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A hypothetical investigation of inductive, capacitive and resistive transduction performance of electric energy converters in electricity industry: A review

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Abstract

We look at transducers as technological devices that are mostly employed for conversion of energy from one form to another; the latter form of which may or may not be directly related to the original form from where it is converted. In this work a given set of energy transduction apparatus is discussed The various mode of structural composition of these components were x-rayed with effect to showcasing the different mechanisms that lead to the functionality of their respective constituents out of which the transducers are constituted. Among the best examined and the most attention – drawing transducer implement that appealed to our interest for discussion include the resistance transducer, capacitive transducer, inductance transducer etc. We could categorize resistance transducer as a unit composite under which some resistance dependent transducers can be classified. The relative effect of natural resistance properties of some resistance dependent transducers such as potentiometer transducer (e.g. strain gauge, bounded strain gauge), resistance thermometer transducer and thermistor transducers was thoroughly examined, with consideration on the parametric compositions and their respective contributions to the device for resistance transduction effect. Other special feature interestingly and briefly investigated is on the perceptive of their respective mode of energy acquisition for effective operation. As such, Tachogenerator transducers, Photovoltaic transducers, Thermocouple transducers and piezoelectric crystal transducer are characterized as self-generating or self-transducing; meaning that they are actually energetically self-supportive and require no external source to effect transduction. Differential Capacitance Pressure transducer is looked into and functionally elucidated with interest on the movable diaphragm, the middle plate through which the operational principle of the device is largely dependent on the two uniquely formed extreme end voltages of the transducer equipment. We developed some mathematical expressions to enhance a more detailed comprehension of the functional mechanisms.

Keywords: Transducer, Operational mechanism, Energy Conversion.

1. Introduction:

Behaviour of every physical substance is naturally governed by the inherent characteristics of the smallest indivisible particles with which these substances are made. These particles generally referred to as atoms are obviously the constitutes of such elements that can exist in form of liquid, solid, gases and plasma. The elements, otherwise known as matters can contain either neutral or ionized atoms just as most experimental observations have shown [8]. Matter by definition is anything that occupies space and can exhibit some weight due to impart of its mass [9]. Apart from some extent of discrepancies in their atomic structural compositions due to varying degrees of geometry and natural configuration, the relative position of the indivisible constituents of these substances obviously accounts for wide range of behavioural differences usually obtained in nature; especially, when exposed under environmental changes. Of course, these attitude are commonly obtained across all the three states of matter; being it in liquid state, gaseous state or solid state.

In this work, our attention is largely placed on transduction impart of some physical quantities: and the characteristics of some physical materials that are mostly obtained when they are allowed to pass through certain conditions that are usually met in practical situations. The attitudinal variations; to some reasonable degree, can be largely due to the changes undergone by those inherent properties of the material media which in return can give rise to alteration of those naturally constituted parameters whenever the condition it adheres to; for such changes, occurs.

These parameters undergo some changes within the parent media, as a result of the interaction of the media; in question, with environmental quantities namely temperature, pressure, light etc. and convert them to other quantities which may or may not be similar to the original form from which the conversion is executed. The intermediate media for conversion in this case is generally referred to as transducers. Therefore, transducers can be called energy converters, as electric energy can be converted to heat energy (e.g. electric heater, electric iron, electric furnace etc) and heat energy to electric energy (thermocouple etc) [10]. In physics as a discipline, transduction can be seen as a mere process of conversion of one type of energy or physical quantities into another, the properties of which are largely dependent on the measurement and conversion: and the conversion tools in this sense is commonly known as transducers [2] . Physical quantities such as pressure can be converted to displacement and sound wave can be converted to electric signal through the microphone along the electric cable which in turn can be returned to original sound energy via the speaker coil. Some of the commonly produced modern transducers may include Thermocouple, Piezoelectric (active transducers) as well as light dependent resistors and Strain gauge transducers which are basically passive in nature [7].Other types of energy transduction converter obtainable in the field include:

i. Galvanometers
ii. Microphones
iii. Loudspeakers
iv. LDR
v. Quartz Crystals
vi. Solar Cells
vii. Thermistors

2. Transducers/Operational mechanism

We categorically looked into transducers under two perspectives based on their principles of design and operation. We categorised the device into electrical and mechanical transducers. Electrical transducers can be seen as those transducers whose mode of construction and design capitalize on the fundamental electric properties that can be manipulated under a properly coordinated principle to achieve a transduction result which may or may not be electrically related. Such parameters as resistance, capacitance and inductances in electric materials do contribute to the functional principles of electric transducers.

Fig.1.0: Diagram showing a galvanometer as a transducer

In this work, we actually made a clear explanation of these devices using these constants and further showed how they can be handled to create some electric effect under which their respective transducer components can operate.

The mechanism of electromagnetic action in electrical engineering is a principal account of interaction between electric and magnetic quantities. The result of this interaction can be coordinated and harnessed for field applications. Exertion of force on current carrying conductor in a field of magnet can be one of many numbers of phenomena adoptable for transduction. On the same hand, an induced voltage on a wound coil on account of flux linkage within a magnetic field is another good example of transduction requirement mainly used for metering as always seen in instrumentation and measurement. Thus, there are wide ranges of transducers that are obtainable under electromagnetic principles.

Other forms of transducers in this category can be self-transuding or self-generating; meaning that they do not require any external electrical source to convert physical quantities like temperature, photon (light energy), force and velocity into the required energy for transduction. These transducers are shown below

1. Tachogenerator transducer
2. Photovoltaic diode transducer
3. Thermocouple transducer
4. Piezoelectric crystal transducer
5. Solar Cell transducer

These transducers are in other words referred to as active transducers for the capability of possessing their own in-built energy needed for operation. However, among the externally powered transducer are

1. Thermistors
2. Resistance temperature detectors
3. Strain gauge
4. Potentiometer or Pot etc.

These transducer types are passive in nature and as such do not have the capability of self-energy transduction.

Fig.1.1: Diagram showing types of piezoelectric transducers

They are rather naturally dependent on externally generated energy source for their operation. Hence, they are popularly referred to as externally powered transduction equipment.

We gave some explanations of transducers in this work following the influence of their parameters and the electric principles upon which their functional mechanisms are based.

