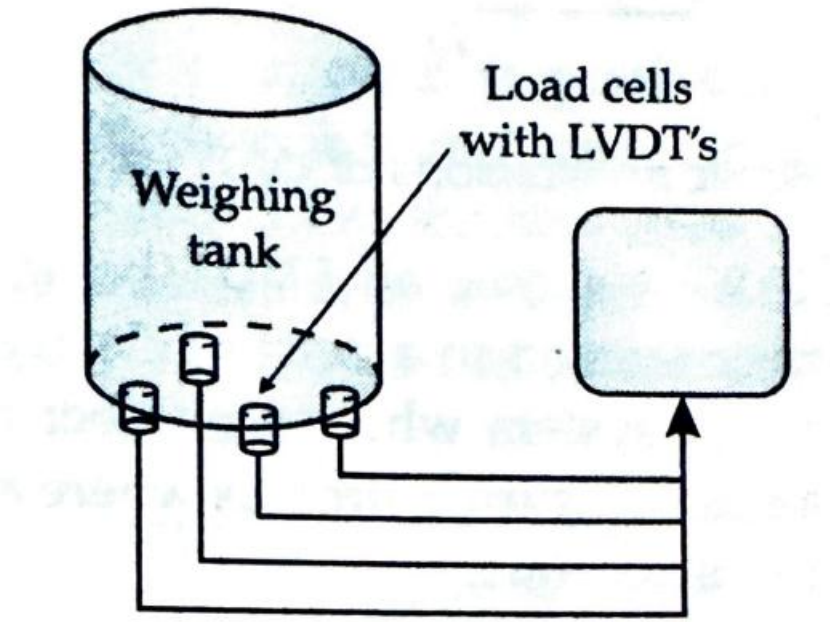
RVDT

- Working principle



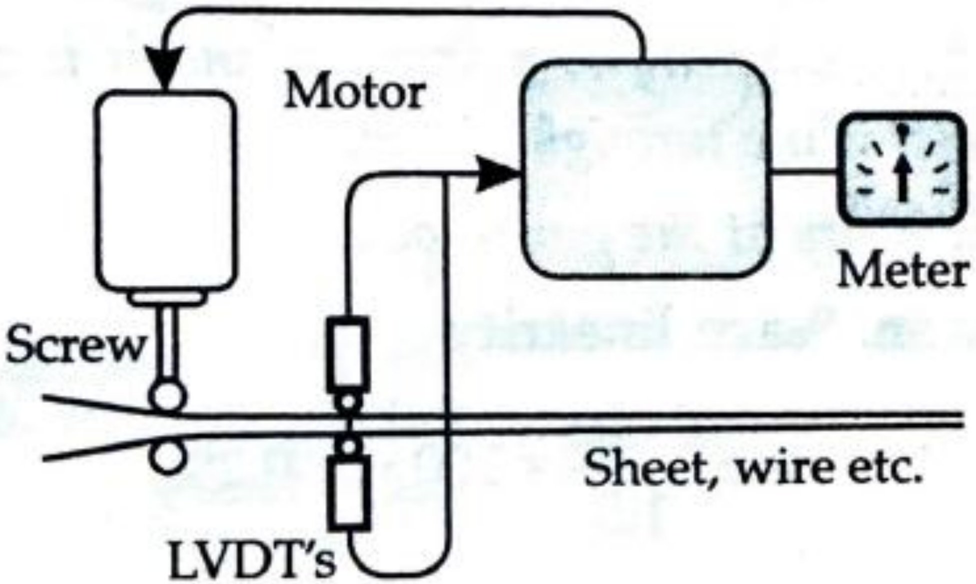
LVDT

- Application:



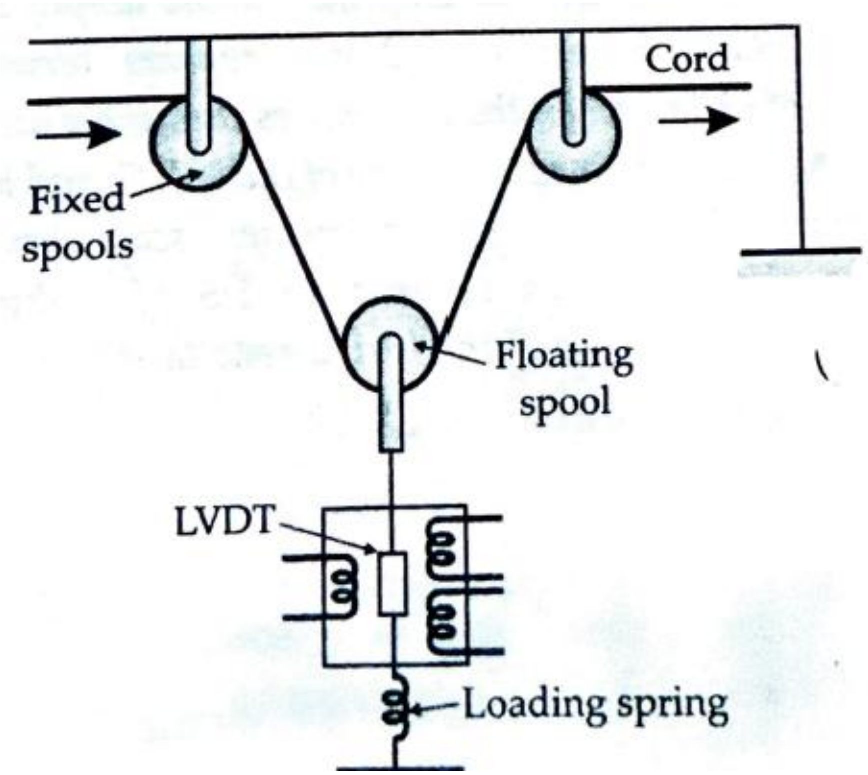
LVDT

- Application:



