Introduction to Variable Resistance Transducers

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Introduction

- **Variable resistance transducers**- the subject of this section are typical ‘active’ transducer; they require an energizing source.

- They may roughly be divided into two classes:
  - ❑ Transducers operating on large changes of resistance, employing mainly potentiometer circuits.
  - ❑ Transducers operating on small changes of resistance, employing mainly bridge circuit.

- The two classes are concerned with different characteristics.
- It is generally seen that methods which involve the measurement of change in resistance are preferred.
- This is because both alternating as well as direct currents and voltages are suitable for resistance measurement.

Principle of Operation

- The resistance of a metal conductor is expressed by a simple equation.
- The relationship is $$R = \frac{\rho L}{A}$$

- Where R= resistance;Ω

L= length of the conductor; m

A= cross-sectional area of the conductor; m2

ρ= resistivity of the conductor material; Ω-m

- The method of varying one of the quantities involved in the above relationship can be the design basis of **an electrical resistive transducer.**

Principle of Operation

- There are a number of ways in which resistance can be changed by a physical phenomenon.

- The **translational and rotational potentiometers** which work on the basis of change in the value of resistance with change in length of the conductor.

- The **strain gauges** work on the principle that the resistance of a conductor or a semiconductor changes when strained. This property can be used for measurement of displacement, force and pressure.

- The resistivity of materials changes with change of temperature and these causing a change of resistance. This property may be used for **measurement of temperature. Example: RTD**

Potentiometer

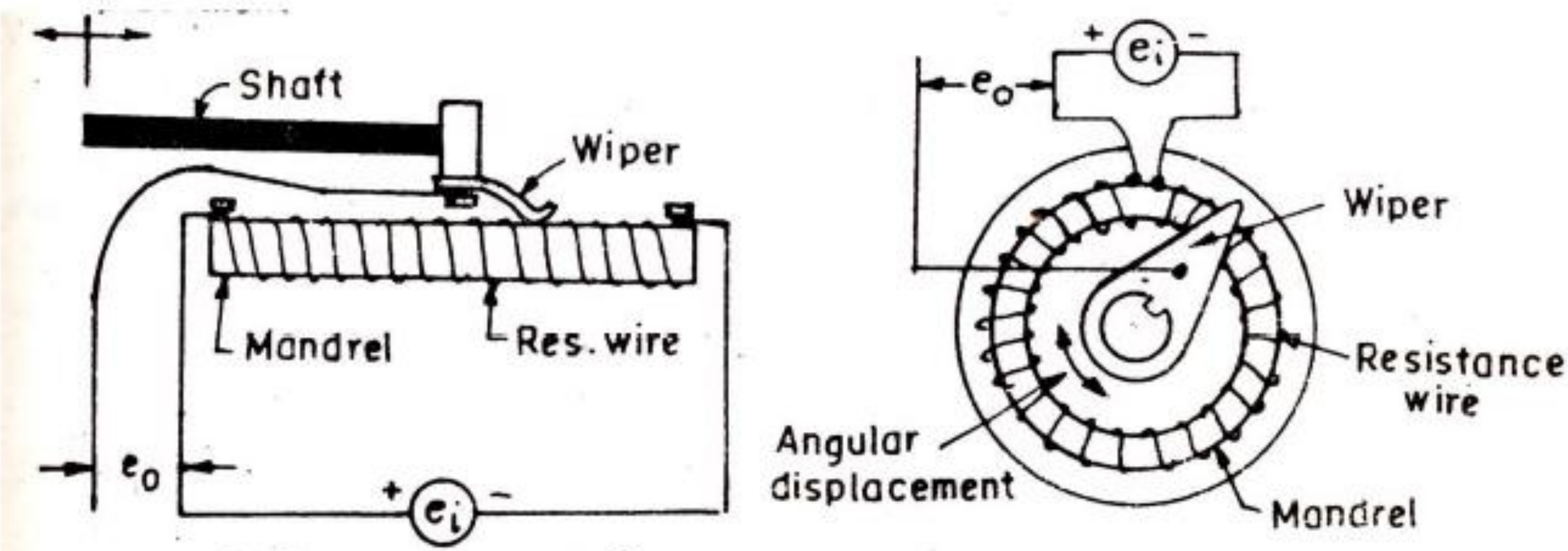
- A **resistive potentiometer** consists of a resistance element provided with a movable/sliding contact.
- It is also known as POT(used for voltage division).

- The contact motion can be translation, rotation, or a combination of the two (helical motion in a multi-turn rotational device helopot), thus allowing measurement of rotary and translatory displacement.

- The resistance element is excited with either dc or ac voltage, and the output voltage is (ideally) a linear function of the input displacement.

- Resistance elements in common use may classified as wirewound, conductive plastic, hybrid, or cermet.

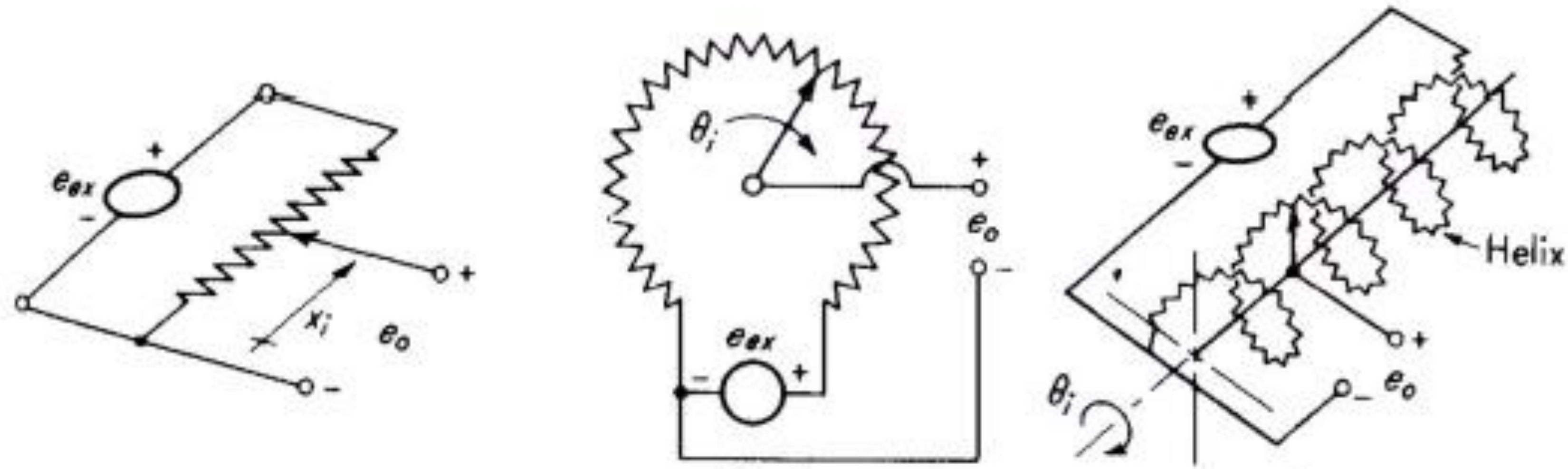
POT



(*a*) Linear (translational) POT (*b*) Rotary POT

Fig. Resistive potentiometers (POTs)

