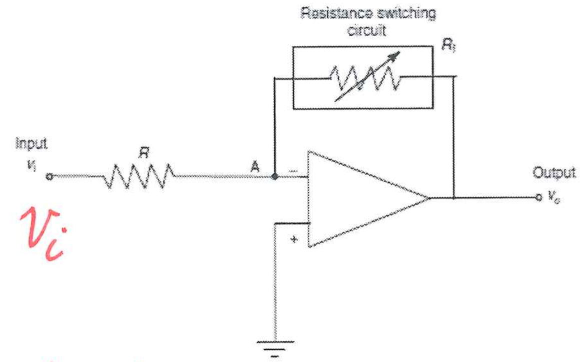
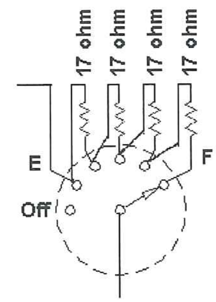
Curve Shaping Circuitry:

- Sort of like an amplifier with adjustable gain.
- Adjustable Feedback resister R_f
- Bank of resistors and automatic switching can be deployed using Zener diodes.



- Amplifier Gain Variable in discrete steps
- One can use a potentiometer as R_f (feed back resistor) so the gain can be adjusted continuous
- Various Resistor steps ⇒ Diff V



Looking at Node-A.

$$\frac{V_i}{R} + \frac{V_o}{R_f} = 0$$

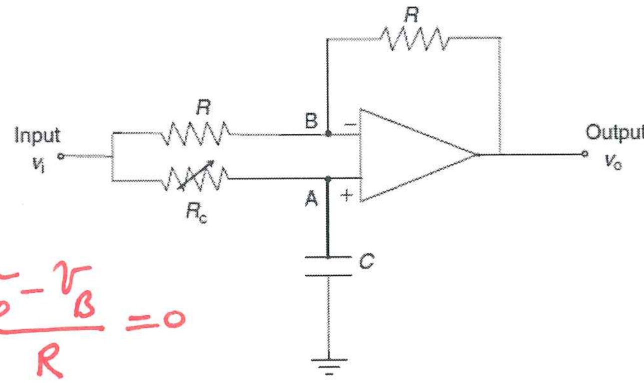
$$V_o = -\frac{R_f}{R} V_i$$

$$\therefore \quad V_o \propto R_f \qquad \text{(ignore -ve sign)}$$

Phase Shifters:

phase Angle $\propto R_c$?

Starting with Nodes A & B.



Node A

$$\frac{v_i - V_A}{R_c} = \frac{C\,dv_A}{dt}$$

$$V_i = v_A + R_c C \frac{dv_A}{dt}$$

Laplace !!

$$v_i = V_A + R_c C\, v_A s$$

$$v_i = V_A(1+\tau s) \quad -①$$

Node B

$$\frac{v_i - V_B}{R} + \frac{v_o - v_B}{R} = 0$$

$$\frac{V_i}{R} - \frac{V_B}{R} + \frac{v_o}{R} - \frac{v_B}{R} = 0$$

$$V_B = \frac{1}{2}(v_i + v_o) \quad -②$$

Ideal op Amp $v_A = v_B$; Sub ② into ①

$$V_i = \frac{1}{2}(v_i + v_o)(1+\tau s) \;; \quad \tau = R_c C \text{ : Time constant.}$$

Transfer function. $G(s)$ can be evaluated as follows:

$$\frac{v_o}{v_i} = G(s) = \frac{1-\tau s}{1+\tau s}$$

Magnitude $|G(j\omega)| = \dfrac{\sqrt{1+\tau^2\omega^2}}{\sqrt{1+\tau^2\omega^2}} = 1.$

