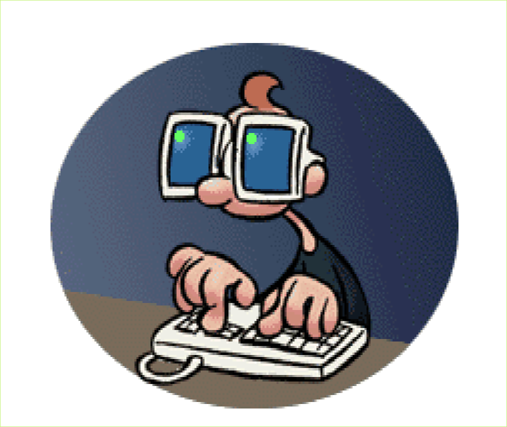


Sensors and Transducers

Objectives

At the end of this chapter, the students should be able to:

- describe the principle of operation of various sensors and transducers; namely..
  - Resistive Position Transducers.
  - Capacitive Transducers
  - Inductive Transducers

Introduction

- Sensors and transducers are classified according to;
  - the physical property that they use (piezoelectric, photovoltaic, etc.)
  - the function that they perform (measurement of length, temperature, etc.).
- Since energy conversion is an essential characteristic of the sensing process, the various forms of energy should be considered.

Introduction

- There are 3 basic types of transducers namely ***self-generating***, ***modulating***, and ***modifying*** transducers.

- The self-generating type (thermocouples, piezoelectric, photovoltaic) does not require the application of external energy.

Introduction

- Modulating transducers (photoconductive cells, thermistors, resistive displacement devices) do require a source of energy.
  - For example, a *thermocouple is self-generating*, producing a change in resistance in response to a temperature difference, whereas a *photoconductive cell is modulating* because it requires energy.
- The modifying transducer (elastic beams, diaphragms) is characterized by the same form of energy at the input and output. The energy form on both sides of a modifier is electrical.

Definition

- The words 'sensor' and 'transducer' are both widely used in the description of measurement systems.

- The former is popular in the USA whereas the latter has been used in Europe for many years. The word 'sensor' is derived from entire meaning 'to perceive' and 'transducer' is from transducer meaning 'to lead across'.

Definition

- A dictionary definition of 'sensor' is `*a device that detects a change in a physical stimulus and turns it into a signal which can be measured or recorded*;
- The corresponding definition of 'transducer' is *'a device that transfers energy from one system to another in the same or in the different form'*.

Features of Sensors

The desirable features of sensors are:

1. *accuracy* - closeness to "true" value of variable; accuracy = actual value - sensed value;
2. *precision* - little or no random variability in measured variable
3. *operating range* - wide operating range; accurate and precise over entire sensing range
4. *calibration* - easy to calibrate; no "drift" - tendency for sensor to lose accuracy over time.
5. *reliability* - no failures
6. *cost and ease of operation* - purchase price, cost of installation and operation

CHOOSING A TRANSDUCER

The following factors should be examined when choosing a sensor for a particular application:

Operating range

The transducers should maintain range requirements and good resolution

Sensitivity

The transducers must be sensitive enough to allow sufficient output

Frequency response & resonant frequency

Is the transducer flat over the needed range? Will the resonant frequency be excited?

Environmental compatibility

Do the temperature range of the transducer, its corrosive fluids, the pressures, shocks, and interactions it is subject to, its size and mounting restrictions make it inapplicable?

CHOOSING A TRANSDUCER

Minimum sensitivity

The transducer must be minimally sensitive to expected stimuli other than the measurand.

Accuracy

The transducer may be subject to repeatability and calibration errors as well as errors expected owing to sensitivity to other stimuli.

Usage & ruggedness

The ruggedness both of mechanical and electrical intensities of the transducer versus its size and weight must be considered. Who will be installing and using the transducer?

Electrical

What length and type of cable is required? What are the signal-to-noise rations when combined with amplifiers and frequency-response limitations?