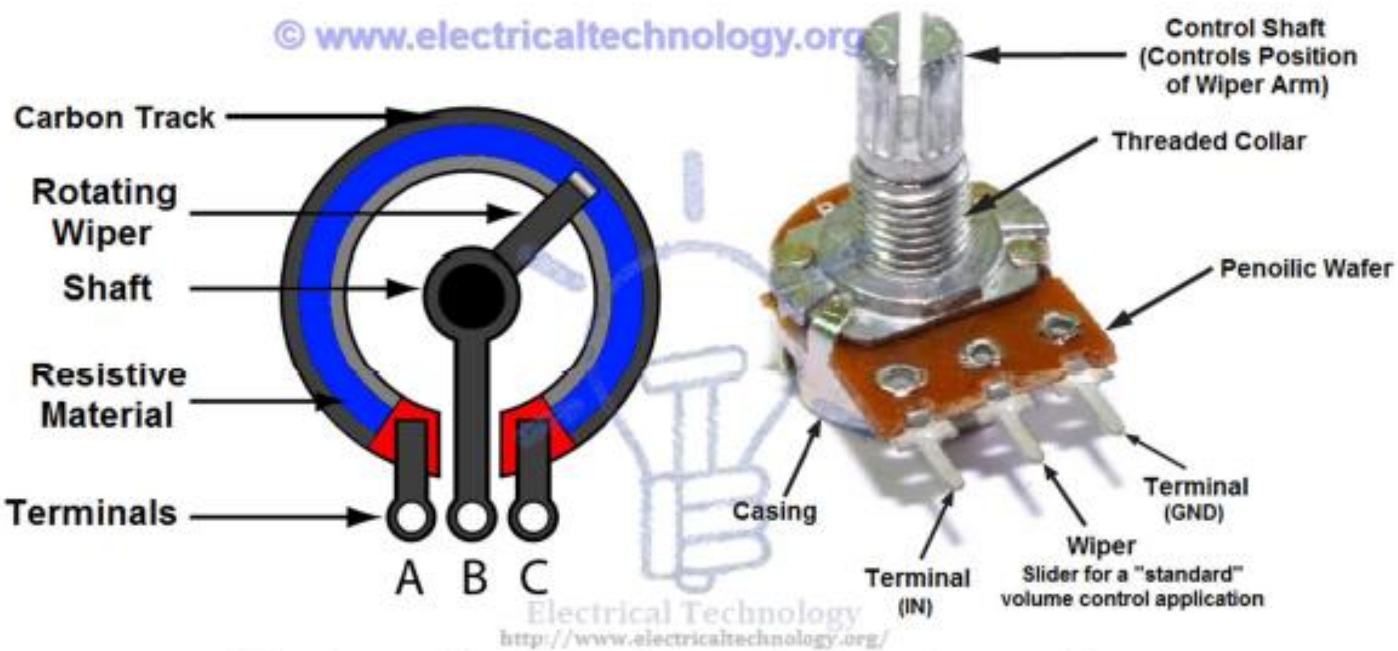
POT



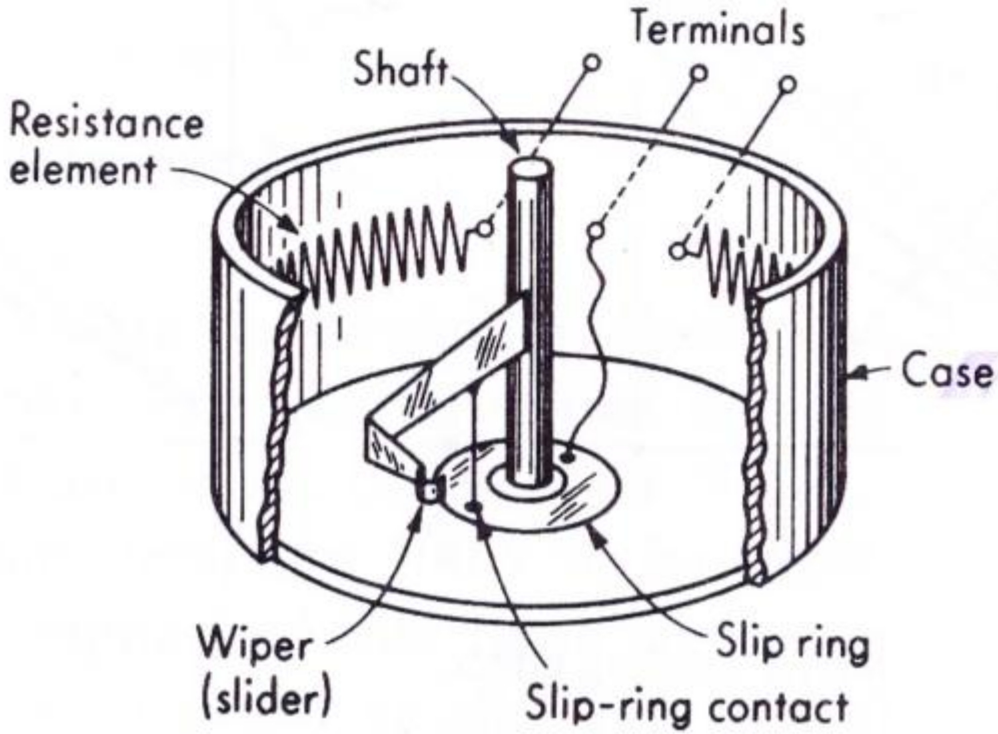
Single-turn Multiturn

Translational Rotational

POT



Potentiometer Construction



Terminals
Shaft
Resistance
element
Case
Wiper
(slider)
Slip ring
Slip-ring contact

Construction

- The translational resistive elements are straight devices and have a stroke of 2mm to 0.5mm.