LVDT

- ❑ Application:

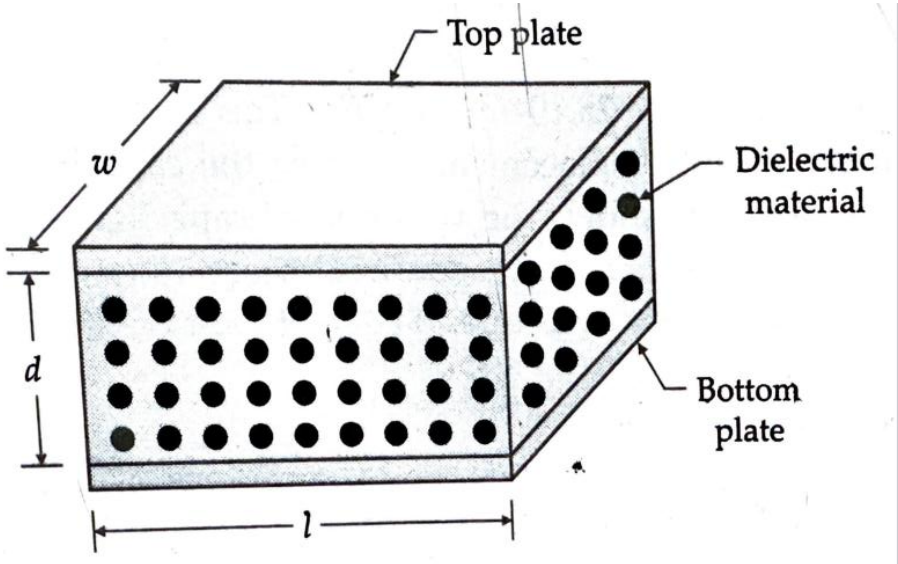


Capacitive transducer

- ❑ Working principle
- ❑ Governing equation

$$C = \varepsilon A/d$$

$$C = \varepsilon_r \varepsilon_0 A/d$$



Capacitive transducer

- Working principle:
  - Change in overlapping area
  - Change in distance
  - Change the dielectric constant

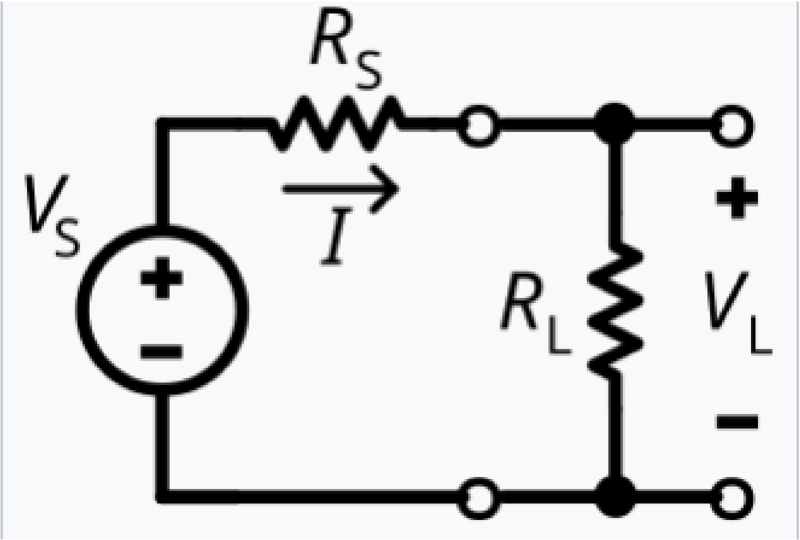
- Output impedance

$$X_c = 1/2\pi f C$$

- Maximum power transfer theorem

Capacitive transducer

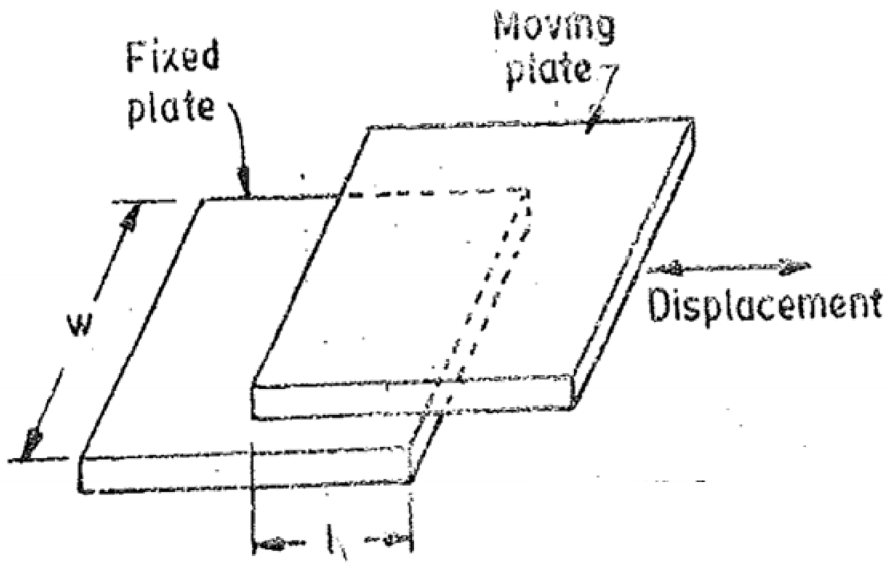
Impedance matching



$$\eta = \frac{P_L}{P_{Total}} = \frac{I^2 \cdot R_L}{I^2 \cdot (R_L + R_S)} = \frac{R_L}{R_L + R_S} = \frac{1}{1 + R_S/R_L}.$$