Sensors Types

A list of physical properties, and sensors to measure them is given below:

ELECTRICAL

Property	Sensor	Input	operation	typ. accuracy
Voltage	voltage transducer	0-5V	lin.	<1%
Current	current transducer	0-5V	lin.	<1%
KW	power integrator	0-5V	exc./lin.	0.25%
power factor	transducers	0-5V	lin.	0.75%
KW-hr	pulse initiator	0-5V digital	exc.	0.1%

operation = excitation. lineation, compensation, offset

Sensors Types

ATMOSPHERIC

Property	Sensor	Input	operation	typ. accuracy
pressure	transducer/transmit.	0-5V,4-20mA	exc./lin.	0.5%
humidity	RH transmitter	4-20mA	exc./lin.	1% RH
precipitation	LVDT rain gauge	0-5V	exc./lin.	0.25%
solar radiation	pyranometer trans.	0-5V	exc./lin.	5%
wind direction	potentiometer	0-5V	exc./lin/off.	1%
wind velocity	pulse initiator	5V pulse	exc.	1%

TEMPERATURE

Property	Sensor	Input	operation	typ. accuracy
temperature	thermistors	resistance	lin.	1%
	thermocouple	0-80 mV	lin./comp.	0.5%
	RTD	4-20 mA	exc./lin.	0.05%
	IC sensor	BCD digital	exc./lin.	0.01%

Common Sensors

Listed below are some examples of common transducers and sensors that we may encounter:

- <u>Ammeter</u> - meter to indicate electrical current.
- <u>Potentiometer</u> - instrument used to measure voltage.
- <u>Strain Gage</u> - used to indicate torque, force, pressure, and other variables. Output is changed in resistance due to strain, which can be converted into voltage.
- <u>Thermistor</u> - Also called a resistance thermometer; an instrument used to measure temperature. The operation is based on change in resistance as a function of temperature.

Sensors Types

- There are several transducers that will be examined further in terms of their principles of operations.
- Those include :

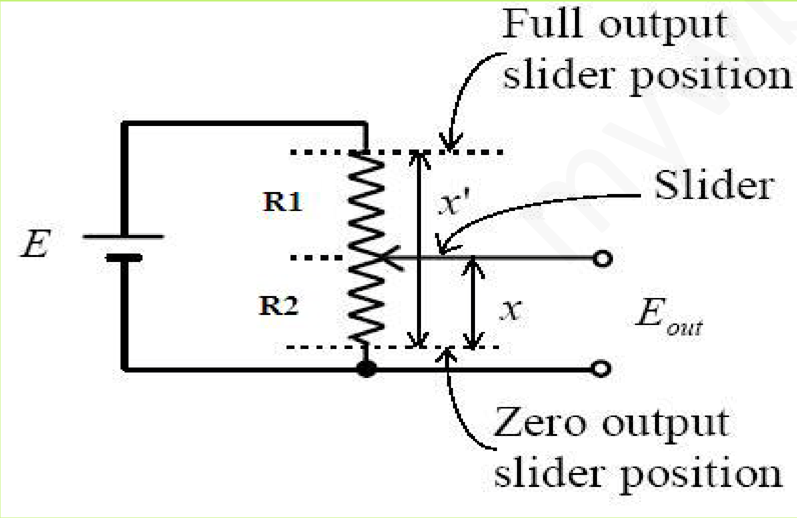
1. *Resistive Position Transducers*
2. *Strain Gauges*
3. *Capacitive Transducers*
4. *Inductive Transducers*
5. *And a lot more…*

Resistive Position Transducers

- The principle of the resistive position transducer is that the measured quantity causes a resistance change in the sensing element.
- A common requirement in industrial measurement and control work is to be able to sense the position of an object, or the distance it has moved.
- One type of displacement transducer uses a resistance element with a sliding contact linked to the object being monitored.
- Thus the resistance between the slider and one end of the resistance element depends on the position of the object.

Resistive Position Transducers

- The output voltage depends on the wiper position and therefore is a function of the shaft position.
- In figure below, the output voltage E_{out} is a fraction of E_T, depending on the position of the wiper.
- The element is considered perfectly linear if the resistance of the transducer is distributed uniformly along the length of travel of wiper.



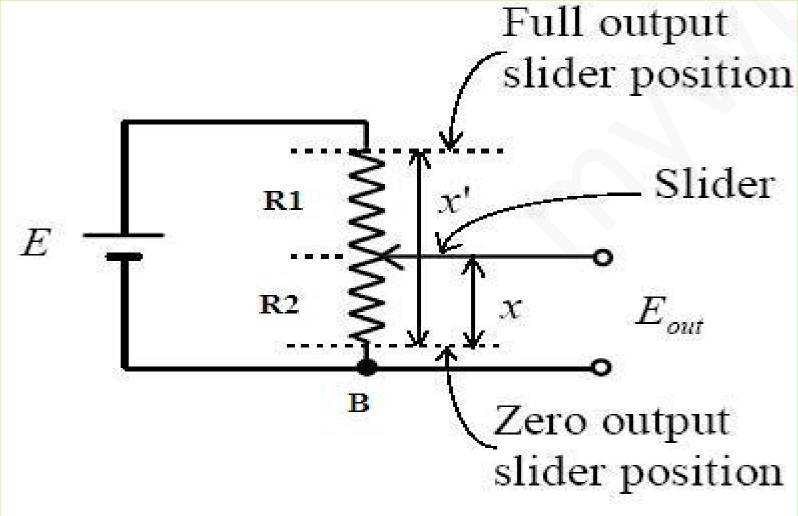
$$\frac{E_{out}}{E_T} = \frac{R_2}{R_1 + R_2}$$