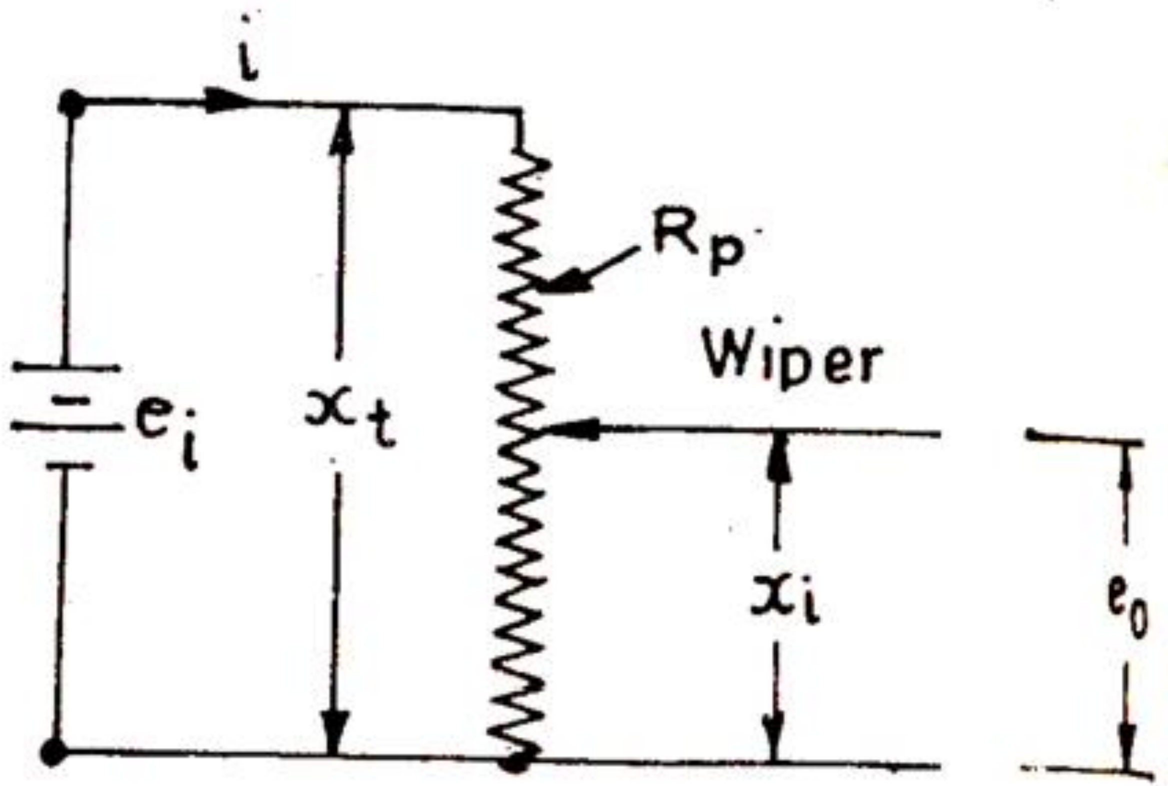
- The rotational devices are circular in shape and are used for measurement of angular displacement as small as 10^{o}. A full single turn POT may provide a accurate measurements up to 357^{o}.

- Multi-turn POT may measure up to 3500^{o} of rotation through helipots.

- The resistive body of potentiometer may be wire wound. A very thin, 0.01mm diameter of platinum of nickel alloy is carefully wound on an insulated former.

- The resistance elements are also made up from cermet, hot molded carbon, carbon film and thin metal.

Input-Output Relationship



Input-Output Relationship

- Let us define our discussion of a dc excited translational potentiometers.
- Let e_i and e_0= input and output voltages respectively; V

x_t= total length of translational POT; m

x_i= displacement of wiper from its zero position; m

R_p=total resistance of the potentiometer; Ω

- If the distribution of the resistance with respect to translational movement is linear, the resistance per unit length is R_p/x_t Ω/m.
- The output voltage

$$e_o = \frac{\left(R_p / x_t \right)}{R_p} \times x_i e_i = \left(\frac{e_i}{x_t} \right) x_i$$

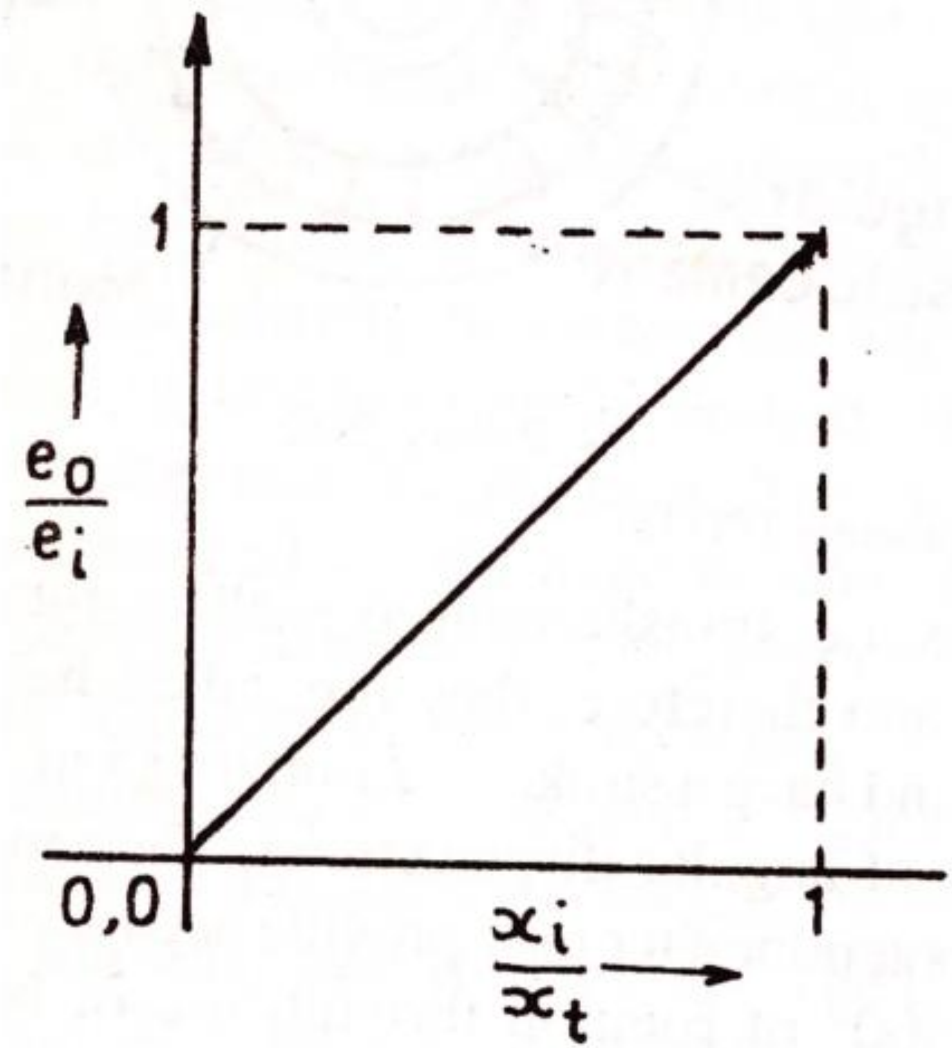
- Under ideal circumstances, the output voltage varies linearly with displacement.

Sensitivity

The **sensitivity of a potentiometer** represents the change in the output signal (Δe_0) associated with a given small change (Δx_i) in the measurand (the displacement).

$$\text{Sensitivity} = \frac{\text{Change in output}}{\text{Change in input}} = \frac{\partial e_o}{\partial x_i} = \frac{e_i}{x_t} = Consant$$

- Thus **under ideal conditions** the sensitivity is constant and the output is faithfully reproduced and has a linear relationship with input.
- The same is true of rotational motion.