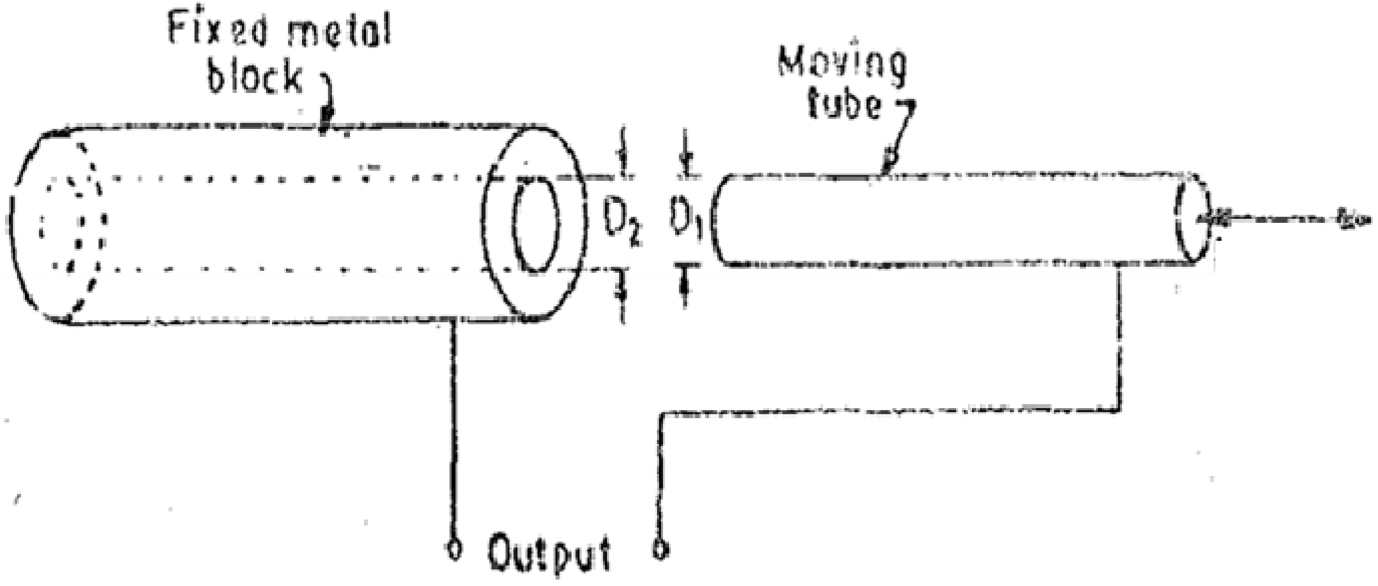
Capacitive transducer

Change in area



Capacitive transducer

Change in area



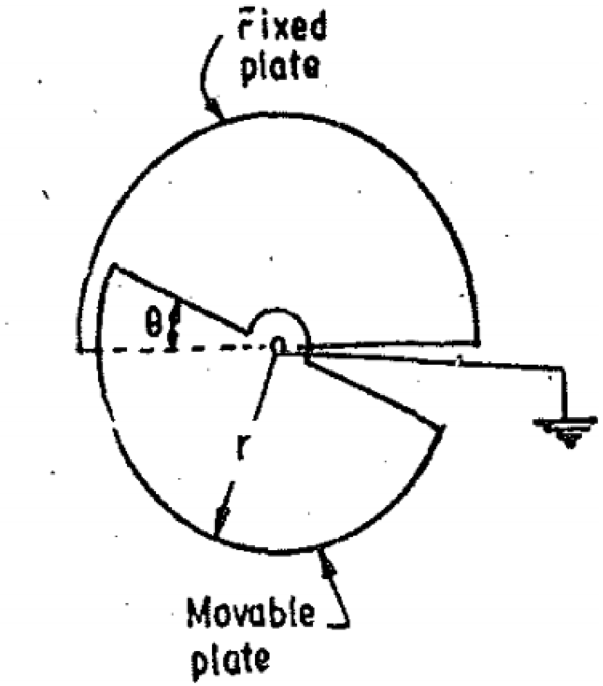
$$C = \frac{2\pi\epsilon l}{\log_e(D_2/D_1)}$$

Capacitive transducer

Change in area (angular displacement)

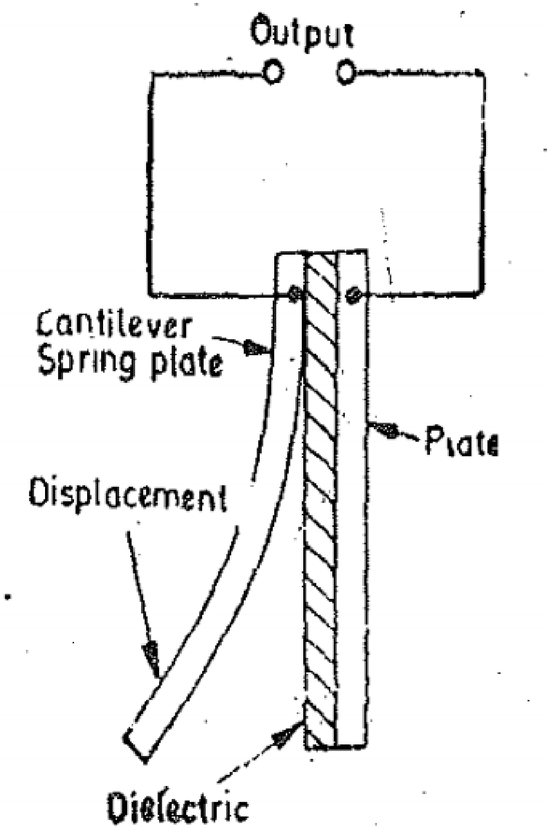
$$C_{\mathrm{multi}} = \frac{\epsilon A}{d} = \frac{\pi \epsilon r^2}{2d}$$