phase Angle $\angle G(j\omega) = -\tan^{-1}\tau\omega - \tan^{-1}\tau\omega$

$$= -2\tan^{-1}\tau\omega$$

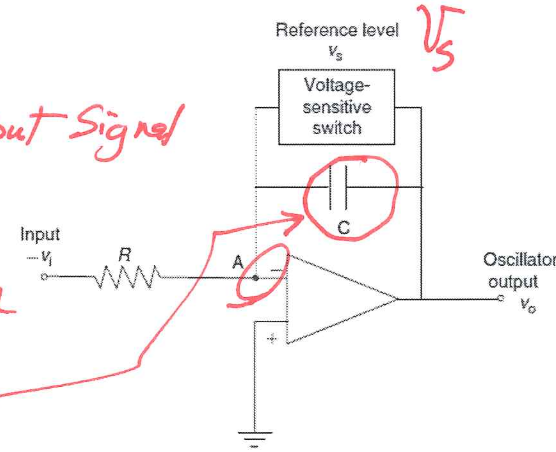
$$= -2\tan^{-1} R_c C\,\omega$$

$\therefore$ Phase Angle $\propto R_c$

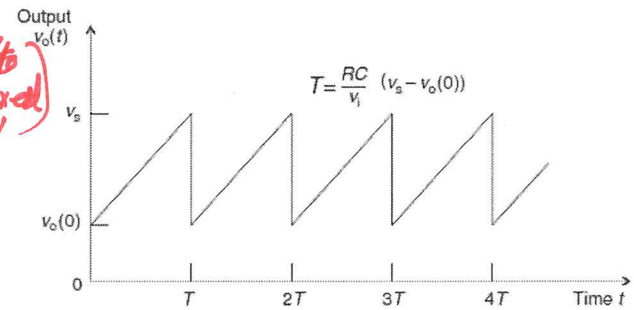
Magnitude $= 1 \Rightarrow$ Undistorted; Angle being $-ve \Rightarrow$ phase lag.

and Phase lag $\propto R_c$

Voltage to Frequency Convertor: (VFC)



- VFC produces a periodic output signal
  output signal 'f' $\propto$ level of V_i
- Also called VCO: Voltage Controlled Oscillator
- Most Common: use a CAP.



- Time required for CAP to charge to fixed V is inversely proportional to charging voltage.

Node-A $\quad \frac{v_i}{R} = C\frac{dv_o}{dt}$

$$V_o(t) = \frac{1}{RC} v_i(t) + V_o(0)$$

Switch closes when $V_o(t) = V_s$ (ref); CAP discharges

CAP charging time T is given by

$$V_s = \frac{1}{RC} V_i T + V_o(0)$$

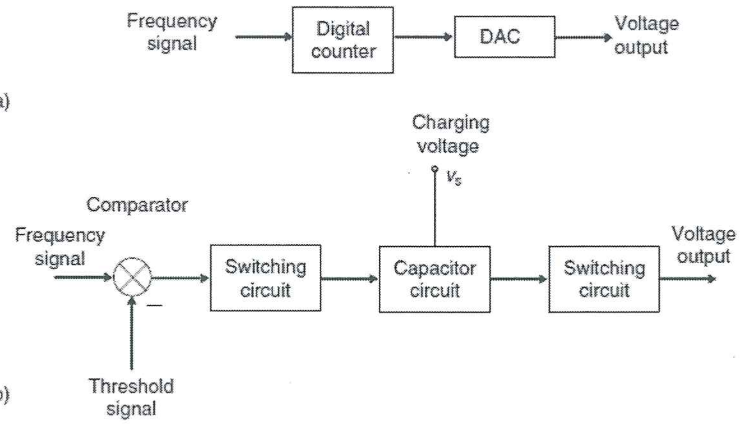
$$\therefore \quad T = \frac{RC}{V_i}\left(V_s - V_o(0)\right)$$

Switch opens again to charge / closes to discharge

$\Rightarrow$ sawtooth wave

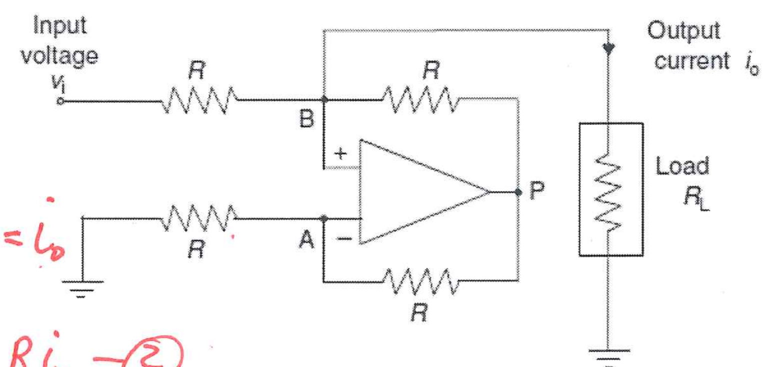
$$f = \frac{V_i}{RC(V_s - V_o(0))}$$

Frequency to Voltage Convertor



* Use digital counter to count signal frequency and use DAC to obtain voltage proportional to frequency
* Frequency signal supplied to comparator with threshold voltage level.
  - output depends on which level is higher or lower than other. (sign)
  - First sign change (− to +) in comparator will trigger switching and connect to charge CAP.
  - Next (+ to −) change will short CAP & discharge.
  - level of charge is dependant on switching period.
  - used for demodulation

