# Capacitive Transducer

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## What is a Transducer?

An electronic instrumentation system consists of a number of components which together are used to perform a measurement and record the result. An instrumentation system generally consists of three major elements: an input device, a signal conditioning device and processing device and an output device.

The input device receives the quantity that is to be measured and delivers a proportional electrical signal to the signal conditioning device. In the signal conditioning device, the signal is amplified, filtered or modified to a format acceptable to the output device. The output device may be a simple indicating meter, an oscilloscope, or a chart recorder for visual display. The kind of system depends on what is to be measured and how the measurement result is to be presented.

The input quantity for most instrumentation system is non-electrical. In order to use electrical methods and techniques for measurement or control of input non-electrical quantity, it must be converted into an electrical signal. And this conversion is made by a device called "Transducers".

We can also define "Transformers" in simple words as it is device which is used for the conversion of energy from its one form to the other.

## What is capacitive transducer?

Capacitive transducers are nothing but the capacitors with the variable capacitance. These are mainly used for the measurement of displacement, pressure etc. It is a Passive type of Transducer.

Principle of Operation:

The capacitive transducers works on the familiar capacitance equation of parallel plate capacitor, which is given by:

$C = \varepsilon o \times \varepsilon r \times A / d$

Where C is the capacitance of the capacitor or the variable capacitance transducer

$\varepsilon o$ is the absolute permittivity

$\varepsilon r$ is the relative permittivity The product of

$\varepsilon o$ & $\varepsilon r$ is also called as the dielectric constant of the capacitive transducer.

A is the area of the plates

d is the distance between the plates

## Construction and working:

The capacitive transducer comprises of two parallel metal plates that are separated by the material such as air, which is called as the dielectric material. In the typical capacitor, the distance between the two plates is kept varying.

In the instruments using capacitance transducers the value of the capacitance changes due to the change in the value of the input quantity that is to be measured. This change in capacitance can be measured easily and it is calibrated against the input quantity, thus the value of the input quantity can be measured directly.

## Capacitance of the Capacitive Transducers:

The capacitance C between the two plates of capacitive transducers is given by:

$C = \varepsilon o \times \varepsilon r \times A/ d$

Where C is the capacitance of the capacitor or the variable capacitance transducer

εo is the absolute permittivity

εr is the relative permittivity The product of

εo & εr is also called as the dielectric constant of the capacitive transducer.

A is the area of the plates

d is the distance between the plates

Now from the equation, we get to know that the capacitance of capacitive transducer depends on the area of the plates and the distance between the plates and it also changes with the change in the dielectric constant of the dielectric material used in it.

**Depending on the parameter that changes for the capacitive transducers, they are of three types as mentioned below:**

### 1) Changing Dielectric Constant type of Capacitive Transducers

In this type of capacitive transducer the dielectric material between the two plates changes, due to which the capacitance of the transducer also changes. When there is a change in the input quantity to be measured, the value of the dielectric constant also changes providing a change in the capacitance of the capacitive transducer. This capacitance, calibrated against the input quantity, directly gives the value of the quantity to be measured.

This principle is used for measurement of level in the hydrogen container, where the change in level of hydrogen between the two plates results in change of the dielectric constant of the capacitance transducer. Apart from level, this principle can also be used for measurement of humidity and moisture content of the air.

2) **Changing Area of the Plates of Capacitive Transducers**

The capacitance of the variable capacitance transducer also changes with the area of the two plates. This principle is used in the torque meter, used for measurement of the torque on the shaft. This comprises of the sleeve that has teeth cut axially and the matching shaft that has similar teeth at its periphery.

3) **Changing Distance between the Plates of Capacitive Transducers**

In these capacitive transducers the distance between the plates is variable, while the area of the plates and the dielectric constant remain constant. This is the most commonly used type of variable capacitance transducer.

For measurement of the displacement of the object, one plate of the capacitance transducer is kept fixed, while the other is connected to the object. When the object moves, the plate of the capacitance transducer also moves, this results in change in distance between the two plates and the change in the capacitance. The changed capacitance is measured easily and it calibrated against the input quantity, which is displacement. This principle can also be used to measure pressure, velocity, acceleration etc.

## Mathematical calculation & necessary equation:

Principle operation based on the equation , $c = \frac{\in a}{d}, c = \frac{\in_0 \in_r a}{d}$

a -overlapping plate area

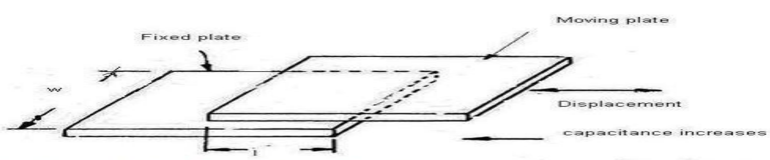
d -distance between the plates

$\in_0 \in_r$ - permittivity of the medium present between the plate

Capacitance transducer work on the principle of-

(1) Change in overlapping area (a).
(2) Change in distance between the plates (d).
(3) Change in dielectric medium ($\in$).