$$C = \frac{\epsilon r^2}{2d} \cdot \theta$$



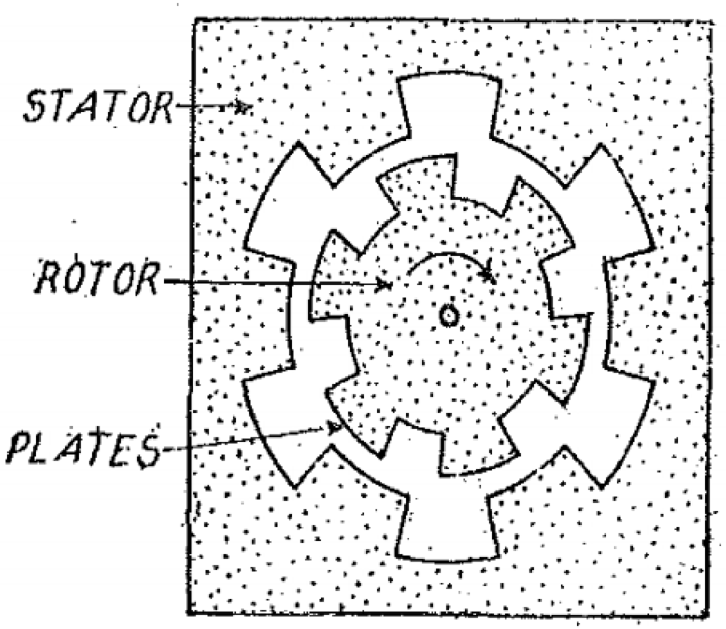
Capacitive transducer

Applications: cantilever spring plate



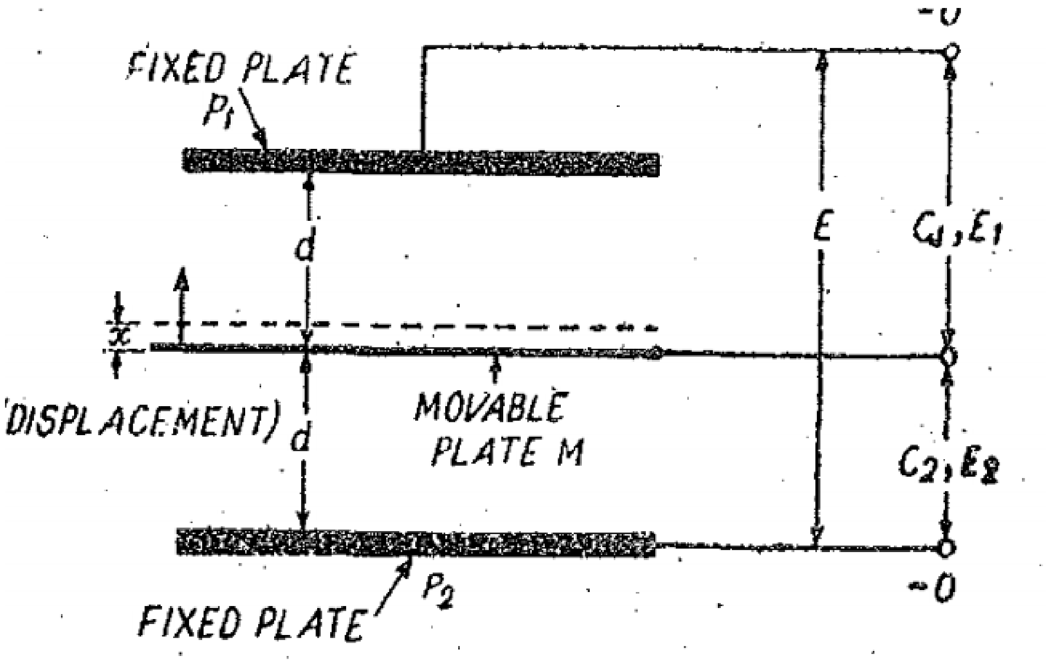
Capacitive transducer

Applications: rotational displacement



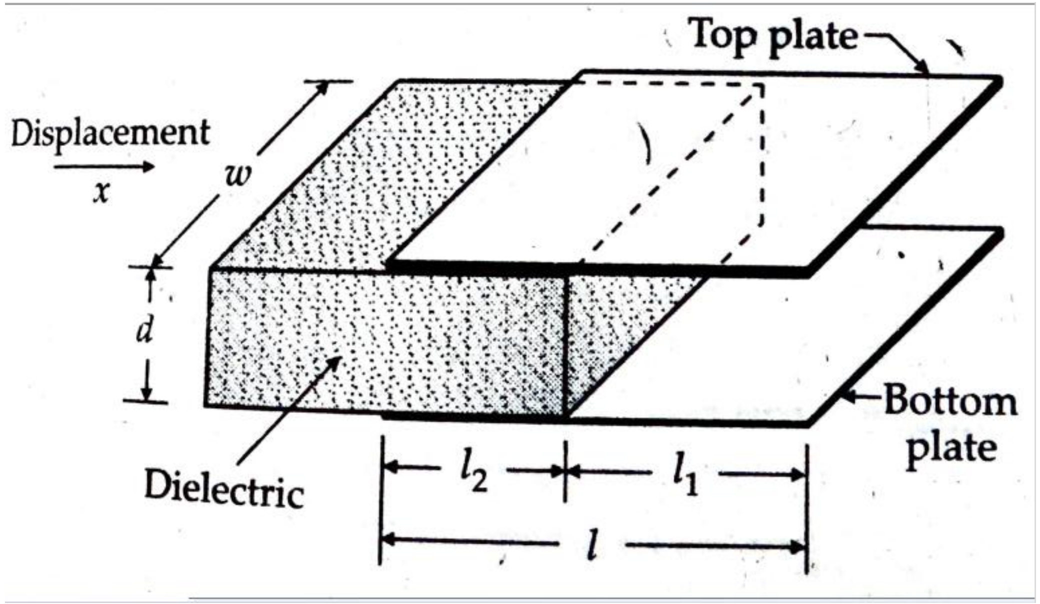
Capacitive transducer

Differential arrangement



Capacitive transducer

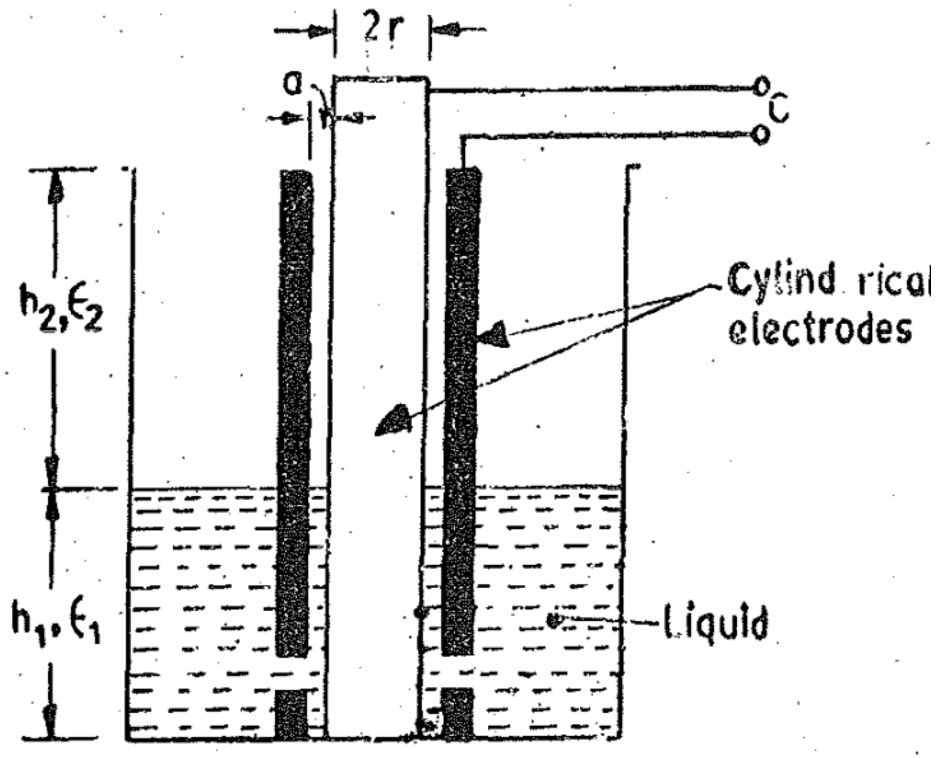
Variation of dielectric constant



Capacitive transducer

Liquid level measurement

$$C = 2\frac{h_1\epsilon_1 + h_2\epsilon_2}{\log_e(1 - a/r)}$$



Advantages of capacitive transducers

- Small operating force
- Extremely sensitive
- Good frequency response
- Minimum loading effect
- Small operating voltage is required
- Low resolution can be obtained using these transducers

Disadvantages of capacitive transducers

- Insulation
- Edge effect → Guard ring
- High output impedance
- Connecting cable
- Environmental effect (dust particles and moisture)
- Temperature sensitivity
- Signal conditioning unit

Capacitive transducer