Voltage to Current Convertor:



Node-A

$$\frac{V_A}{R} = \frac{V_P - v_A}{R}$$

$$\Rightarrow 2V_A = v_P \quad (1)$$

Node-B

$$\frac{V_i - V_B}{R} + \frac{V_P - V_B}{R} = i_o$$

$$\Rightarrow V_i - 2V_B + v_P = R i_o \quad (2)$$

using fact $v_A = v_B$
sub (1) into (2)

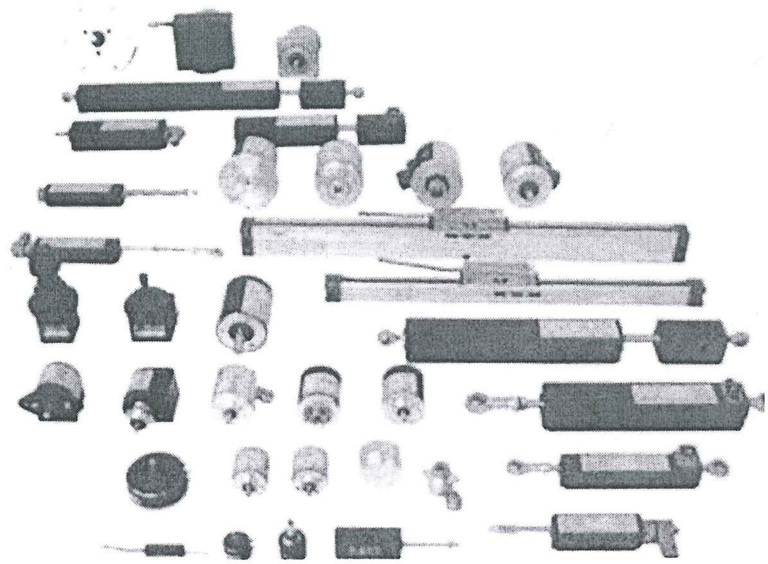
$$i = \frac{v_i}{R} \qquad \therefore i \propto v_i$$

Motion Transducers:

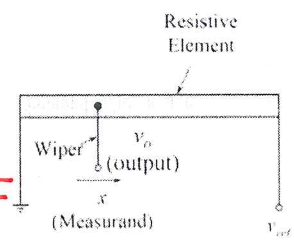
- Potentiometers (resistively coupled)
- Variable inductance (electromagnetically coupled)
- Variable capacitance
- Eddy current
- Piezoelectric

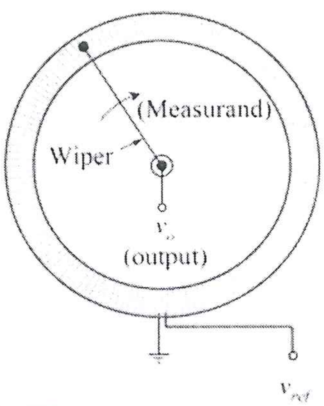
Potentiometer:

- Uniform coil of wire or a film of high resistive material- Carbon, platinum, or conductive plastic.