**Variation of Area :**




**Flat Type of Capactive Transducer**

x- length of overlapping plate

w -width of the overlapping area

d –distance between them

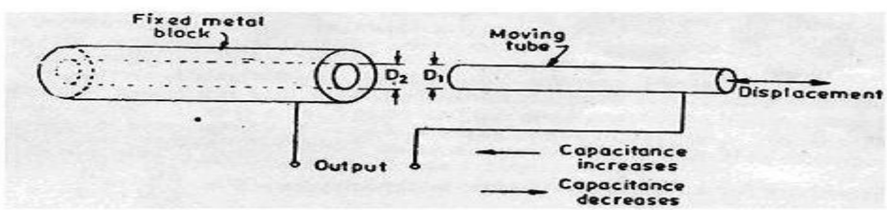
$$\text{therefore , capacitance- } c = \frac{\in a}{d} = \frac{\in wx}{d}$$

$$\text{Sensitivity , } s = \frac{\partial c}{\partial x} = \frac{\in w}{d}$$

Sensitivity for fractional change in capacitance-

$$s' = \frac{\partial c}{c \partial x} = \frac{1}{x}$$

**For cylindrical capacitor—**



Concentric Type of Capacitive Transducer

x —length of overlapping region

$d_2$ – inner diameter of outer cylinder

$d_1$ – outer diameter of inner cylinder

$$\text{therefore , capacitance } \quad c = \frac{2\pi \in x}{\log_e {}^{d_2}\!/_{d_1}};$$

$$\text{Sensitivity } \; s = \frac{\partial c}{\partial x} = \frac{2\pi \in}{\log_e {}^{d_2}\!/_{d_1}}$$

**For circular capacitor—**

Here the angular rotation of second plate changes the overlapping area. The capacitance is maximum when they are completely overlapping i.e. θ=180

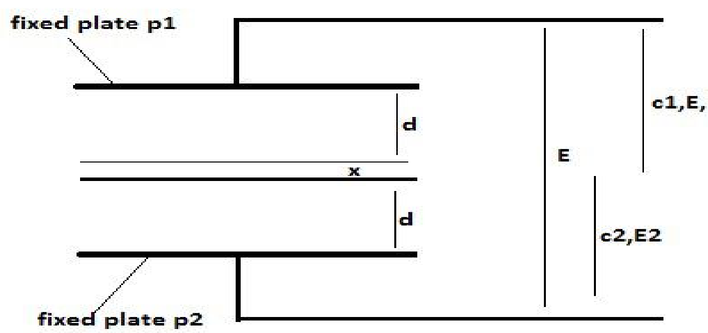
$$\text{Therefore, } c_{\max} = \frac{\in a}{d} = \frac{\in \pi r^2}{2d}$$

$$\text{And capacitance at angle } \theta \text{ , } c_\theta = \frac{\in \theta r^2}{2d}$$

$$\text{Sensitivity } s = \frac{\partial c}{\partial \theta} = \frac{\in r^2}{2d}$$

## Change in distance between the plate—

## Differential arrangement:




When the moveable plate is not moving in either direction, initially both the capacitor having same value.

$$c_1 = \frac{\in a}{d}, c_2 = \frac{\in a}{d}$$

As, $C_1$=$C_2$ then $E_1$=$E_2$

voltage across the $C_1$ is-- $E_1 = \frac{Ec_2}{(c_1+c_2)} = \frac{E}{2} and E_2 = \frac{Ec_1}{(c_1+c_2)} = \frac{E}{2}$

therefore differential output, $\Delta E = E_1 - E_2 = 0$

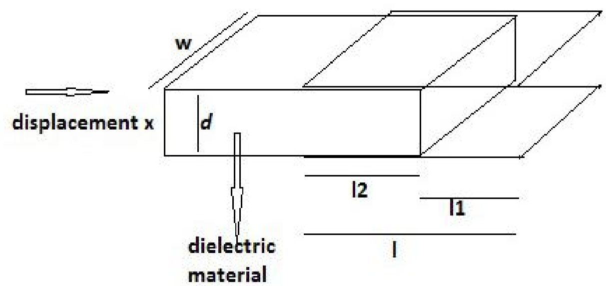
now moveable plate goes upward for a distance x, $c_1 = \frac{\in a}{d-x} and c_2 = \frac{\in a}{d+x}$

therefore, $E_1 = \frac{d-x}{2d}E$ and $E_2 = \frac{d+x}{2d}E$

differential output voltage $\Delta E = E_2 - E_1 = \frac{Ex}{d}$ , so, output voltage varies linearly with displacement x. hence sensitivity,-- $s = \frac{\Delta E}{\Delta x} = \frac{E}{d}$