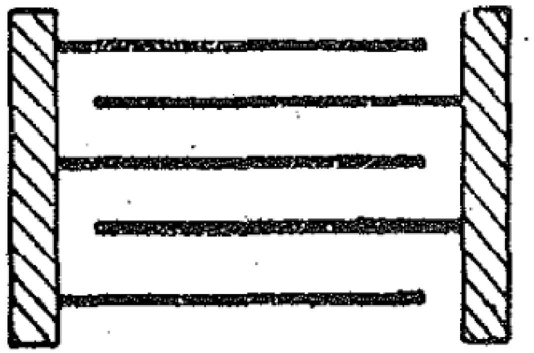
Applications of capacitive transducers

- Measurement of linear and angular displacement
- Measurement of force and pressure
- Pressure sensor → Change in dielectric constant
- Measurement of humidity

Capacitive transducer

Numerical example 1:

The figure shows a capacitive transducer using five plates. The dimensions of each plate are 25 × 25 mm and the distance between plates is 0.25 mm. This arrangement is to be used to measure displacement by observing the change in capacitance with the distance x. Calculate the sensitivity of the device. Assume that the plates are separated by air. The permittivity of air is 8.85×10^{-12} F/m.



Ans: 3.54 pF/mm

Numerical example 2:

A capacitive transducer uses two quartz diaphragms of area 750 mm^2 separated by a distance of 3.5 mm. A pressure of 900 kN/m^2 when applied to the top diaphragm produces a deflection of 0.6 mm. The capacitance is 370 pF when no pressure is applied to the diaphragms. Find the value of capacitance after the application of a pressure of 900 kN/m^2.