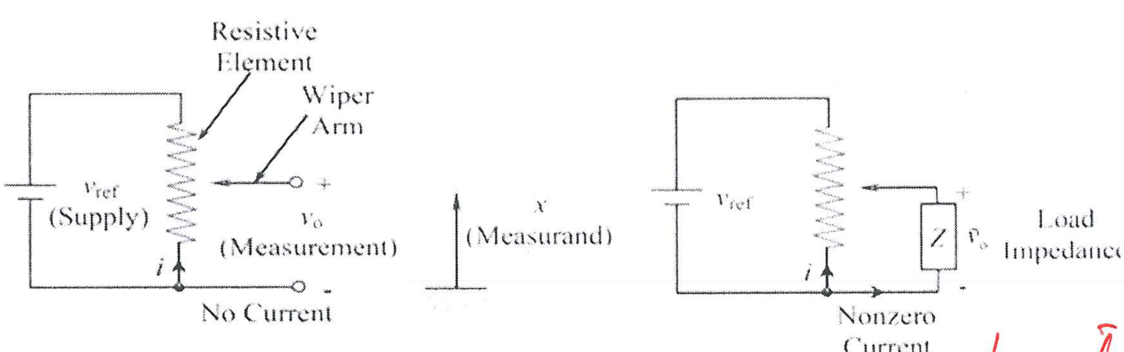


Recti linear





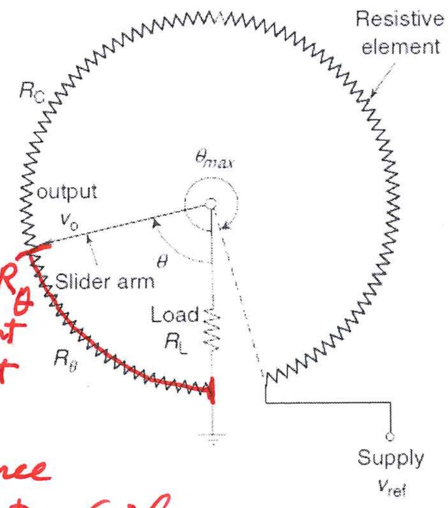
Angular Motions



Loading

As load is connected Vref will change?

Loading Nonlinearity:



- What is the significance of the electrical loading nonlinearity error caused by a purely resistive load connected to the pot?

- For general position θ of Arm, let $R = R_\theta$ in Output Segment
- Assuming Coil is Uniform

$$\therefore \quad R_\theta = \frac{\theta}{\theta_{max}} R_C \leftarrow \text{Total Resistance of Potentiometer Coil} \qquad (1)$$

- Current Balance @ Sliding Node (pt.) is:

from here

$$\frac{V_{ref} - V_o}{R_C - R_\theta} = \frac{V_o}{R_\theta} + \frac{V_o}{R_L} \leftarrow \text{Load Resistor}$$

Multiply by R_C & use (1)

$$\frac{V_{ref} - V_o}{1 - \frac{R_\theta}{R_C}} = \frac{V_o}{\frac{R_\theta}{R_C}} + \frac{V_o}{\frac{R_L}{R_C}}$$

θ/θ_{max}

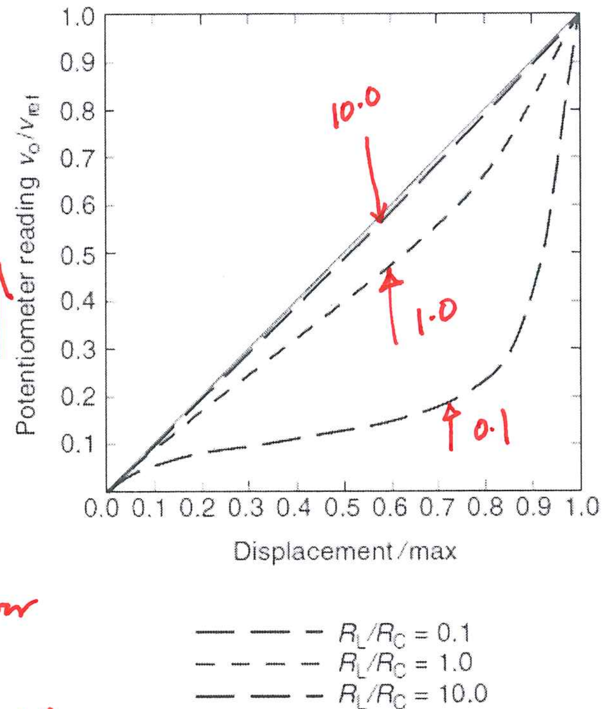
$$\therefore \frac{V_{ref} - V_o}{1 - \frac{\theta}{\theta_{max}}} = \frac{V_o}{\theta/\theta_{max}} + \frac{V_o}{R_L/R_C}$$

$$\frac{V_{ref}}{\frac{\theta_{max} - \theta}{\theta_{max}}} = \frac{V_o}{\frac{\theta_{max} - \theta}{\theta_{max}}} + \frac{V_o}{\theta/\theta_{max}} + \frac{V_o}{R_L/R_C}$$