1
$\frac{e_o}{e_i}$
0,0
$\frac{x_i}{x_t}$
1

Rotational Motion

- Let, θ_i=input angular displacement in degrees.
  θ_t=total travel of the wiper in degrees.

The output voltage $$e_o = e_i\left(\frac{\theta_i}{\theta_t}\right)$$

This is true for single turn potentiometer only.

Loading Effect

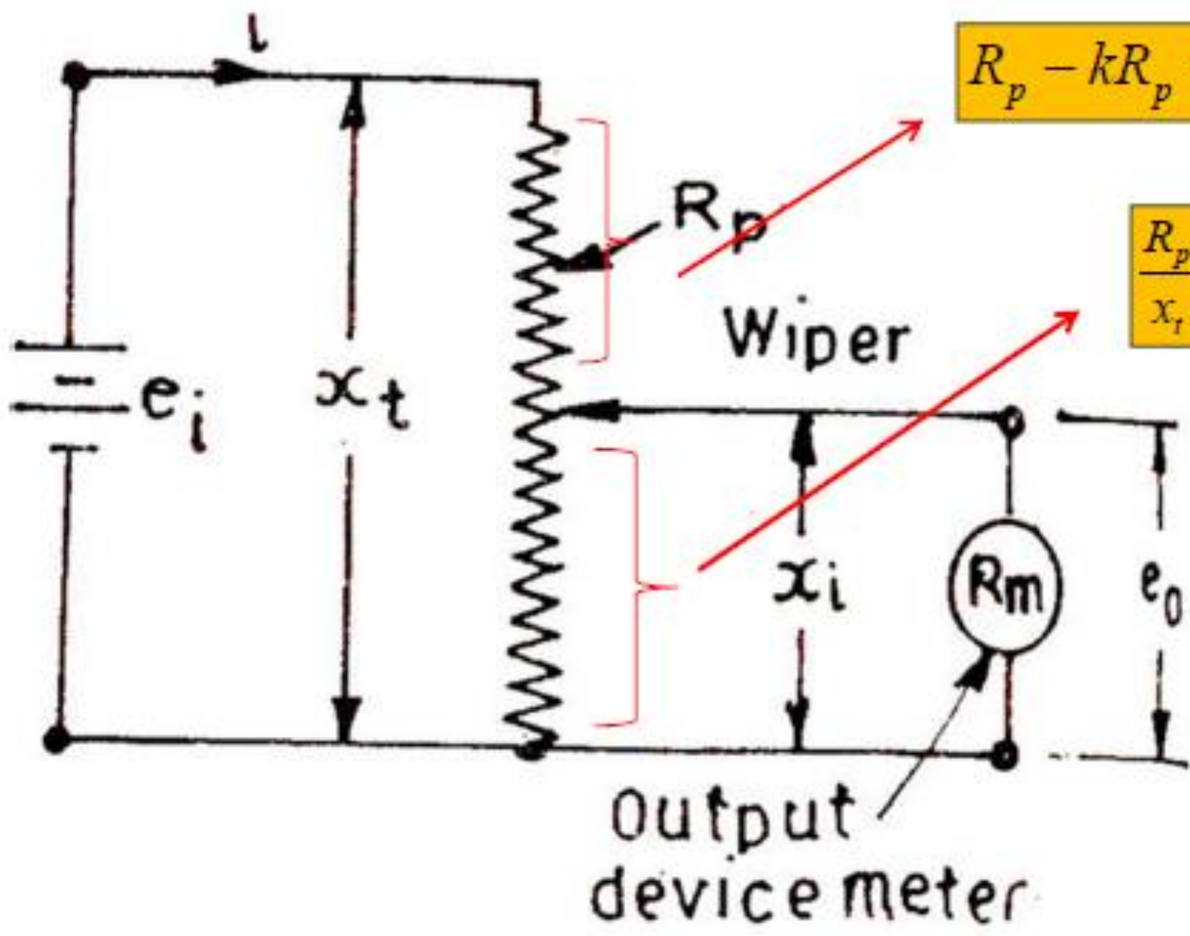
- Above equations are based upon the following assumptions

❑The distribution of resistance with respect to linear or angular displacement is uniform.

❑ **The resistance of the voltage measuring device (i.e. output device) is infinite.**

- In actual practice, however, the load (the circuitry into which the POT signal is fed-e.g., measuring, conditioning, interfacing, processing, or control circuitry) has a finite impedance.
- Consequently, the output current(the current through the load) is nonzero.
- The output voltage thus drops, even if the input voltage is assumed to remain constant under load variations.
- This consequence is known as the electrical **loading effect of** the transducer.

Loading Effect



$$\boxed{R_p - kR_p = (1-k)R_p}$$

$$\boxed{\frac{R_p}{x_t} x_i = \frac{x_i}{x_t} R_p = kR_p}$$

Loading Effect

• Under these conditions, the linear relationship would no longer valid, causing an error in the displacement reading.

• Loading can affect the transducer reading in two ways:

❑ By changing the reference voltage (i.e. loading the voltage source).

❑ By loading the transducer.

• To reduce these effects,

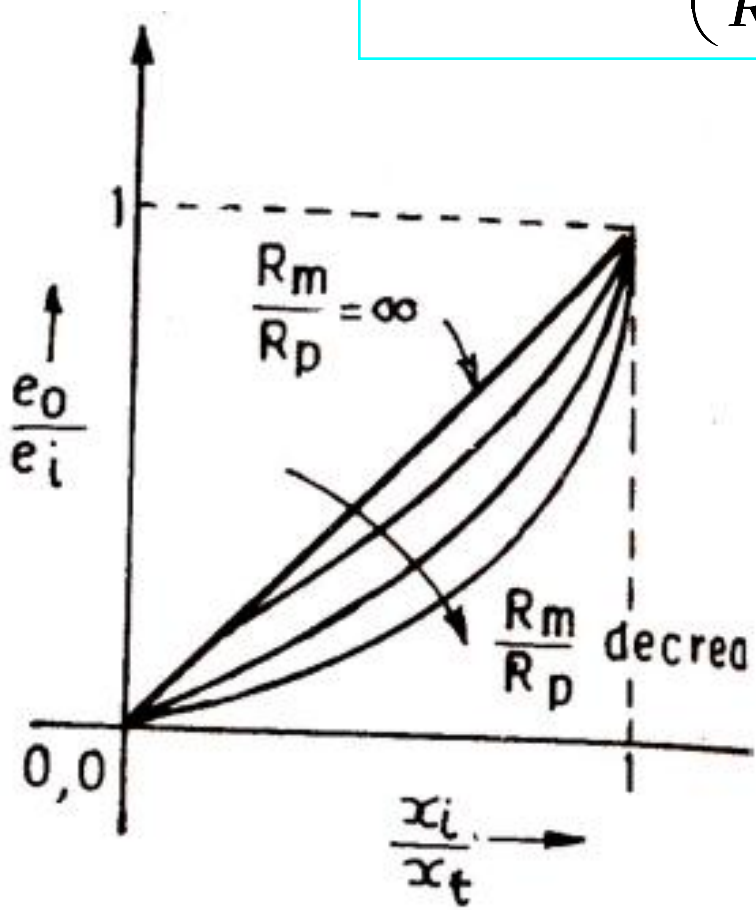
❑ a voltage source that is not seriously affected by load variations (e.g., a regulated or stabilized power supply, which has low output impedance) should be used.