Ans: 306.6 pF

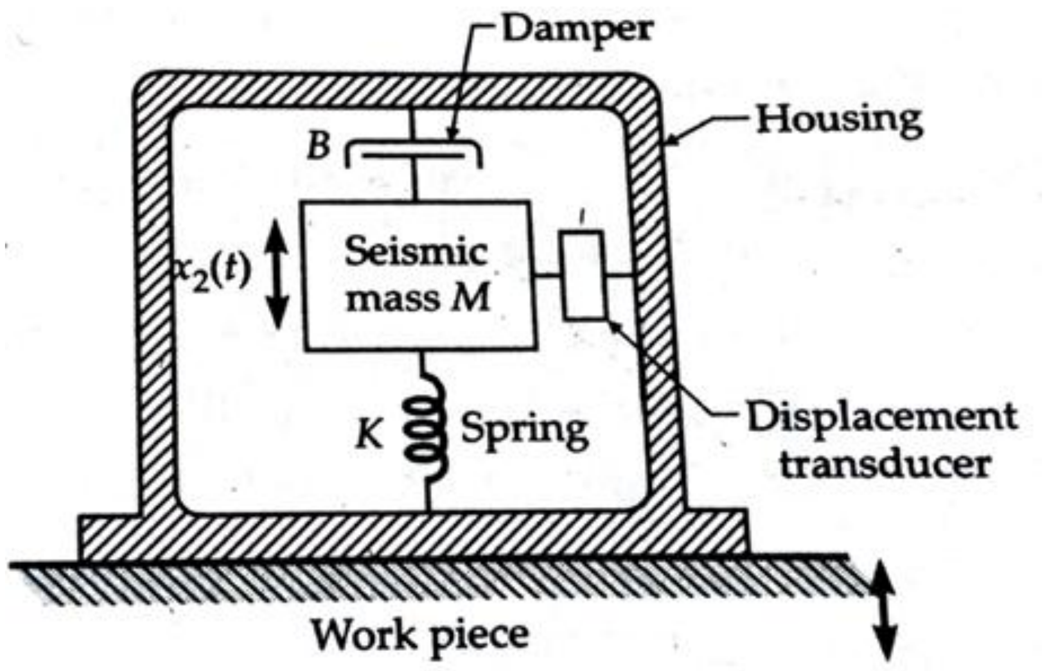
Numerical example 3:

A capacitive transducer is made up of two concentric cylindrical electrodes. The outer diameter of the inner cylindrical electrode is 3 mm and the dielectric medium is air. The inner diameter of the outer electrode is 3.1 mm.
(a) Calculate the dielectric stress when a voltage of 100 V is applied across the electrodes. Is it within safe limits? The breakdown strength of air is 3 kV/mm.
(b) The length of electrodes is 20 mm. Calculate the change in capacitance if the inner electrode is moved through a distance of 2 mm. The permittivity of air is 8.85×10^{-12} F/m.

Ans: a) 2 kV/mm b) 3.4 pF

Accelerometer

- ❑ Measurement of vibration (Displacement, velocity, vibration, peak value, and frequencies)
- ❑ Working principle
- ❑ Modes: displacement and acceleration