Applying Algebra:

$$\frac{V_o}{V_{ref}} = \left[\frac{(\theta/\theta_{max})(R_L/R_C)}{\left(R_L/R_C + (\theta/\theta_{max}) - (\theta/\theta_{max})^2\right)}\right]$$

$$\frac{V_o}{V_{ref}} = \left[\frac{\left(\theta/\theta_{max}\right)\left(R_L/R_C\right)}{\left(\frac{R_L}{R_C} + \left(\theta/\theta_{max}\right) - \left(\theta/\theta_{max}\right)^2\right)}\right]$$



- High Loading Error for Low $\frac{R_L}{R_C}$ ratio. ↑ $\frac{V_o}{V_{ref}}$
- Good Accuracy for $R_L/R_C > 10$ & Small Values of θ/θ_{max}

What to do to reduce loading Error in Pots?

- Increase R_L/R_C : Load Impedance V_s Coil Impedance.
- Use Pots to measure Small values of θ/θ_{max}; Calibrate Only a Small Segment of Resistance element for Linear reading

Loading - non-linearity is given by

$$e = \frac{\left(\frac{V}{V_{ref}} - \theta/\theta_{max}\right)}{\theta/\theta_{max}} * 100\%$$

$\frac{R_L}{R_C}$	$\underline{\underline{e}}$ @ $\theta/\theta_{max} = 0.5$
0.1	−71.4 %
1.0	−20 %
10.0	−2.4 %

<u>Resolution</u>: defined by # of turns in COIL.
Coil of N turns, resolution $r = \frac{100}{N}\%$

Example:

A high-precision mobile robot uses a potentiometer attached to the drive wheel to record its travel during autonomous navigation. The required resolution for robot motion is 1 mm, and the diameter of the drive wheel of the robot is 20 cm. Examine the design considerations for a standard (single-coil) rotatory potentiometer to be used in this application.

1mm = 0.1 cm; Diameter = 20 cm ∴ $r = 10$

Circumference = $2\pi(10) = 20\pi$.

Solution:

- Assuming POT is directly connected to drive wheel.
- Required POT resolution; $\frac{0.1\text{ cm}}{20\pi} * 100\% = 0.16\%$
- using $\gamma = \frac{100}{N}\%$ ⇒ $N = \frac{100}{0.16} = 625$ turns
- Pot Dia = 10 cm; Wire diameter = d
- Potentiometer circumference = $\pi * 10 = 625 * d$

$$\therefore d = 0.5\text{mm}$$

- Assume POT resistance = 5Ω
  Wire Resistivity = $4\mu\Omega\,\text{cm}$

  Diameter of Core = $\frac{4 * 10^{-6} \times \pi D * 625}{\pi(0.05/2)^2} = 5\Omega$

- Resistivity = resistance * (X-Sectional Area)/Length

$$\therefore D = 1.25\text{ cm}$$

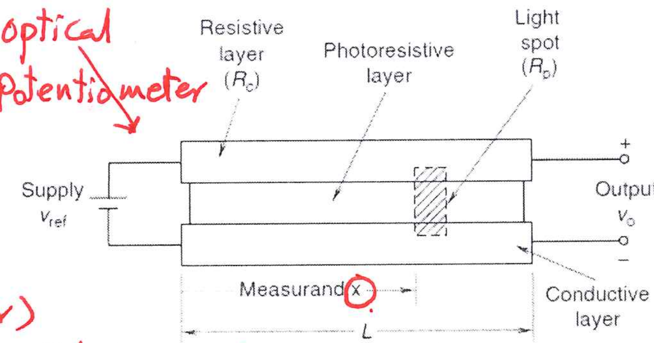
- Potentiometer Sensitivity $S = \frac{\Delta v_o}{\Delta\theta}$; $\frac{\text{Change in } v_o}{\text{Change in } \theta}$

Read Example 4.2 (first Edition) Text.

Optical Potentiometer:

The optical potentiometer, shown is a displacement sensor. A layer of photo-resistive material is sandwiched between a layer of ordinary resistive material and a layer of conductive material.