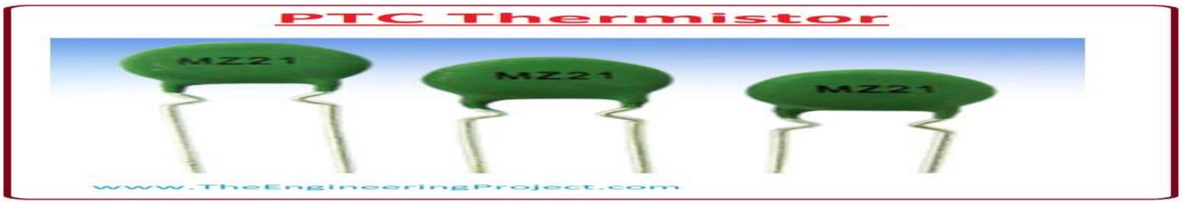


Fig.1.2: Diagram showing a typical picture of Thermistor transducers

The first set of transduction devices under this discussion falls within the inductor, resistance and capacitance parameter families, with resistance transducer being the first in the list for explanation.

We list these devices after the names of their various parameter constituents as shown below

1. Resistance transducers
2. Capacitance transducers
3. Inductance transducers

2.1. Resistance Transducer

Fabrication of these transducers is possible considering the resistance effect of electric conductors. This in other words can be seen as an opposing effect to normal flow of electric charges within or along an energised conductor length .Resistance of a conductor can be related to physical variables like conductor length (L) and the cross-sectional area of the conductor represented as A. The resistively (ρ) designates the constant due to the inherent nature of the electric conductor. And so, we can express the resistance, R as a function of the area (A) and length (L) taking the resistivity as a constant of proportional as shown:

$$R \ \alpha \ L \qquad (1)$$

$$R \ \alpha \ {}^{1}/_{A} \qquad (2)$$

From equation (1):

$$R = KL \qquad (3)$$

and in equation (2)

$$R = {}^{K}/_{A} \qquad (4)$$

Therefore when we combine equations (3) and (4), We can resolve the two equations into one to obtain

$$R = {}^{KL}/_{A}$$

Putting K = ρ

Then,

$$R = {}^{\rho L}/_{A} \qquad (5)$$

where,

R = resistance of conductor in ohm

L = Length of conductor in cm

A = Uniform cross-sectional area of the conductor in cm^2

ρ = Resistivity of the conductor in

The variation of any of the resistive quanities in equation (5) will definitely give a corresponding varying result of the resistance, R. As a result, many of resistive transducers are manufactured on this principle. This is seen with translational and rotational potentiometer transducers which are good examples of resistive transducers.

Some resistance values of these transducers runs within the range of 100 to 1K Ω with a sizeable level of temperature coefficient ($\propto$) at 25^0C ,room temperature. About 0.4 percent for every one degree centigrade is essentially a considerable factor in designing a resistance thermometer.

Fig.1.3: Diagram showing a structural view of a resistance thermometer transducers

By reason of resistance maneuvering, which is always the case when manufacturing resistive transducers, the resistance of those transducers can be made photo-sensitive, magneto-resistive, thermally sensitive etc.; meaning they can transduce as their resistances are varied when exposed to changes in light intensity, magnetic field intensity and high level of heat respectively. In effect, the transducers that respond to the first two conditions (i.e. light and magnetic field intensity) are said to operate under photoconductive and magneto resistive effects.

We can look at most of the principal transducers that work on the basis of resistance adjustment as obtained in this category. Such transducers are as shown:

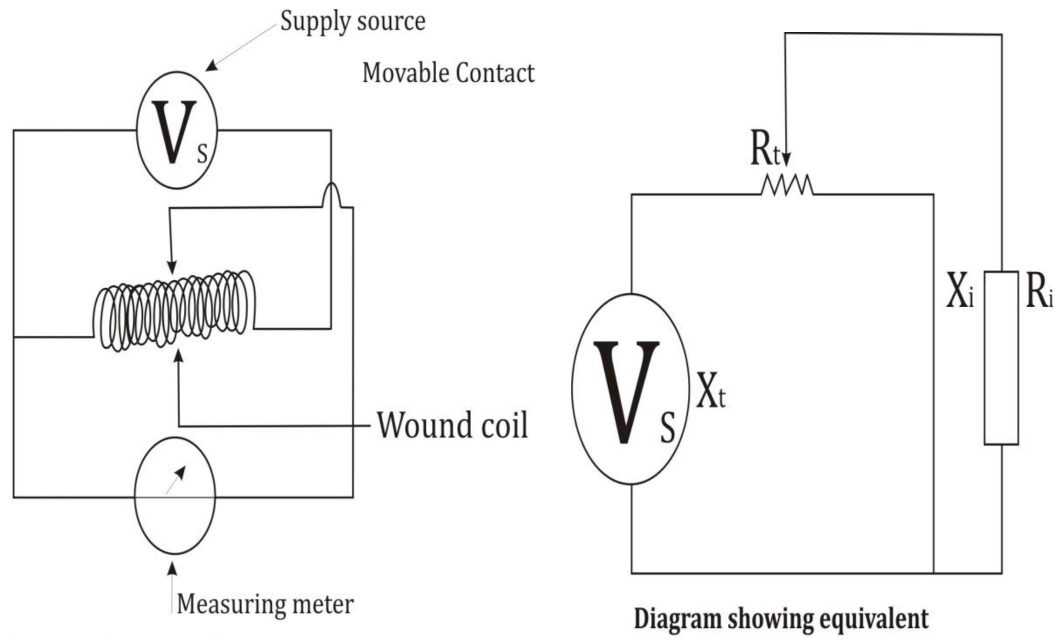
i. Potentiometer or pot
ii. Strain gauge
a. Bounded strain gauge
b. unbounded strain gauge
iii. Resistance thermometer
iv. Thermistors

2.2. Potentiometers

These are basically known as resistive Potentiometer. They are built with movable contacts, and on resistance properties of the material with which they are manufactured.

The contact movement can be translational or rotatory. It may adopt the two manner of movement to make a helical motion in multiturn rotational transduction equipment that measures both translational and rotatory displacement.

The resistance element in this device can work with ac or dc supply to give a linear output voltage that depends largely on the input displacement. The most commonly used Potentiometer is manufactured with wound wire conductors, conducting plastic or carbon film element. See example below.