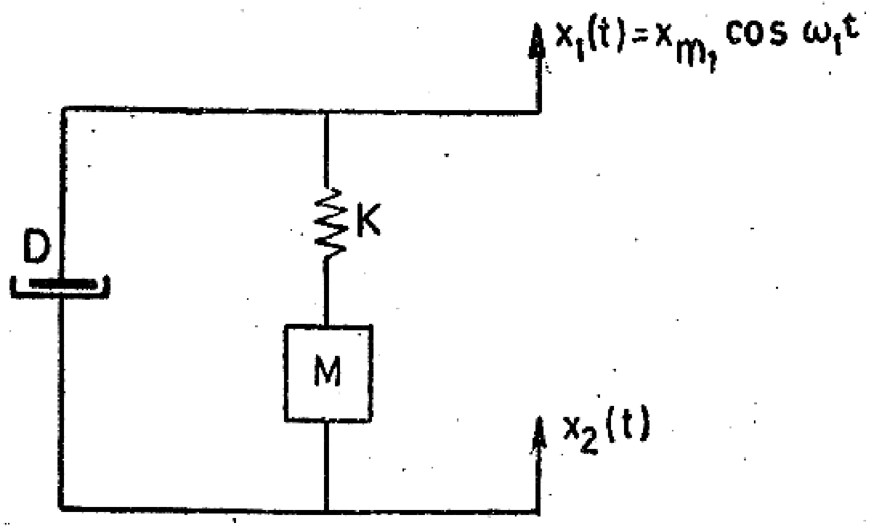
Accelerometer

$$X_1 = X_{m1}\cos(\omega_1 t).$$

$$M\ddot{x}_2 + B\dot{x}_2 + Kx_2 = B\dot{x}_1 + Kx_1$$

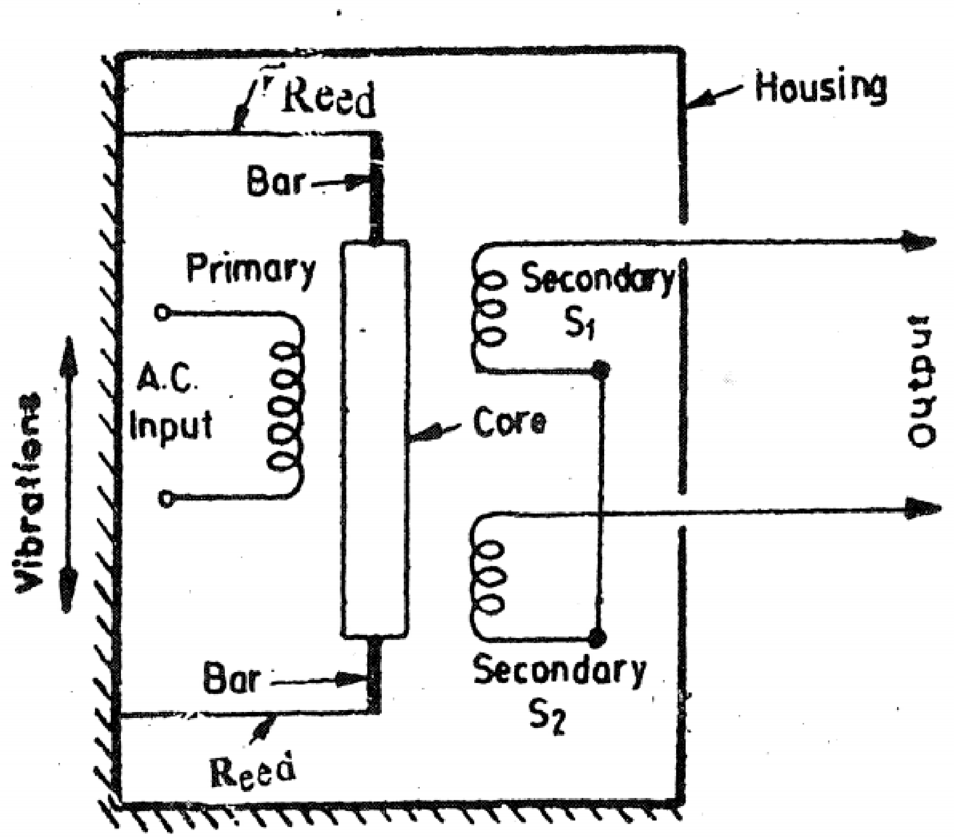
$$\ddot{x}_2 + \left(\frac{D}{M}\right)\dot{x}_2 + \left(\frac{K}{M}\right)x_2 = x_0\left[\left(\frac{K}{M}\right)\cos\omega_1 t - \left(\frac{D}{M}\right)\omega_1 \sin\omega_1 t\right]$$

$$x = x_2 - x_1 = \frac{Mx_{m1}\omega_1^2\cos(\omega_1 t - \phi)}{\sqrt{(K - M\omega_1^2)^2 + D^2\omega_1^2}}$$