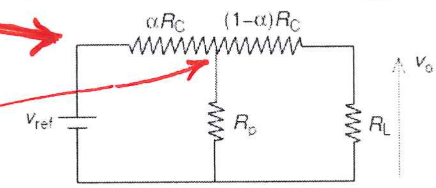
optical Potentiometer



(a)

* At equivalent ckt, R_L (Load Resistor) is present at the output of POT

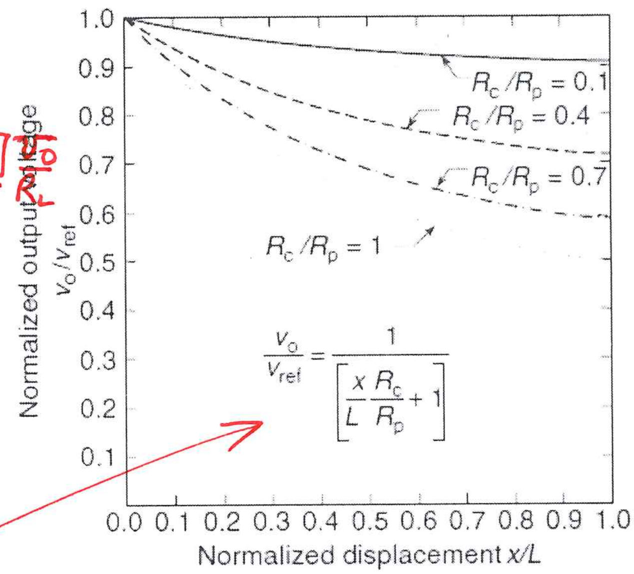
Equivalent Circuit $\alpha = x/L$



(b)

* Current through Load V_o/R_L
* $\alpha = \frac{x}{L}$; Fractional Position of light spot
* Current balance @ Junction:

$$\frac{V_{ref} - [(1-\alpha)R_c + R_L]\frac{V_o}{R_L}}{\alpha R_c} = \frac{V_o}{R_L} + \frac{[(1-\alpha)R_c + R_L]\frac{V_o}{R_L}}{R_p}$$



Can be re-written as:

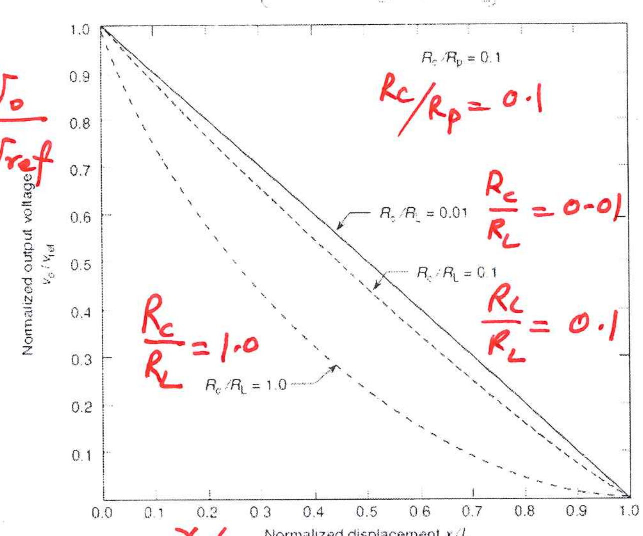
$$\frac{V_o}{V_{ref}}\left\{\frac{R_c}{R_L}+1+\frac{x}{L}\frac{R_c}{R_p}\left[\left(1-\frac{x}{L}\right)\frac{R_c}{R_L}+1\right]\right\}=1$$

If $R_L \gg R_c$; $R_c/R_L \simeq 0$

$$\therefore \frac{V_o}{V_{ref}} = \frac{1}{\left[\frac{x}{L}\cdot\frac{R_c}{R_p}+1\right]};$$

$$\frac{v_o}{V_{ref}}\left\{\frac{R_c}{R_L}+1+0.1\frac{x}{L}\left[\left(1-\frac{x}{L}\right)\frac{R_c}{R_L}+1\right]\right\}=1$$

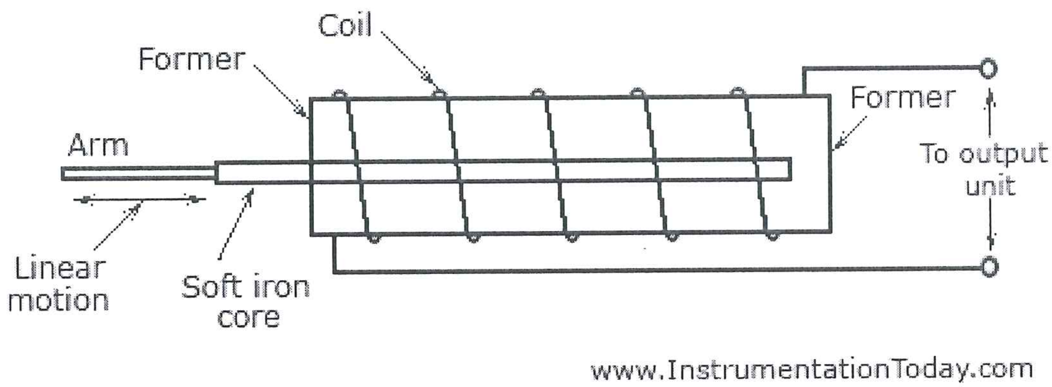
→ Original Equation is plotted → $\frac{V_o}{V_{ref}}$