Circuit Diagram of a potentiometer

Diagram showing equivalent circuit of a potentiometer

Fig1.4: Diagram showing a typical circuit and equipment circuit of a Potentiometer

2.2.1. Circuit modelling:

From the equivalent circuit,

$$x_t^2 \,.\, R_i^2 V_o + R_t R_i x_i x_t V_o - R_t x_i^2 R_i V_o = V_S R_i^2 x_i x_t \qquad (6)$$

From which we have

$$R_i \left[x_t^2 R_i V_o + R_t x_i x_t V_o - R_t x_i^2 V_o\right] = V_S R_i^2 x_i x_t$$

$$V_o \left[x_t^2 R_i + R_t x_t x_i - R_t x_i^2\right] = V_S R_i^2 x_i x_t$$

$$V_o / V_s = \frac{x_i x_t R_i}{\left[x_t^2 R_i + R_t x_t x_i - R_t x_i^2\right]} \qquad (7)$$

$$1 \Big/ \left[V_o / V_s\right] - 1 = \frac{1}{\frac{x_t^2 R_i + R_t R_i x_t x_i - R_t x_i^2 R_i}{R_i^2 X_i X_t}} \qquad (8)$$

$$1 \Big/ \left[V_o / V_s\right] - 1 \equiv \frac{1}{x_t / x_i + R_t / R_i - \frac{R_t x_i}{R_i x_t}} \qquad (9)$$

From the equation, we make the following deduction,

1. At open circuit condition when the output resistance is disconnected, the ratio of R_t to R_i ideally amounts to zero

Thus, the expression for ${}^{V_o}/_{V_s}$ becomes

$$ {}^{V_o}/_{V_s} = \frac{1}{\left[{}^{x_t}/_{x_i} + 0 - 0\right]} $$

$$ = {}^{1}\Big/ \; {}^{x_t}/_{x_i} \; => {}^{1}/_{1} \div {}^{x_t}/_{x_i} $$

$$ = {}^{x_t}/_{x_i} $$

This further shows that

$\mathrm{V_s x_i = V_o x_t}$

⇨ ${}^{V_s}/_{x_t} = {}^{V_o}/_{x_i}$ which is the resistivity of the system.

2. The graph of ${}^{V_o}/_{V_s}$ and ${}^{x_i}/_{x_t}$ is ideally linear; thus, making a straight diagonal line from the origin to show the direct proportionality relation that exist between ${}^{V_o}/_{V_s}$ and ${}^{x_i}/_{x_t}$.

During operation, the moving wiper normally initiates the resistance variation, thus sliding from one turn to the other along the horizontal or circular coil-wound plane. In most cases the practical allowable space limit can be 25 numbers of turns of coil for every one millimeter. This gives a wide range of acceptable resistance value for good resolution, although resolution in this type of device is wholly dependent on the fabrication of resistance material. The resolution can be better improved upon by using carbon film or conductive plastic materials as resistance elements. The functional effectiveness of the potentiometer transducer is highly limited by the output voltage fluctuation which occurs as a spontaneous signal at the device output when the sliding wiper moves along the wound wire. There are many existing factors to this effect and these can be itemized as given below:

(a) Dirt due to dust and some deposited organic matters on the slider contacts or coil-wound plane.
(b) Wear on the plane or wiper due to frequent sliding motion of the wiper.
(c) Variation of output voltage due to the slider as it moves across the wound coils on the plane.
(d) The bouncing effect of the slider contact as it slides from one coil to the other on the plane.

These generally constitute disturbances known as noise to the device while in operation.

2.3. Resistance Thermometer:

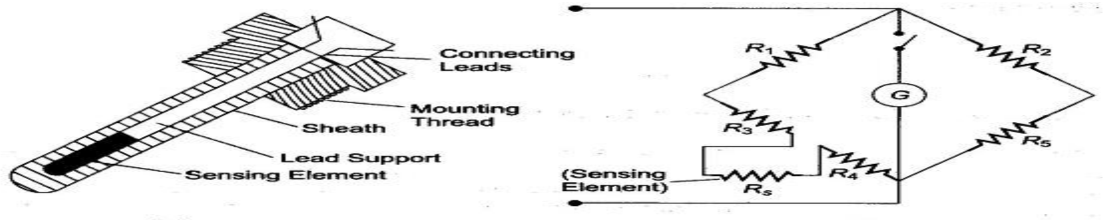
The work of this device is derived from the direct relation of the resistance and temperature; and this can be clearly seen in the expression below,

$$ \mathrm{R} = R_o \; (1 \; + \; \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \alpha_4 T^4 - - - - \alpha_n T^n) $$

where,

R = variable resistance of the medium in question
R_o = Resistance at T = 0
T = Temperature of the medium
a = Constants

In a real practical senerio, thermometer is an instrument for temperature measurement. There are different types of thermometers depending on the field application.



(a) (b)

Fig. 13.11 (a) Industrial Platinum Resistance Thermometer (b) Bridge Circuit

Fig1.5: Diagram showing a typical view of a wheatstone bridge circuit and platinium thermometer

Resistance thermometers as transducers are among the transducer devices whose principle of operation are hinged on the thermal response of the resistance element with which they are made. Platinum, cobalt and mercury are among the metallic elements for the thermometer construction; and empirical facts have revealed the low extent of increase in resistivity of the platinum metal at high temperature when compared with other metallic materials that are used in resistance thermometer building. For platinum, constant, α_1, obtained from the temperature-resistance expression, R = R_o $(1 + \alpha_i T\ \alpha_2 T^2 - - - - \alpha_n T^n)$ at temperature range of 0^0c to 100^0c approximates to 0.4 percent for every 1^0c.

Platinum wires are put in a spiral form – that is, in a sort of spirally wound-conductive-platinum structure that is specially installed within the thermometric transducer; during fabrication. The spiral – like element can be encased within a transparent material such as glass. It can also be in quartz or porcelain etc.

2.4. Thermistor:

Thermistor is one of the resistance dependent temperature transducer. The resistance increases or decreases in proportion to increase or decrease of ambient temperature. Thus, the resistance-temperature characteristics are non-linear; and the temperature coefficient at normal room temperature – 25^0C is within the neighbourhood of minus four percent per degree centigrade. The temperature and resistance of the device are commonly related to each other as seen in the expression below:

$$R = R_o \exp\left[\beta\left({}^{1}/_{T} - {}^{1}/_{T_0}\right)\right]$$

where

R = Resistance at temperature, T

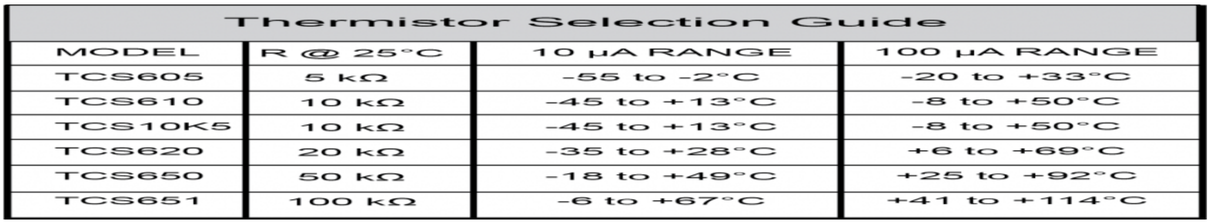
R_o = Resistance at temperature, T_0

β = constant

Thermistor can be made into disc or rod shapes. It is mostly a product of powdered manganese, nickel and cobolt oxides that are compressed and sintered as a mixture under a very high temperature.