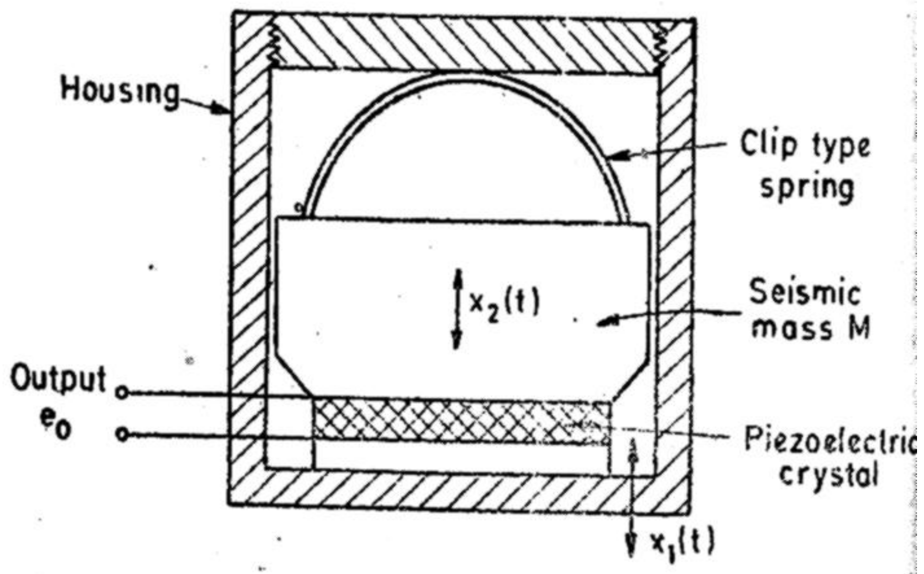
Accelerometer

- ❑ Potentiometric type accelerometer
- ❑ LVDT accelerometer

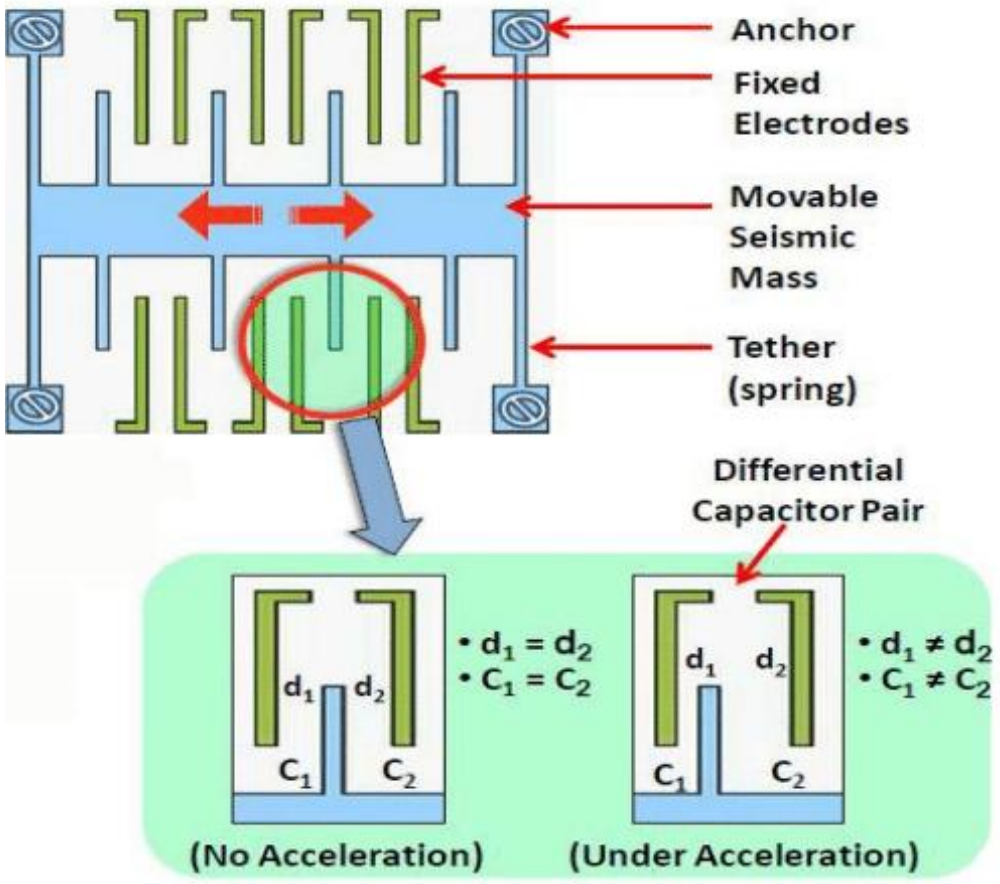


Accelerometer

Piezoelectric accelerometer



MEMS Accelerometer

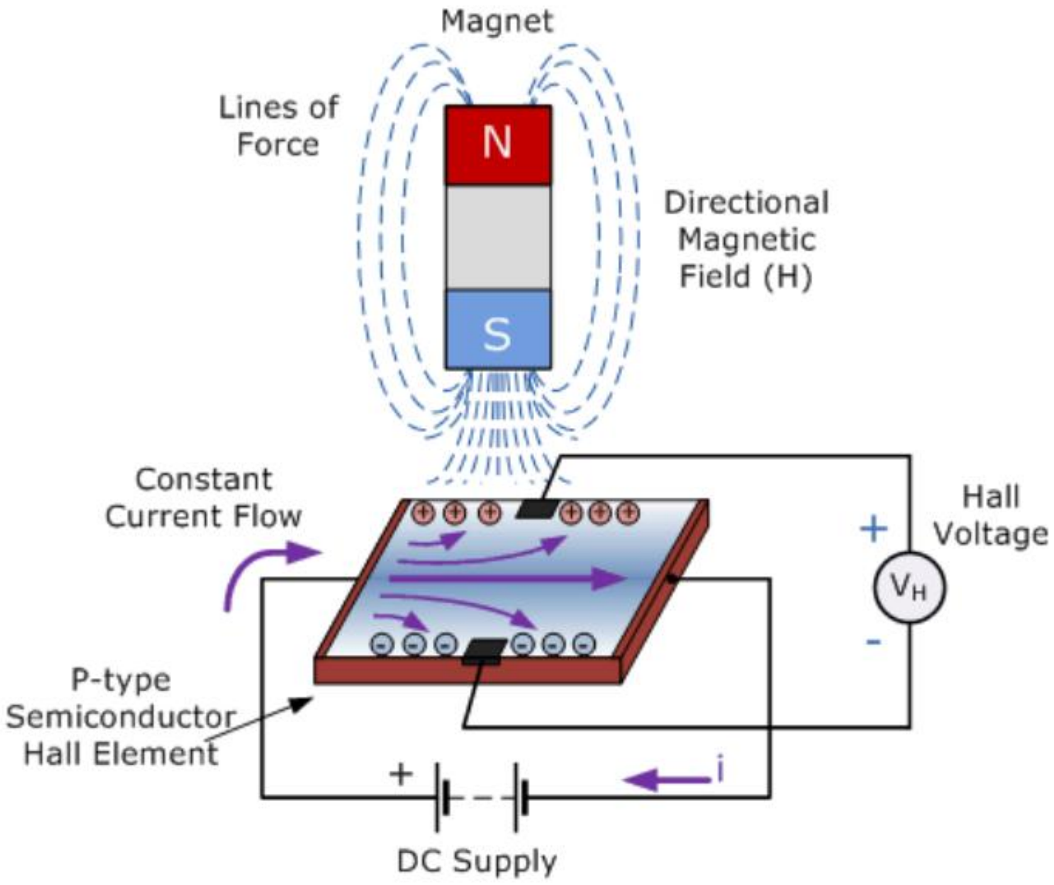


Amerini et al. 2016

Hall effect sensor

Hall voltage

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



Hall effect sensor

Lorentz force $F = q(v_d \times B)$

Balancing magnetic force $qE_H = qv_dB$

Current density $J = nqv_d$, $v_d = \dfrac{J}{nq} = \dfrac{I}{nqA} = \dfrac{I}{nqwt}$, $E_H = \left(\dfrac{I}{nqwt}\right) B$

Hall voltage $V_H = E_H \cdot w$

$$V_H = \left(\frac{I}{nqwt} B\right) w$$

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

$$V_H = \frac{IB}{nqt}$$

Hall effect sensor

Application

- Position sensing
- Velocity sensing
- Measurement of current

References

- Measurement Systems: Application and Design, Ernest O. Doebelin, Paperback
- Sensor & transducers, D. Patranabis, 2nd edition, PHI
- Instrument transducers, H.K.P. Neubert, Oxford University press
- Measurement systems: application & design, E.A.Doebelin, Mc Graw Hill.
- Electrical and Electronics Measurement, A. K. Sawhney, *Dhanpat Rai & Co* (2005)

Thank you for your attention!