* Behaviour of optical POT becomes more linear for higher Values of load resistance

Variable Inductance Transducers:

- When the flux linkage (defined as magnetic flux density times the number of turns in the conductor) through an electrical conductor changes, ***a voltage in proportion to the rate of change of flux*** is induced in the conductor.



- This voltage in turn, generates a magnetic field, which opposes the original (primary) field. Hence, a mechanical force is necessary to sustain the change of flux linkage.

- If the change in flux linkage is brought about by a relative motion, the associated mechanical energy is directly converted (induced) into electrical energy.

- This is the basis of electromagnetic induction, and it is the principle of operation of electrical generators and variable-inductance transducers.

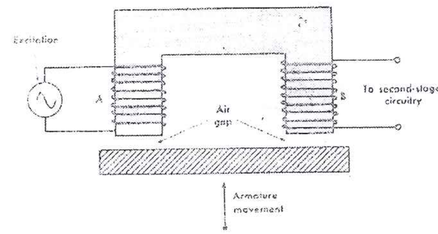
- ***The induced voltage or change in inductance may be used as a measure of the motion.***

Three primary types can be identified as:

- Mutual-induction transducers
- Self-induction transducers
- Permanent-magnet transducers.

Mutual-induction transducers:

- Arrangement of a mutual-induction transducer constitutes two coils, the primary winding and the secondary winding. One of the coils (primary winding) carries an alternating-current (ac) excitation, which induces a steady ac voltage in the other coil (secondary winding).

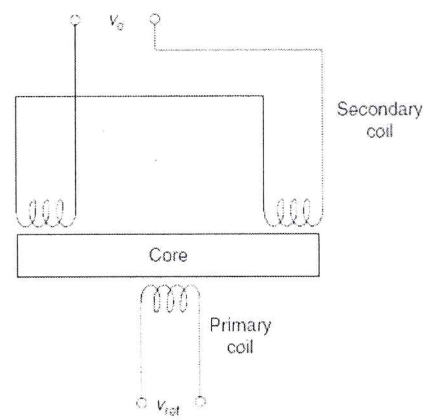


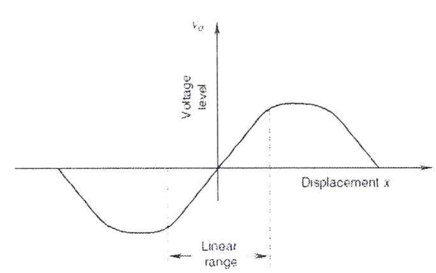
- The level (amplitude, rms-value, etc.) of the induced voltage depends on the flux linkage between the coils.
- None of these transducers employ contact sliders or slip-rings and brushes as do resistively coupled transducers (potentiometer) which results in increased design life and low mechanical loading.
- In mutual-induction transducers, a change in the flux linkage is effected by one of two common techniques.

  - One technique is to ***move an object made of ferromagnetic material within the flux path between the primary coil and the secondary coil.***
  - The other common way to ***change the flux linkage is to move one coil with respect to the other.***
  - Motion can be measured by using the secondary signal (i.e., induced voltage in the secondary coil).