Under a room temperature of 25^0C, the device resistance can be varied over a considerable range of values, starting from several hundreds of ohms to mega ohms.

Table 2.4: Thermistor selection guide



Thermistor Selection Guide			
MODEL	R @ 25°C	10 µA RANGE	100 µA RANGE
TCS605	5 kΩ	-55 to -2°C	-20 to +33°C
TCS610	10 kΩ	-45 to +13°C	-8 to +50°C
TCS10K5	10 kΩ	-45 to +13°C	-8 to +50°C
TCS620	20 kΩ	-35 to +28°C	+6 to +69°C
TCS650	50 kΩ	-18 to +49°C	+25 to +92°C
TCS651	100 kΩ	-6 to +67°C	+41 to +114°C

Thermistor transducer lacks the capability for self-transduction and as a result cannot generate its own energy to function like some self-energy generating converters. It is said to be passive in nature, and their operation thrives well under DC energy supply.

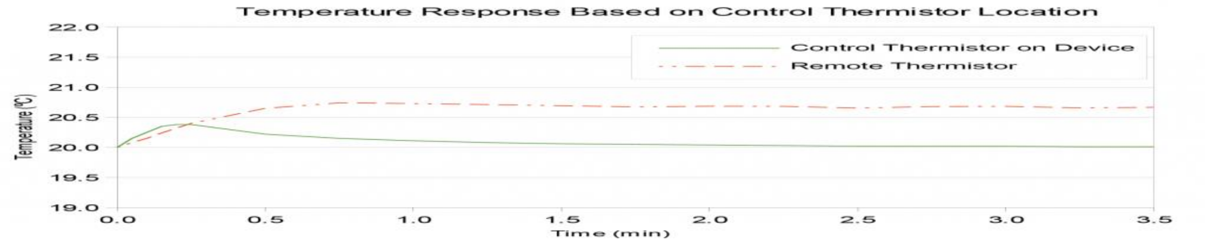


Fig 1.6: Diagram showing a temperature response of Thermistor transducers

Thermistors can be grouped into two basic categories namely, positive temperature coefficient (PTC) and negative temperature coefficient transducers (NTC).

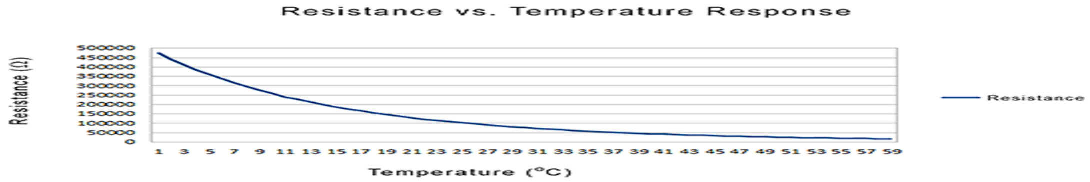


Fig 1.7: Diagram showing a resistance vs temperature response of resistance dependent transducers

The latter widely champions a greater number of the components in the market and at a higher negative temperature coefficients. It is much more frequently subscribed for in terms of construction. For NTC transducers , resistance of the device responds inversely to the ambient temperature growth; thus, increasing in value as the temperature of the surrounding is decreasing. Such considerable values of 0.05 to 0.06 temperature coefficient are often obtainable. Their application finds much accommodation in industrial works where they are mostly employed for temperature measurement and system control owing to their high degree of sensitivity.

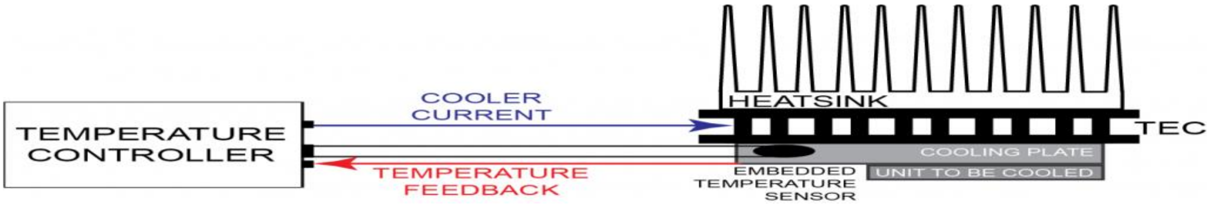


Fig 1.8: Diagram showing a temperature dependent transducers

It is mainly regarded as sensors for temperature measurement. Thermistor is composed of sintered mixture of metal – oxide materials such as Mn, N, Co, Fe and Uranium, and can be found in different sizes and shapes of packages ranging along with disk type , washer type, bead and bulb types.

Fig1.9: Diagram showing different types of thermistor transducers

Among the most popularly used is the bead type with a usual diameter of about 0.15mm. The diameter size of other types we mentioned here could approximate 2.5mm to 25mm. Typical rang of thermistor resistance could be from 0.5 ohms up to 100M ohms while the temperature may range from – 100 degree centigrade to 300 degree centigrade.

Fig 2.0: Diagram showing some types of thermistor transducers

Current to voltage characteristics of the component is directly proportional until certain magnitude is reached at which the component experiences self-heating, and as a result, the current flow retards. And so, the level of current flow across the component can be limited up to several milliampares.

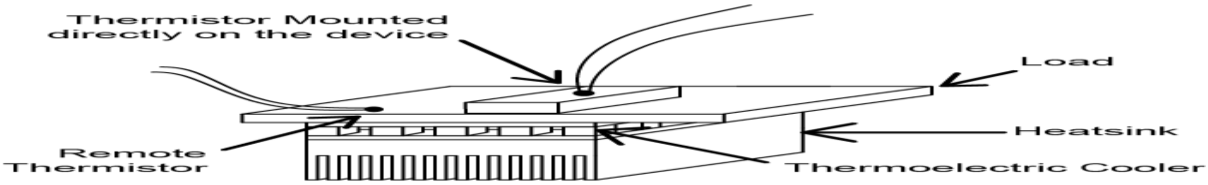


Fig 2.1:Diagram showing a typical picture of a thermistor transducer mounted on a heatsink and thermoelectric cooler

The current-voltage relationship is non-linear in some thermistor as soon as excessive self-heating is met. Configuration of resistive components into pararell or series order can be applied to annul the non-linearity characteristics and this plays important role in application of the device in a wide rage of temperature usage. The temperature bound of -60^{0}C and 100^{0}C can be efficiently managed by the transducer in a well-coordinated practical scenarios with an appreciable accuracy of about 0.1% at 100^{0}c.