❑ Data acquisition circuitry (including signal conditioning circuitry) that has a high input impedance should be used.

Loading Effect

- The ratio of output voltage to input voltage under load condition is:

$$\frac{e_o}{e_i} = \frac{k}{k(1-k)\left(\frac{R_p}{R_m}\right)+1}$$



- This equation shows that there exists a nonlinear relationship between output voltage e_0 and input displacement x_i.
- In case $R_m = \infty, \frac{e_o}{e_i} = k$
- It is evident from above equation that the ratio of $\frac{R_m}{R_p}$ decreases the nonlinearity goes on increasing. This is shown in figure.

Error analysis

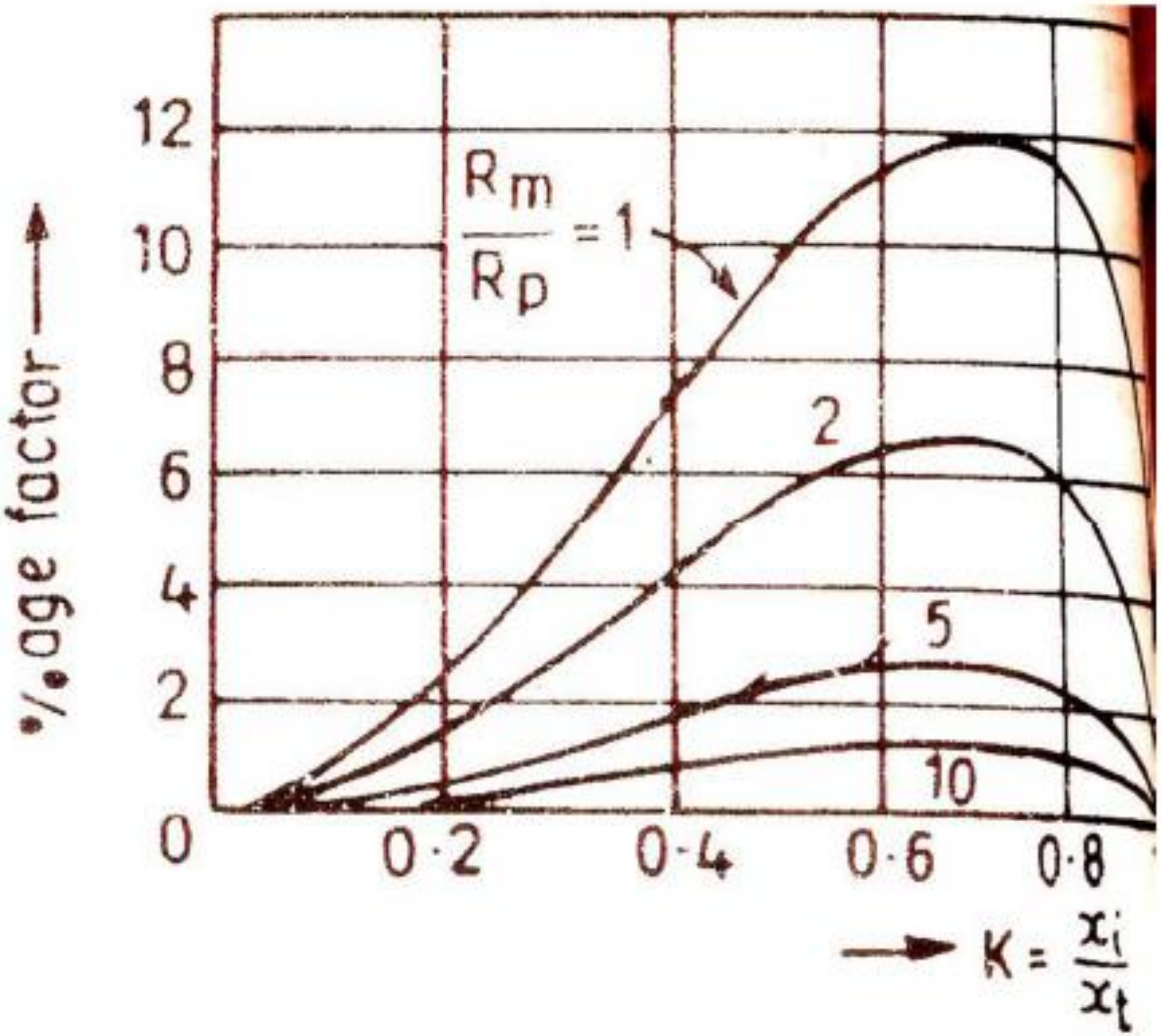
- Thus in order to keep linearity the value of $\frac{R_m}{R_p}$ should be as large as possible.
- Error= Output voltage under no load-output voltage under load.