## Variation of di-electric constant for measurement of displacement—

Initially dielectric placed between the two plates are $\varepsilon_r$




For this arrangement initial capacitance is— $c = \in_0 \frac{wl_1}{d} + \in_0 \in_1 \frac{wl_2}{d}$

Now consider the capacitor moves distance x along the direction indicated.so change of capacitor is $\Delta c$

So , $c + \Delta c = \frac{\in_0 w}{d}(l_1 - x) + \frac{\in_0 \in_r w}{d}(l_2 + x)$

$$= \in_0 \frac{w}{d}[l_1 - x + \in_r (l_2 + x)]$$

$$= \in_0 \frac{w}{d}(l_1 + \in_r l_2) + \in_0 \frac{w}{d}(\in_r - 1)x$$

$$= c + \in_0 \frac{w}{d}(\in_r - 1)x$$

Therefore change in capacitance-- $\Delta c = \in_0 \frac{w}{d}(\in_r - 1)x$

Here also change in capacitance proportional to displacement.

## Applications

### Precision positioning

One of the more common applications of capacitive sensors is for precision positioning. Capacitive displacement sensors can be used to measure the position of objects down to the nanometer level. This type of precise positioning is used in the semiconductor industry where silicon wafers need to be positioned for exposure. Capacitive sensors are also used to pre-focus the electron microscopes used in testing and examining the wafers.

### Disc drive industry

In the disc drive industry, capacitive displacement sensors are used to measure the run out (a measure of how much the axis of rotation deviates from an ideal fixed line) of disc drive spindles. By knowing the exact run out of these spindles, disc drive manufacturers are able to determine the maximum amount of data that can be placed onto the drives. Capacitive sensors are also used to ensure that disc drive platters are orthogonal to the spindle before data is written to them.

### Precision thickness measurements

Capacitive displacement sensors can be used to make very precise thickness measurements. Capacitive displacement sensors operate by measuring changes in position. If the position of a reference part of known thickness is measured, other parts can be subsequently measured and the differences in position can be used to determine the thickness of these parts. In order for this to be effective using a single probe, the parts must be completely flat and measured on a perfectly flat surface. If the part to be measured has any curvature or deformity, or simply does not rest firmly against the flat surface, the distance between the part to be measured and the surface it is placed upon will be erroneously included in the thickness measurement. This error can be eliminated by using two capacitive sensors to measure a single part. Capacitive sensors are placed on either side of the part to be measured. By measuring the parts from both sides, curvature and deformities are taken into account in the measurement and their effects are not included in the thickness readings. The thickness of plastic materials can be measured with the material placed between two electrodes a set distance apart. These form a type of capacitor. The plastic when placed between the electrodes acts as a dielectric and displaces air (which has dielectric constant of 1, different than the plastic). Consequently the capacitance between the electrodes changes. The capacitance changes can then be measured and correlated with the material's thickness.[ Capacitive sensors circuits can be constructed that are able to detect changes in capacitance on the order of a $10^{-5}$ picofarads (10 attofarads).

### Non-conductive targets

While capacitive displacement sensors are most often used to sense changes in position of conductive targets, they can also be used to sense the thickness and/or density of non-conductive targets as well. A non-conductive object placed in between the probe and conductive target will have a different dielectric constant than the air in the gap and will therefore change the Capacitance between probe and target. (See the first equation above) By analyzing this change in capacitance, the thickness and density of the non-conductor can be determined.

# Advantages and Disadvantages of Capacitive Transducers:

## Advantages:

1. Very little force is required to operate them and hence they are very useful in small systems.

2. They are extremely sensitive.

3. They have a good frequency response and can measure both the static as well as dynamic changes.

4. A resolution of 2.5 x 10^-3 mm may be obtained with these transducers.

5. Very high input impedence . Hence loading effect is minimum.

6. Small power is required

## Disadvantages:

1. The metallic part of the capacitor must be insulated from each other.

2. Their performance is severely affected by dirt and other contaminants because they change the dielectric constant.

3. They are sensitive to temperature variations and there are possibilities of erratic or distorted signals due to long lead length.

4. Output impedence of capacitive transducer is very high due to small value of capacitance. Therefore it leads to loading effect.