2.4.1. Advantages /Disadvantages of Thermistor transducers

Advantages:

i. They are appreciably small both in size and cost.
ii. They exhibits a huge output variation with a given change in temperature
iii. Thermistor displays a considerable degree of fast response in the face of narrow range of temperature variation.

Disadvantages:

i. A high degree of non-linearity is characteristically recorded in comparative accessement of the resistance and temperature behaviour of the sensor equipment
ii. It is not suitably recommendable for measurement that entails a wide range of temperature.
iii. Owing to the high level of inherent resistance, the usage of a properly shielded cable should be unavoidable in order to reduce effect of interference.
iv. Inclusion of wheatstone bridge circuit and external power source to operate the device may add to the cost of the project implementation.

2.4.2. Application of Thermistor transducers

a. They are usually applied in various types of temperature regulators
b. They are useful in automatic electric furnace control
c. They can be used in temperature control soldering iron
d. They are applicable for gas detection
e. Application can also be needed in Thermometer fabrication

3.1 Inductance Transducers

Just like resistance and capacitive transducers, all inductive transducers base their manner of operation on the influence of inductance property of the constituting or manufacturing materials.

Inductance of an electric material arouses an account of flux that links the materials. This is called flux linkage. A current carrying conductor can produce a flux which can impinge on other conductive materials in a circuit. In a situation where the flux links the conductor from where it is produced, we referred to such as self-flux linkage; and this is due to current flow in the conductor. Thus, L for self-inductance can be represented as

$$L = {N^2}/{S}$$

But, $S = {L}/{\mu_0 \mu_r A}$

Which by substitution results

$$L = {N^2}/{1} \div {L}/{\mu_0 \mu_r A}$$

$$= {N^2}/{1} \times \frac{\mu_0 \mu_r A}{L}$$

$$= \frac{N^2 \mu_0 \mu_r A}{L} \text{ (in henry)}$$

Where,
N = Number of the coil turns
L = the length of coils in meter
A = Cross-sectional Area of the coil (m^2)
μ_r = Relative permeability
μ_o = Permeability of the free space

From the relation as shown in the equation, inductance, L of electric circuit can be varied using any of the expression variables – L, A or the number of turns, N. This is a very important feature upon which every inductance transducers functional behavior is tied.

Fig 2.2: Diagram showing a typical picture of an inductance transducer

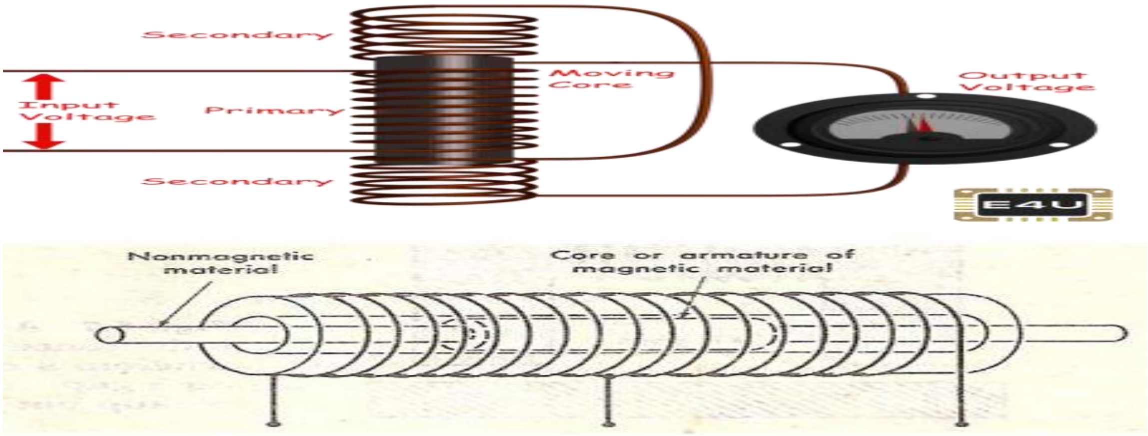


Fig 2.3: Diagram showing a typical picture of an inductance transducer

There are many number of inductance transducers which can exhibit angular or translational motion. This follows the alteration of inductance parameters of the transducer component which may be either self-inductance dependent as in the case of one-coil inductance transducer or mutually inductance dependent as in a two or more coil transducer device.

Any of these can be arranged into a differential structure with four arms and a central output terminal for output display whenever there is input displacement on a specified branch. The output response due to self or mutual inductance variation is not always responsive to any magnetic field in the surrounding, temperature variation, changes in the bridge supply voltage or frequency variation. Good examples of inductance transducer are

i. Air core inductance transducer
ii. Ferromagnetic or iron core inductance transducer
iii. Eddy current inductance transducer.

In the case of air core inductance transducer, there is no material medium as a core. Instead, the wound coil is within the air medium; hence, the name, air core inductance transducer. The changes in inductance; in this transducer, are very small compared with the ferromagnetic type. This could be due to absence of metallic material. Thus the operating frequency is very high.

Unlike the air core type, the iron or ferromagnetic type of inductance transducer has an inbuilt iron- core which is flux linkage enhancing. There are always large inductance changes with this transducer. Inductance can vary correspondingly with variation in current along the coil length. There is a noticeable effect on coil impedance due to core losses when the frequency is very high.

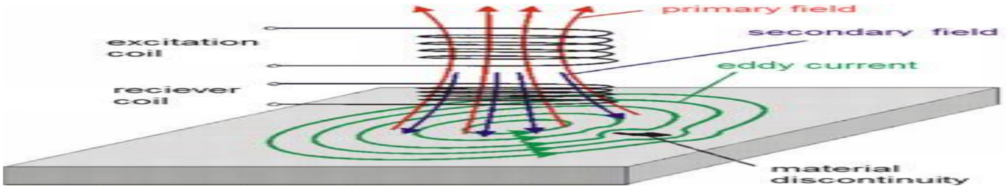


Fig 2.4: Diagram showing a typical picture of an Eddy current transducer

Eddy current type is built with a conducting plate that is closely situated to the alternating current carrying coil. The generated flux from the coil spreads across the plate which induces eddy current on the plate conductor. The magnetic field due to the eddy current on the plate interacts with the field created by the current along the coil to vary the effective inductance of the circuit. As a consequence, the small gap due to the relative position of the coil and plate changes.

A typical example of inductance transducer is the linear variable differential transformer, which is commonly known as LVDT in short form. The structure of this transducer accounts for two distinct sections of the device. The primary section shows a set of coils which are homogenously wound along the entire transducer length. Over the primary wound coils are the secondary wires that occupy either side of the transducer middle with a centrally located magnetic core which is free to move within the surrounding coil arrangement. The position of the coils with the core allows little or no fiction at the time of core movement.