Resistive Position Transducers

Example 1

An RPT with a shaft stroke of 5.5 inches is applied in the circuit as below. The total resistance of the potentiometer is 4.7kΩ. The applied voltage is E_T= 3V.

When the wiper is 0.9 in. from B, what is E_{out}?



STRAIN GAUGE

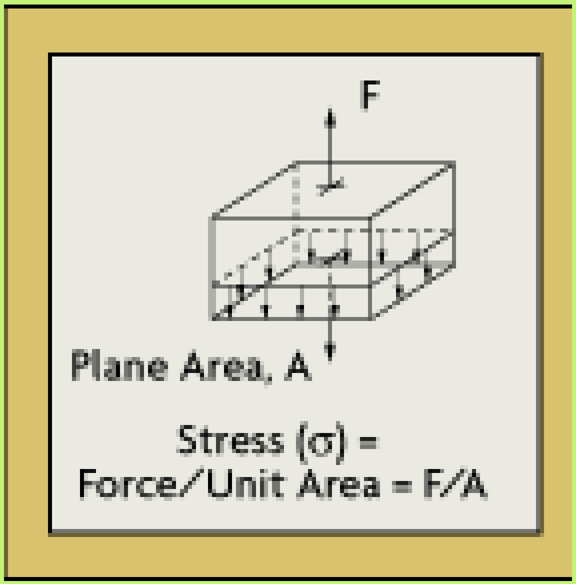
- Strain gauge is a passive transducer that uses "***electrical resistance variation***" in wires to *sense the strain* produced by a *force* on the wires.
- Measurement for
  - Weight
  - Pressure
  - Mechanical force
  - Displacement

STRAIN GAUGE

When external forces are applied to a stationary object, stress and strain are the result.

Stress is defined as the object's internal resisting forces.

For a uniform distribution of internal resisting forces, stress can be calculated by dividing the applied force (F) by the unit area (A):



$$\text{Stress } (\sigma) = F/A$$

kg/m²

m²

kg

Stress – “tekanan”

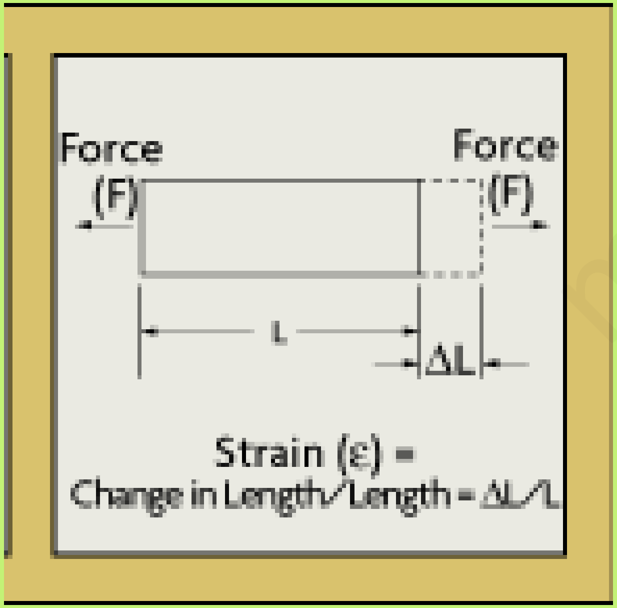
Strain – “regangan”

STRAIN GAUGE

Strain

- A fractional change (ΔL/L) in the dimensions of an object as a result of mechanical stress (force/area)