$$= -e_i \frac{k^2(k-1)}{k(1-k)+\frac{R_m}{R_p}}$$

- Now based upon full scale output, this relationship may be written as

$$\% e = -\left[\frac{k^2(k-1)}{k(1-k)+\frac{R_m}{R_p}}\right]\times 100$$

Error analysis



Thevenin equivalent circuit calculation: Potentiometric displacement sensor

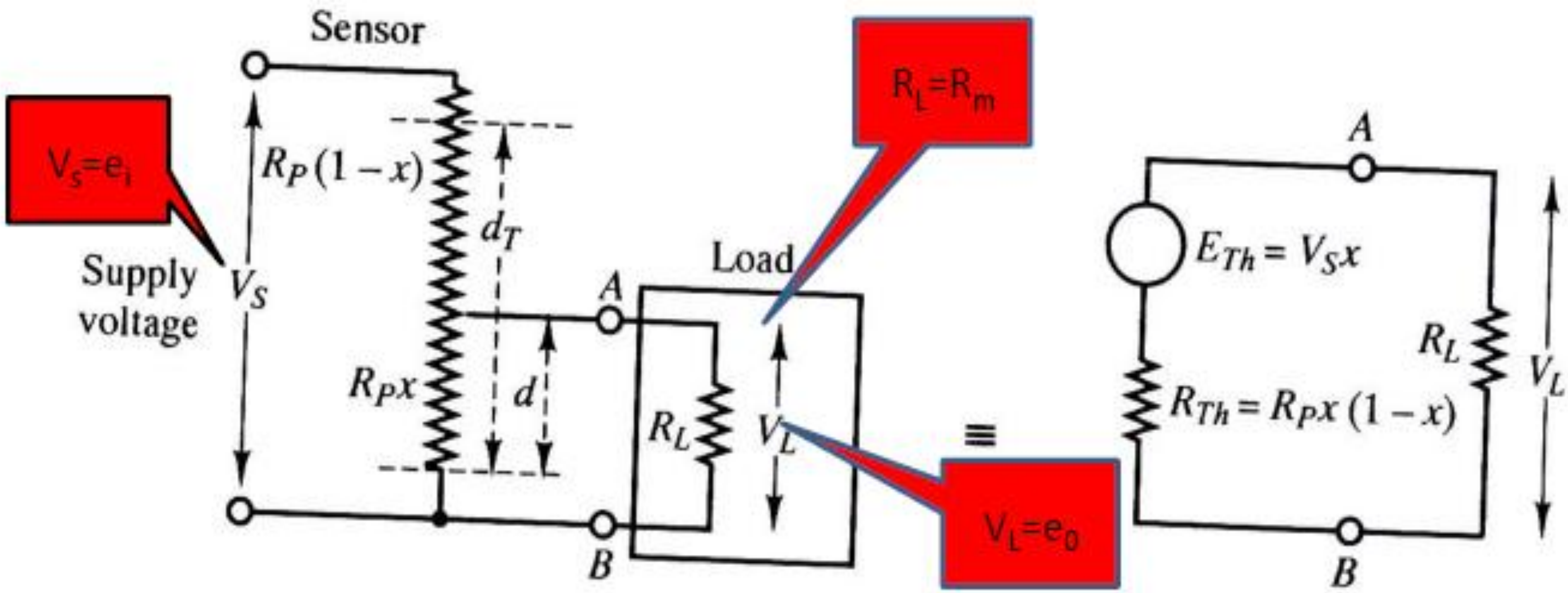
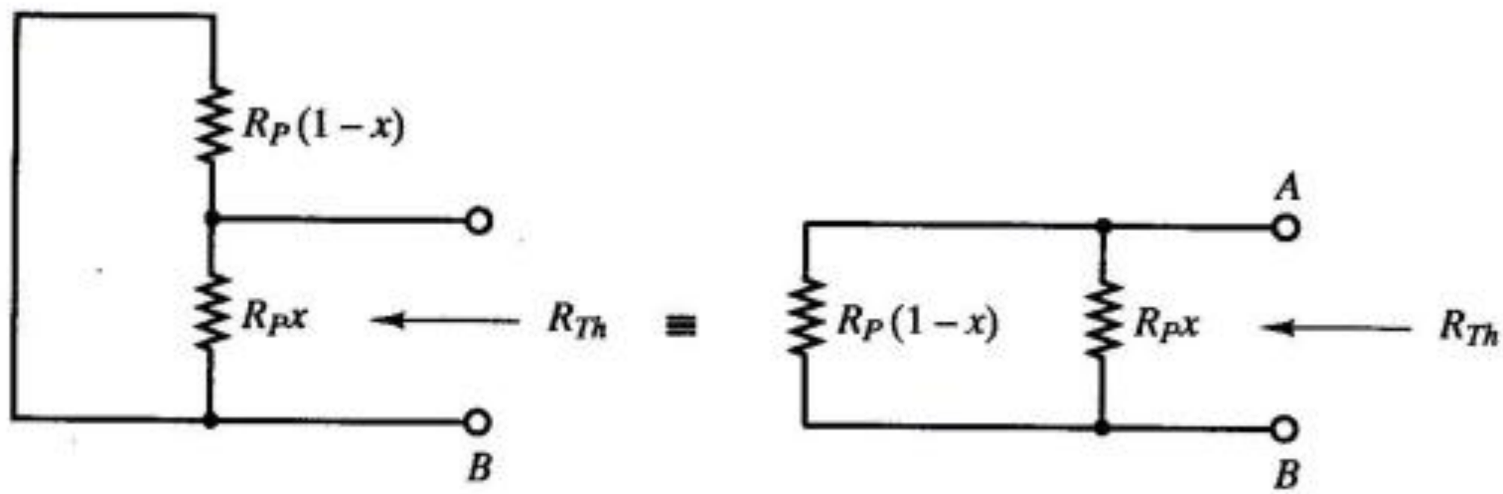
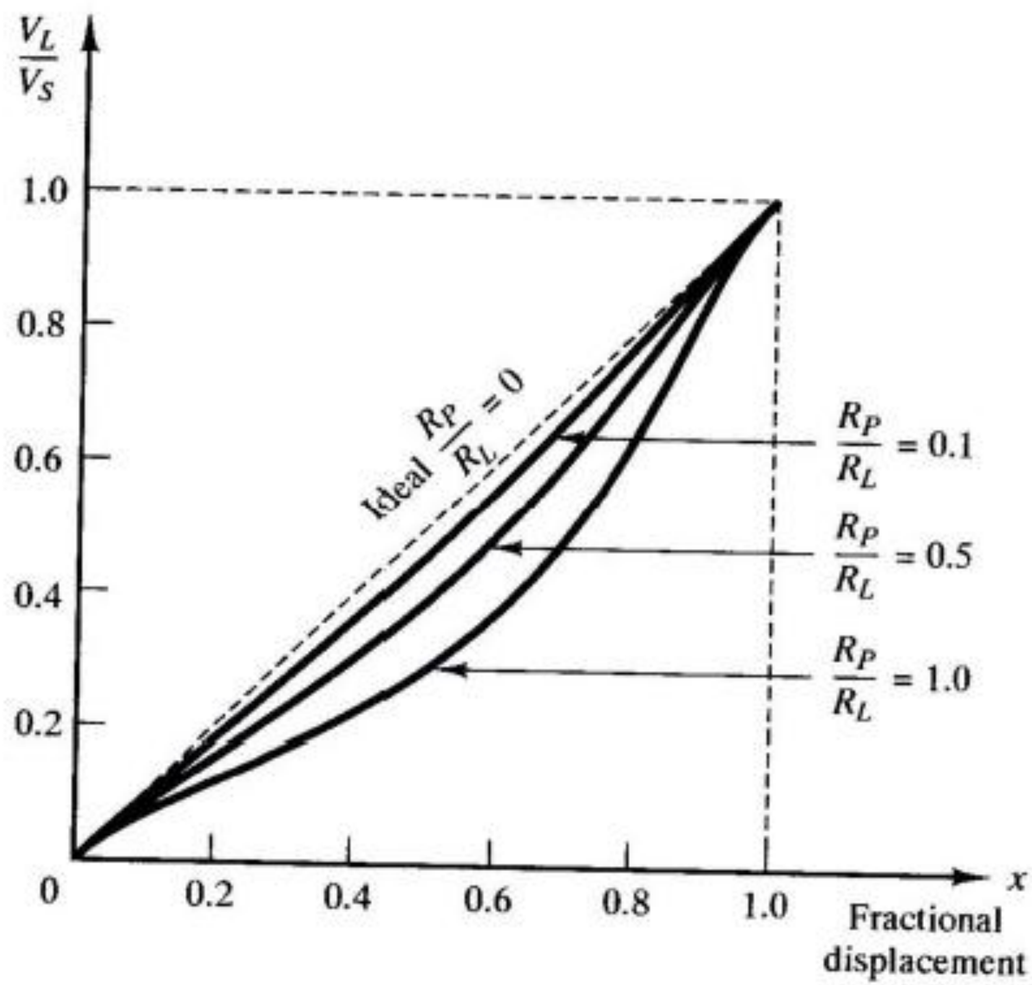


Figure shows a schematic diagram of a potentiometric sensor for measuring displacements *d.*
Let k=*x=d/dT is the fractional displacement, the corresponding resistance* is R_pk*, where* R_p *is the total resistance of the POT.*

Calculation of R_{Th}



Nonlinear characteristics of loaded potentiometer



Sensitivity & maximum power requirements

- Sensitivity = $\frac{\partial e_o}{\partial K} = e_i$

- The POT are designed with a definite power rating which is related directly to their heat dissipating capacity.