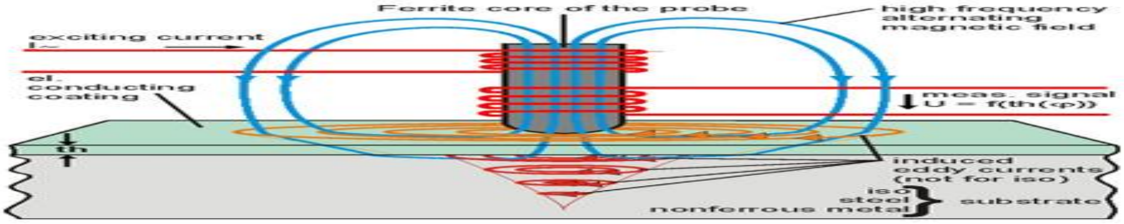


Fig. 2.5: *Diagram showing a typical picture of an Eddy current as an example of inductance transducer*

To fight the induced eddy current in the circuit, a nickel alloy T rod core is always inserted in a longitudinal manner. This is in a magnetic field environment that exists within a longitudinal slot along the field line.

Adjustment of the magnetic core at the center of the wound coil length brings about the variation of the output voltage, V_0 which is the outcome of the two generated voltages, V_1 and V_2 of the secondary coil just as an alternating current is fed into the primary coil.

The output voltage, V_0 equals the differential value of V_1 and V_2 (i.e $V_0 = V_1 - V_2$) in series and counter connection of the two secondary coils. However, the core at the mid – point of the coil length ideally makes the output voltage, V_0 zero (i.e $V_0 = V_1 - V_2$)

In real sense of the field work, it is always difficult to obtain an absolutely balanced arrangement, as such there is often times a development of a residual voltage along the core.

There are translational and rotary LVDTs with sensitivity of about 0.1V/cm – 40mV/µm and in order of 10mV/degree respectively.

5. Capacitance Transducer:

We can build a capacitor when we have two metallic plates that are electrically conductive and place them in parallel to each other with a dielectric material as an insulator that separate them two apart.

Application of a voltage on the metallic plates emerges electric charges on the plates; and these charges are always equal in magnitude but opposite in polarity. The charge that appears in every capacitor is a mathematical product of the applied voltage and capacitance of the component. Therefore,

$$Q = CV$$

Where,

C is the capacitance which can be expressed as a ratio of the charge, Q to the applied voltage, V. Thus,

$$C = Q/V$$

Similarly, C, can be related to the natural variables of the capacitor constituting parameters such as the area of the conducting metallic plates, the distance, d that separates the plates and the permittivity constants of the insulator medium ($\varepsilon_0\ \varepsilon_r$).

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

From the equation, capacitance, C is directly proportional to the area of the plates but inversely proportional to the distance, d that separates the two plates.

The expression shows that capacitance of a capacitor can be varied along side with variation of any of the capacitor variables such as the area of the plates, the distance apart of the two plates and possibly the dielectric of the insulator medium. This is the basis of the functional manipulation of a capacitance based transducer.

In capacitance transducers with two plate capacitor, varying the capacitance with distance, d gives a hyperbolic and almost a linear response over a minute displacement range. The sensitivity is in inverse proportion to the square of the separating distance, d of the two capacitor plates; and this provides a seemingly high sensitivity of the devices with a little change in d.

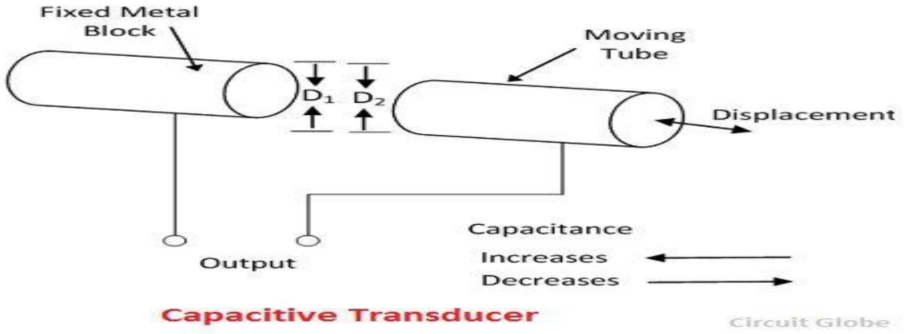


Fig. 2.6: Diagram showing a skeletal view of a capacitive transducer

There is always a linear characteristic behaviour in this device when the displacement is large enough; and to achieve this, a mica substrate is placed between the two plates. As well, full scale linearity can be reasonably achieved through a feedback capacitance connected with an amplifier. As an alternative a 3-plate deferential circuit can be used. In such arrangement, two fixed plates are usually mounted and are complemented with a third plate which is made movable in-between the already mounted two fixed plates. As a result a capacitor building principle emerges by virtue of the two parallel plates formed as we take from both end of the fixed plates to the moveable middle plates. This makes it possible to have two capacitances, C_1 and C_2 which are variable given the adjustment of the middle plate.

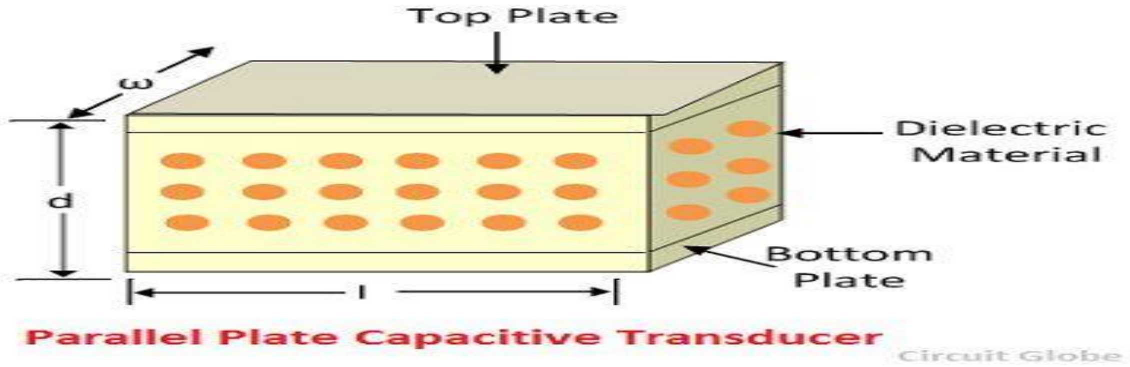


Fig 2.7: Diagram showing a typical picture of a capacitive transducer

The differential capacitance pressure transducer that is the composite product of such arrangement do possess circular fixed plates with a movable thin diagram plate within the space between the circular immovable plates. It is on this thin movable diagram that the differential pressure to be measured is directed.