- Calculated by dividing the **total deformation of the original length** by the **original length** (L):



$$\text{Strain } (\varepsilon) = (\Delta L)/L$$

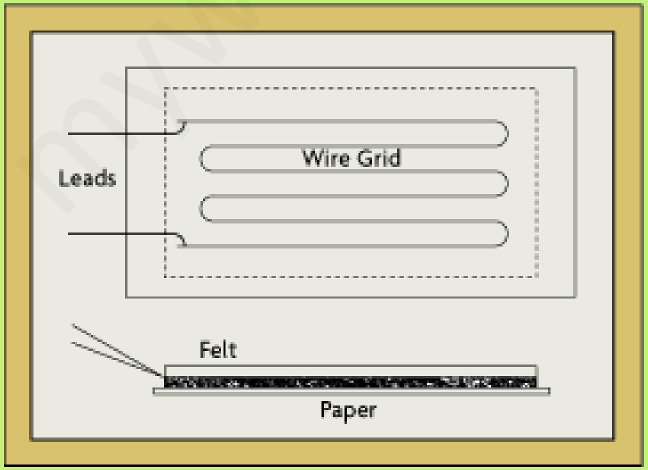
Unit-less

STRAIN GAUGE

Stress & Strain

Stress (σ) = F/A

Strain (ε) = $(\Delta L)/L$



STRAIN GAUGE

The constant of proportionality between stress and strain for linear stress-strain curve is known as the modulus of elasticity of the material, E, or Young's modulus.

$$E = \frac{\sigma}{\varepsilon}$$

E → Young's modulus in kilograms per-square meter

σ → The stress in kilograms per square meter

ε → The strain (no units)

STRAIN GAUGE

A device whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge is the bonded metallic strain gauge.

Designed to convert mechanical motion into an electronic signal.

If a wire is held under tension, it gets slightly longer and its cross-sectional area is reduced.

Resistance is related to length (l) and area of cross-section of the resistor (A) and resistivity (ρ) of the material as

$$R \equiv \frac{\rho l}{A}$$

STRAIN GAUGE

This changes its resistance (R) in proportion to the *strain sensitivity* of the wire's resistance. When a strain is introduced, the strain sensitivity, which is also called the gauge factor (GF), is given by:

GF = (Δ R/R)/(Δ L/L) = (Δ R/R)/ Strain

$$GF = \frac{(\Delta R / R)}{\varepsilon}$$

$$\varepsilon = \frac{\Delta L}{L}$$

GF is a measure of sensitivity

GF = gauge factor

R = the initial resistance in ohms (without strain)

ΔR = the change in initial resistance in ohms

L = the initial length in meters (without strain)

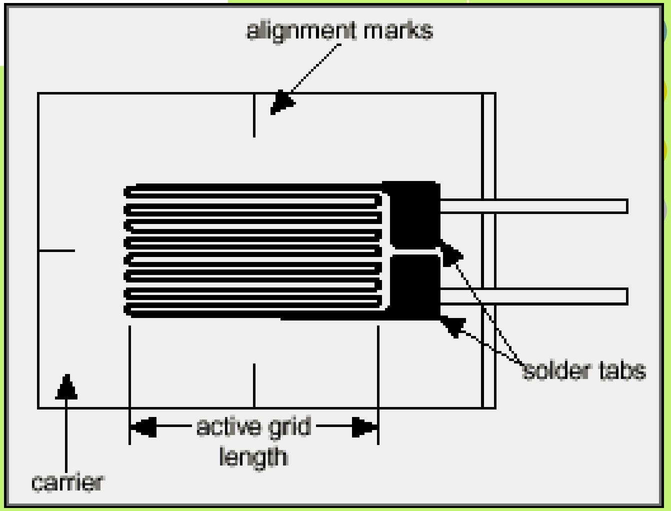
ΔL = the change in initial length in meters

STRAIN GAUGE

For strain gauge applications, a *high degree of sensitivity* is very desirable. A high gauge factor means a relatively large resistance change for a given *strain*. Such a change is more easily measured than a small resistance change.