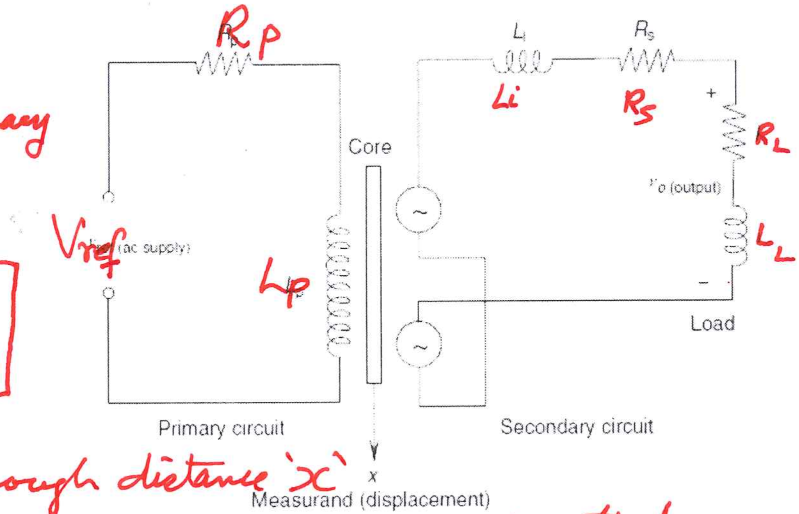
Linear-Variable Differential Transformer (LVDT)

- As the core moves, the reluctance of the flux path between the primary and the secondary coils changes.
- The ***degree of flux linkage*** depends on the axial position of the core.
- Since the two secondary coils are connected in series opposition, so that the potentials induced in the two secondary coil segments oppose each other, it is seen that the ***net induced voltage is zero when the core is centered between the two secondary winding*** segments. *This is known as the null position.* When the core is displaced from this position, a nonzero induced voltage is generated. At steady state, the amplitude $V_0 \propto$ Core displacement x in the linear (operating) region. Consequently, $\boldsymbol{V_0}$ ***may be used as a measure of the displacement.***
- Note that because of opposed secondary windings, the LVDT provides the direction as well as the magnitude of displacement.





Linear-Variable Differential Transformer (LVDT) Equivalent Circuit.



Magnetizing Voltage in Primary Coil is given by:

$$V_p = V_{ref}\left[\frac{j\omega L_p}{R_p + j\omega L_p}\right]$$

*Suppose we move Core through distance 'x' from "Null Position."

CORE of length L_0

*Induced Voltage in ONE secondary segment

$$V_a = V_p K_a\left(\frac{L}{2} + x\right)$$

in the other

$$V_b = V_p K_b\left(\frac{L}{2} - x\right)$$

; K_a, K_b non-linear functions of Core position & complex functions of frequency variable (x).

* Due to series Connection of two segments:

Secondary Voltage $V_s = V_a - V_b = V_p\left[K_a\left(\frac{L}{2}+x\right) - K_b\left(\frac{L}{2}-x\right)\right]$

*Ideal Case: $K_a(\cdot), K_b(\cdot)$ are equal $\therefore V_a = V_b$ and $V_s = 0$ May be ϕ-diff.

* If ϕ-difference; $K_a\left(\frac{L}{2}\right) - K_b\left(\frac{L}{2}\right)$ will have a small diff (Magnitude) but phase will be 90° w.r.t both $K_a + K_b$; This is Quadrature error.

FOR SMALL x, TAYLOR SERIES EXPANSION

$$V_s = V_p\left[K_a\left(\frac{L}{2}\right) + \frac{\partial K_a}{\partial x}\left(\frac{L}{2}\right)x - K_b\left(\frac{L}{2}\right) + \frac{\partial K_b}{\partial x}\left(\frac{L}{2}x\right)\right.$$

If $K_0 = K_a = K_b$ $\quad V_s = 2V_p \dfrac{\partial K_0}{\partial x}\left(\frac{L}{2}\right)x$;

or $\quad V_s = V_p K x$; where $K = 2\dfrac{\partial K_0}{\partial x}\left(\frac{L}{2}\right)$

In this Case Induced Voltage proportional to x is given by:

$$v_s = v_{ref}\left[\frac{j\omega L_p}{R_p + j\omega L_p}\right] Kx$$

Output Voltage v_o at Load is given by:

$$v_o = \left[\frac{j\omega L_p}{R_p + j\omega L_p}\right]\left[\frac{R_L + j\omega L_L}{(R_L + R_s) + j\omega(L_L + L_1)}\right] Kx$$

For Small displacements:

$$v_o\,(LVDT) \propto \text{displacement } x$$

ϕ-lead @ the output is given by:

$$\phi = 90^\circ - \tan^{-1}\frac{\omega L_p}{R_p} + \tan^{-1}\frac{\omega L_L}{R_L} - \tan^{-1}\frac{\omega(L_L + L_1)}{R_L + R_s}$$

* Level of dependancy of ϕ-shifts on the load including Secondary Can be:

Reduced by increasing the Load Impedance.