We can illustrate the above device as shown below with A, B as the fixed extreme plates and T to be the adjustable diagram.

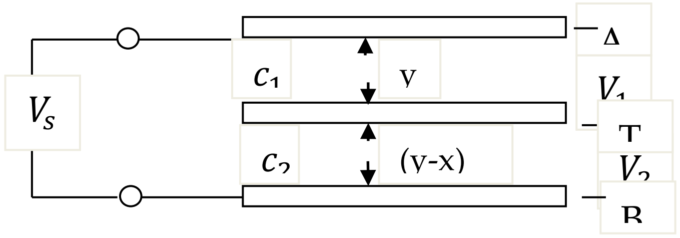


Fig 2.9: Diagram showing a typical circuit of a mid-plate capacitive transducer

V_s is a source voltage that is applied on the extended terminal of the two fixed plates . V_1 and V_2 are the voltages that develop across plates AT; and TB respectively. ‘d' is the distance between AT, and TB when plate T is moved to the middle of the two extreme plates, A and B. x is the distance plate T can be adjusted, while C_1 and C_2 are the capacitances due to plates A,T and TB when T is adjusted to the midpoint of distance 2 y between plates A and B.

The equivalent circuit can be given as shown below:

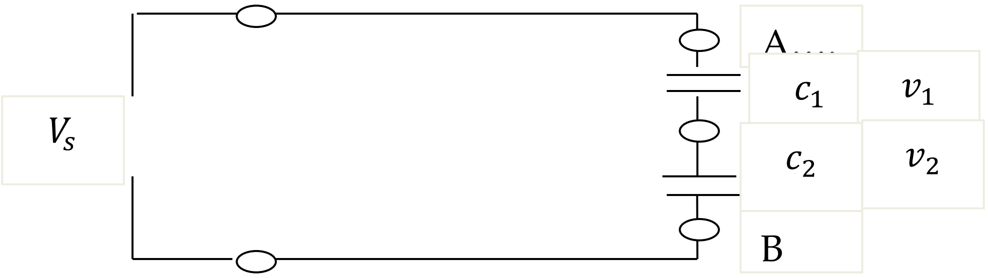


Fig 2.8: Diagram showing a typical circuit of a mid-plate capacitive transducer

Assuming T is moved x distance from the midpoint, plate, B will be (y – x) from T and A will be (y + x) from T. As a result, C_1 and C_2 can be expressed as

$$C_1 = \frac{\varepsilon_0 \varepsilon_r A}{y+x} \qquad 1$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{y-x} \qquad 2$$

but,

$$X_1 = {}^{I}/_{J\omega C_1} \qquad 3$$

$$X_2 = {}^{I}/_{J\omega C_2} \qquad 4$$

$$X_1 = {}^{I}/_{J\omega} \left(\frac{E_o E_r A}{y+x}\right) \qquad 5$$

$$X_2 = {}^{I}/_{J\omega} \left(\frac{E_o E_r A}{y+x}\right) \qquad 6$$

Applying the rule of voltage divider principles and mathematical addition of capacitors in series, we will have

$$V_1 = \frac{V_s \cdot X_2}{X_2 + (X)} \qquad 7$$

$$= V_s \left[{}^{I}/_{J\omega} \left(\frac{E_o E_r A}{y-x}\right)\right] / \left[{}^{I}/_{J\omega} \left(\frac{E_o E_r A}{y-x}\right) + {}^{I}/_{J\omega} \left(\frac{E_o E_r A}{y+x}\right)\right] \qquad 8$$

$$= \frac{V_s(y-x)}{y+y+x-x} \qquad 9$$

$$= \frac{V_s(y-x)}{2y}$$

$$= \frac{V_s y}{2_y} - \frac{V_s x}{2_y}$$

$$= \frac{V_s}{2} - \frac{V_s x}{2_y} \quad = \quad {}^{V_s}/_2 \left(1 - \frac{x}{y}\right) \qquad 10$$

Solving for V_2, we obtained

$$V_2 = \frac{V_2(y+x)}{2_y} \qquad 11$$

$$= {}^{V_s}/_2 \left(1 + {}^{x}/_{y}\right) \qquad 12$$

Taking ϑv as the voltage difference between V_1 and V_2, we can find the expression of the two voltages as

$$\Delta V = V_1 - V_2$$

$$= \left[{}^{V_s}/_2 \left(1 - {}^{x}/_{y}\right) - {}^{V_s}/_2 \left(1 + {}^{x}/_{y}\right)\right]$$

$$= {}^{V_s}/_{2y} \left[(y - x) - (y + x)\right]$$

$$= {}^{V_s}/_{2y} (y - x)$$

$$= -\frac{2x\, V_s}{2y}$$

$$= V_s \, {}^{x}/_{y} \qquad 13$$

NB: Equation (13) is the resultant output voltage expression of the transducer due to the effect of capacitor c1 and c2.

Assuming that plate T is positioned at the middle of the two end plates of the transducer with each end measuring ymm from the center (ie from T plate). Taking the numerical value of y to be 40mm, and dividing y distance into 10 equal parts; if we decide to make a discrete adjustment/movement with x variable such that the T plate moves with the x variable to covers 4.0mm in every adjustment made along y length from the center; then the range and pattern of the mid-plate movement made from the center between c1 and c2 could be listed as follows:

Δx: 0.0 mm, 4mm, 8mm, 12mm, 16mm, 20mm, 24mm, ……,40mm

Note that a distance of 4mm is added in each adjustment of the plate from the center. Recall that we obtained the resultant output voltage of the transducer to be

$$\Delta V = V_1 - V_2$$
$$= V_s \, {}^{x}\!/_{y}$$

while V_1 and V_2 are expressed as

$$V_2 = {}^{V_s}\!/_2 \left(1 + {}^{x}\!/_{y}\right)$$ and

$$V_1 = {}^{V_s}\!/_2 \left(1 - \frac{x}{y}\right)$$

The calculation of the various parameters of the device such as V_1, V_2 and ΔV was done and the values obtained recorded as shown on the table below

Table 5.0 showing the Output voltages,v_1 and v_2 variation with change in midplate displacement, X(mm)

X(mm)	0.0	4	8	12	16	20	24	28	32	36	40
V_1	5V	4.5V	4V	3.5V	3V	2.5V	2V	1.5V	1V	0.5V	0.0V
V_2	5V	5.5V	6V	6.5V	7V	7.5V	8V	8.5V	9V	9.5V	10V

Where, V_s = 10V, y = 40mm and the range of the adjustable x variable are as indicated: Δx: 0.0 mm, 4mm, 8mm, 12mm, 16mm, 20mm, 24mm, ……,40mm

The output voltage response of the device as calculated from each point of the adjusted x variable are as shown on the table below