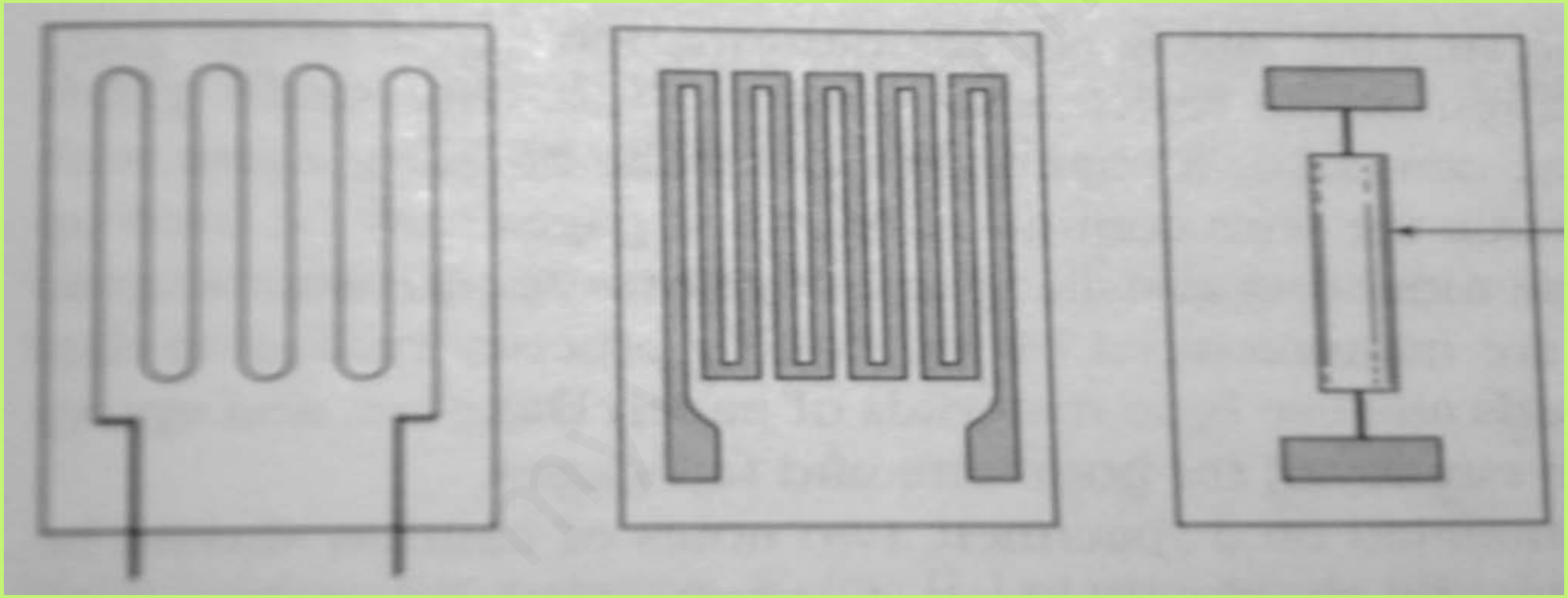
STRAIN GAUGE

- **Fabrication and use**
  - Typical strain gauges consist of a foil or wire grid covered by two sheets of insulation (polyimide)
  - The gauge is attached to the desired object with an adhesive
  - Longitudinal segments are aligned with the direction of stress



STRAIN GAUGE

Common types of resistance strain gages



(a) (b) (c)

Three types of resistance strain gages. (a) Wire gage; (b) foil gage; (c) semiconductor gage

STRAIN GAUGE

Just for your knowledge !!!!

The bonded-wire gage employs wire sizes varying between 0.0005 and 0.001 in (12 and 23 μm)

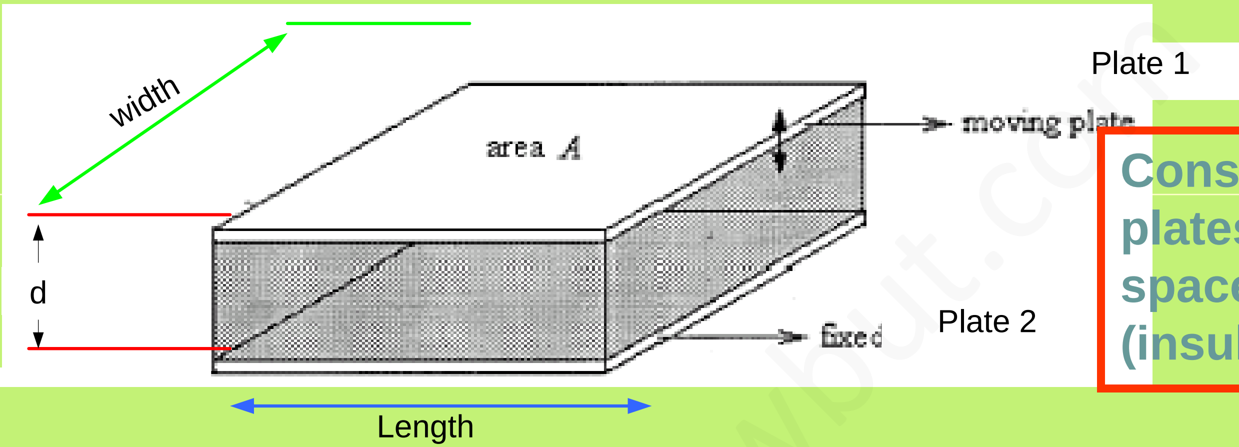
The foil gage usually employs a foil less than 0.001 in thick and is available in a wide variety of configurations which may be adapted to different stress measurement situation. Because of this flexibility, it it the most commonly used gage.