- Since power $P = \frac{e_i^2}{R_p}$, the maximum input excitation voltage that can be used is $(e_i)_{\max} = \sqrt{PR_p}$

Linearity and sensitivity are two conflicting requirements!!!

- In order to achieve **good linearity,** the R_P, should be as low as possible.
- In order to get a **high sensitivity** the output voltage e_0 should be high which in turn require high input voltage e_i.
- Due to the limitations of **power dissipation,** the input voltage is limited by the resistance R_p.
- In order to keep the power dissipation at low level, the input voltage should be small and resistance of the POT should be high.
- Thus for a high sensitivity, the input voltage should be large and this calls for a high value of resistance Rp. On the other hand if we consider the linearity, the resistance of the POT Rp, should be as low as possible.
- The resistance of the POT cannot be made low because the power dissipation goes up.

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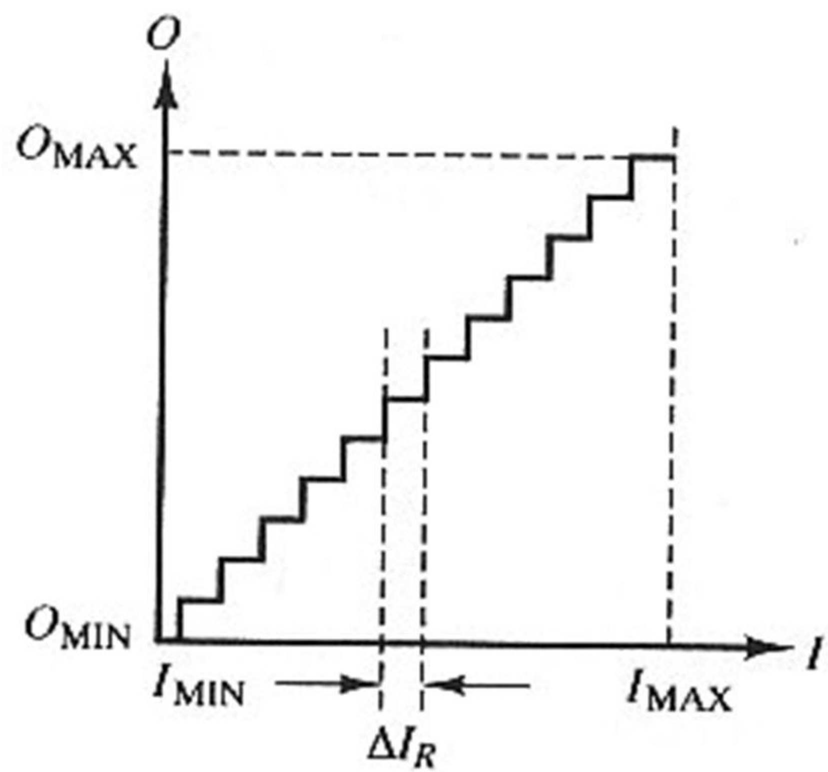
- The linearity and sensitivity are therefore two conflicting requirements.
- If R_p made small, the linearity improves, but a low value of R_p requires a lower input voltage e_i in order to keep down the power dissipation and a low value of e_i results in a lower value of output e_0 resulting in lower sensitivity.
- Thus the choice of POT resistance R_p, has to be made considering both linearity and sensitivity.

Resolution

- In some instruments, the output increases in discrete steps, for continuous increase in the input, as shown in Fig.
- It is defined as the largest change in input *I that can occur* without any corresponding change in output *O.*

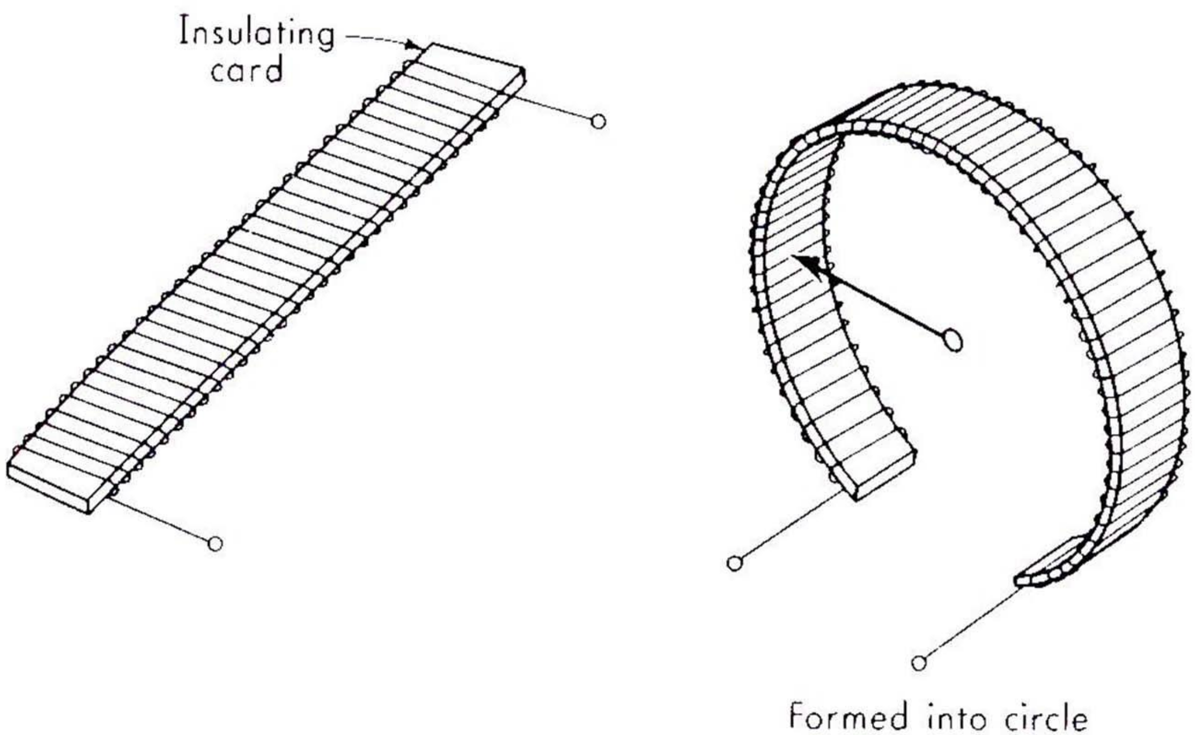
- Thus in fig. resolution is defined in terms of the width ΔI_R *of* the widest step; resolution expressed as a percentage of full scale deflection is thus:

$$\frac{\Delta I_R}{I_{MAX} - I_{MIN}} \times 100\%$$



Resolution

- If wire wound type of construction is adopted, the variation of resistance is not linear continuous change but in small steps as wiper moves one turn to another.