Table 5.1 showing Source the voltage, Vs and differential output voltage, ΔV variation with change in midplate displacements, X(mm) and Y(mm)

X(mm)	0.0	4	8	12	16	20	24	28	32	36	40
Y(mm)	40	40	40	40	40	40	40	40	40	40	40
V_s	10V	10V	10V	10V	10V	10V	10V	10V	10V	10V	10V
ΔV	0.0V	1V	2V	3V	4V	5V	6V	7V	8V	9V	10V

From the table, when the diagram, T is steady at the midpoint of capacitor C_1 and C_2 (i.e. at X = 0.0mm), the voltage of the two capacitors is 5V each. As it is adjusted to 4mm away from the centre, V_1 and V_2 become 4.5V and 5.5V respectively. The distance of the T plate from the centre to 8mm length gives the C_1 and C_2 capacitors the voltage values of 4V and 6V respectively. 12mm away from 0.0mm point (from the centre) yields 3.5V and 6.5V respectively for C_1 andC_2. At 16mm distance we have 3V for C_1 and 7V forC_2. Capacitor C_2 has a voltage value of 7.5V while C_1 produces 2.5V at 20mm along the line between the two end plates. Capacitor C_1 gives 2.0V while C_2 gives 8.0V at 24mm distance away from the centre. When x is 28mm, C_1 output voltage becomes 1.5V and C_2, 8.5V. At 32mm, C_1 gives 1.0V while C_2 gives 9.0V. As X increases to 36mm, C_1 yields 0.5V and C_2, 9.5V. Lastly when X is 40mm, and enables a facial contact between C_1 and the diagram, T, C_1, gives 0.0V while C_2.produces 10V and at this point X is assumed to be equal to y, neglecting the thickness of capacitor C_1.

However, the differential output of the two capacitors, (V_1-V_2) can be computed using the expression as shown; or applying the already derived expression, $\frac{Vx}{y}$ (ΔV).

where,

ΔV = $^{Vx}/_{y}$

We express the output voltage response at every point of x adjustment as shown on the graph below: From the graph, it is very easy to note the relationship that exists among the variables$X$,V_1, $V_2$and ΔV. Of course, these variables depend on one another for issuance of the required operation of the transducer.

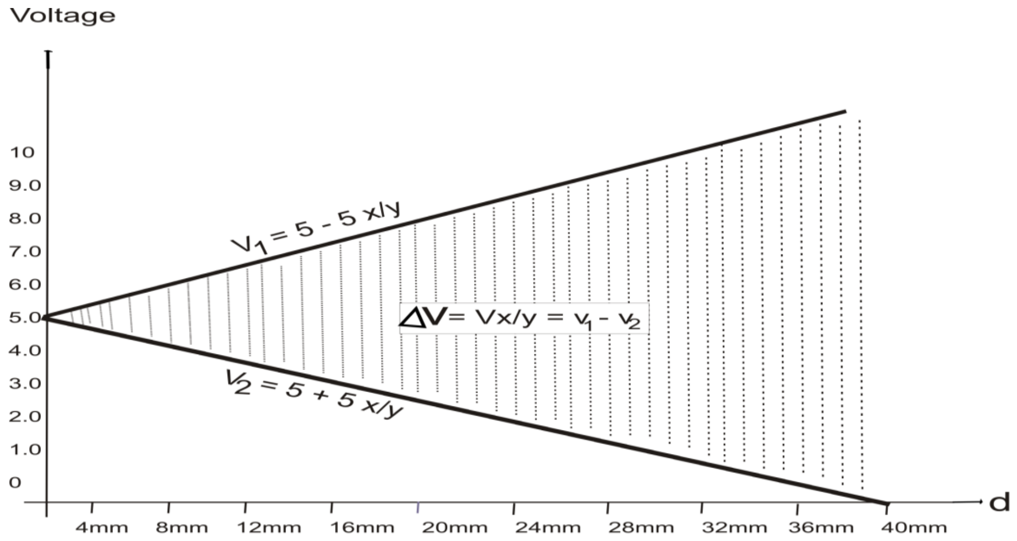


fig.1.4
Diagram showing a graphical output characteristics
of the adjustable capacitive transducer

The adjustment of *x* variable from the centre manifests the two straight diagonal lines that intersect at the middle of the vertical axis which is taken as the voltage axis The intersection of these straight lines makes a seemingly “V” looking shape that is shaded in the graph. It is within the V shaded portion of the graph that all the outputs, ΔV of the transducer are traceable as the mid plate, T is being adjusted through all the X discrete values from the centre to the end plate of C_2 and C_1 capacitors. Thus, with the transducer output, ΔV, sweeping across inbetween the two diagonally divergent lines that originate from the 5V of the voltage axis, every other voltage like $V_1$and V_2 which is made by the two end capacitors with the mid plate T are all obtained outside the transducer output. The C_1 expression forms the lower diagonal line with gradient of $^5/_{40}$ $(ie\ ^1/_8)$ while C_2 from the equation forms the upper diagonal line whose gradient is --$^1/_8$ in value

5.1. Advantages, Disadvantages and Uses of Capacitive transd.

Advantages:

1. They have very high impedance, as such; loading effects are highly reduced in the measuring circuits.
2. They have excellent frequency response which could be as high as 50 kHz as a result they can be applied for measurement of both static and dynamic situations.
3. They are not easily affected by stray magnetic fields. For this, the capacitive transducers can be used where stray magnetic fields seriously affect inductive transducers

Disadvantages:

1. They have very high output impedance. This makes their measuring circuit very complicated.
2. Insulation resistance of the system cannot be neglected because of high output impedance of the transducer. This, reduces its sensitivity, moreover with change

Uses of Capacitive Transducers:

1. Capacitive transducers can be used for measuring both linear and angular displacements. They are highly sensitive and can be adopted in measuring highly small displacements such as 0.01 pm. Conversely, the device can be used in measuring large distances of approximately 30 m as in airplane altimeters.
2. These transducers can be applied for measuring force and pressure, which are first converted into displacement , and this changes the capacitance.

6. Conclusion:

The vital influence of transduction technology has come to stay; and the effect is today being rapidly felt; thus, spreading even beyond Engineering technology that owns transducer equipment by fabrication. Their wide acceptance in other fields of life endeavour namely medical sciences and so on are breeding a welcome success; in that, the equipment are deep growing in rendering some aids for fabrication of sophisticated medical instruments that assist lifesaving. Going by this, a thorough research oriented programs should be annually conducted and always embarked upon to give hands in studding to exhume more knowledge about them. This will go a long way to encourage more discoveries for addition of new ones into the already existing number and advance our knowledge to other more areas of transducer application.

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