Construction of wirewound resistance elements.

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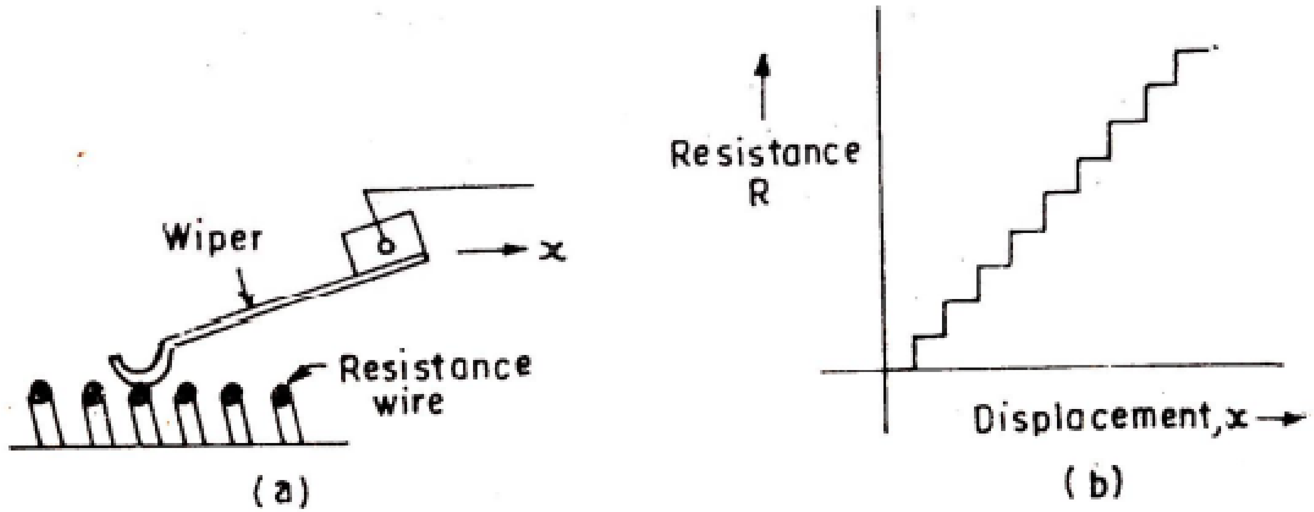
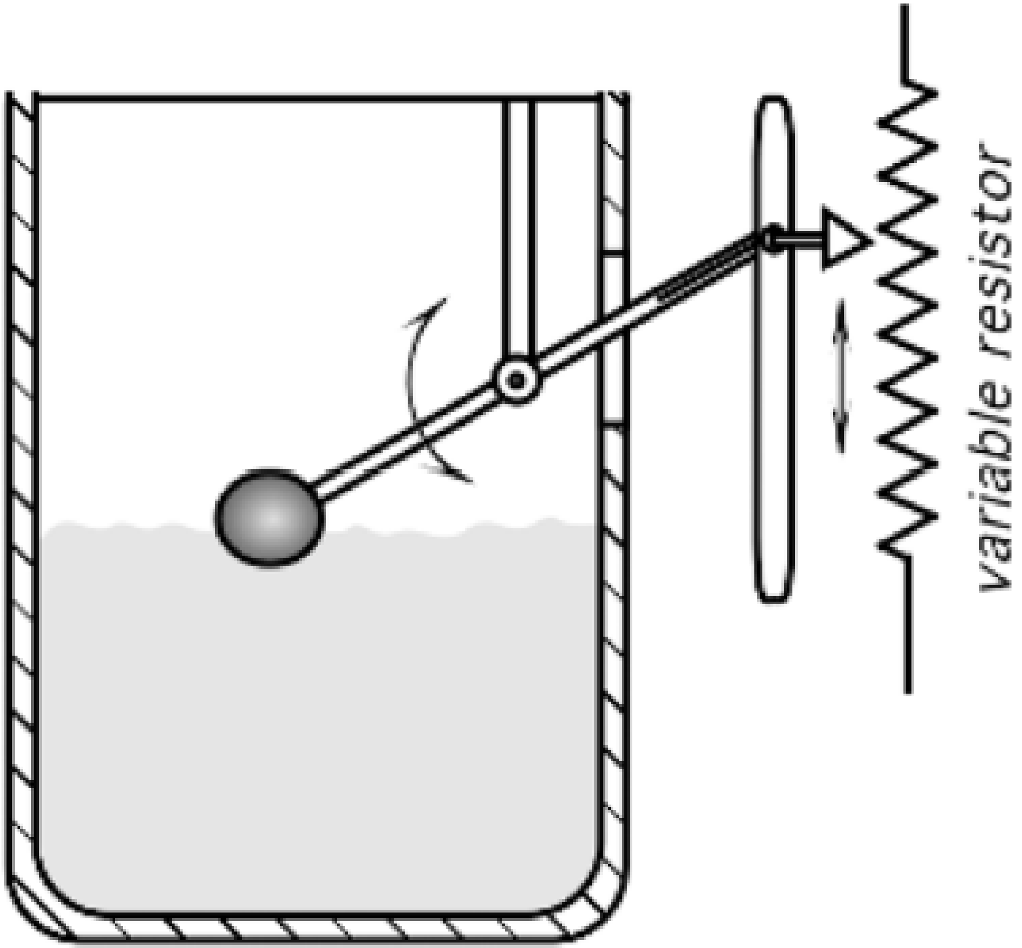


Fig. 25.48. Translational potentiometer and its characteristics.

Since the variation in resistance is in steps the resolution is limited. For instance, a translational POT has about 500 turns of resistance wire on a card 25mm in length and for this device the resolution is limited to 25/500=0.05mm.

If the wiper could be arranged to touch only one wire at a time the volatge resolution will be $\Delta V = \dfrac{V}{n}$

Application



fluid level sensor with a float

Limitations and Disadvantages of POT

- The force needed to move the slider (against friction and arm inertia) is provided by the displacement source. This mechanical loading distorts the measured signal itself.
- High frequency measurements are not feasible because of such factors as slider bounce, friction, and inertia resistance.
- Variations in the supply voltage cause error.
- Electrical loading error can be significant when the load resistance is low.
- Resolution is limited by the number of turns in the coil uniformity. This limits small displacement measurements.

Advantages

- They are relatively inexpensive.
- POTs provide high-voltage (low impedance) output signal, requiring no amplification in most applications. Transduce impedance can be varied simply by changing the coil resistance and supply voltage.