The silicon gage employs a silicon base material that is strain-sensitive and has the advantage that very large values of GF may be obtained (GF~100). The material is usually produced in brittle wafers having a thickness of about 0.01 in (0.25mm). Semiconductor gages also have very high temperature coefficients of resistance.

Example 2

- A resistant strain gauge with a gauge factor of 2 is fastened to a steel member, which is subjected to strain of $1x10^{-6}$. If the original resistance value of the gauge is 130Ω, calculate the change in resistance.

CAPACITIVE TRANSDUCER



Consist of two parallel plates separated by an air space or by dielectric (insulating material)

$$C = \frac{kA\varepsilon_o}{d}$$

k = dielectric constant of the material in the gap

ε_o = the permittivity of free space

= 8.854 x 10^{-12} farad/meter

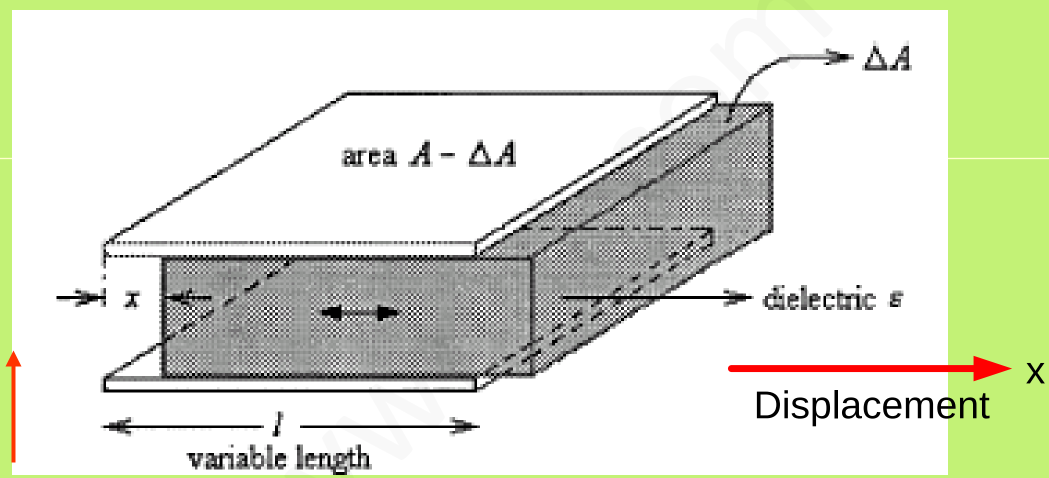
A = Plate area (m^2)

d = the separation between plate (m)

CAPACITIVE TRANSDUCER

Variation in Capacitance

$$C = \frac{kA\varepsilon_o}{d}$$



ΔA

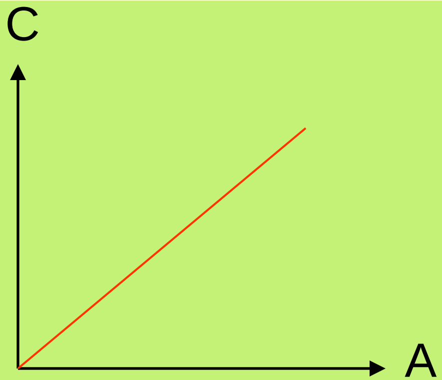
Δk

Δd

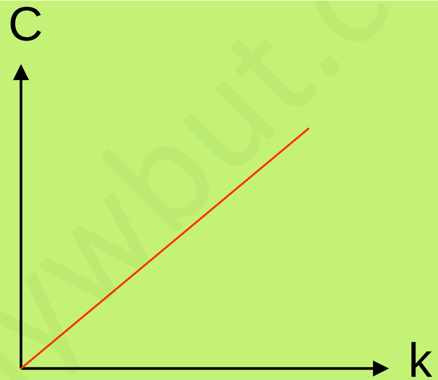
CAPACITIVE TRANSDUCER

Variation in Capacitance

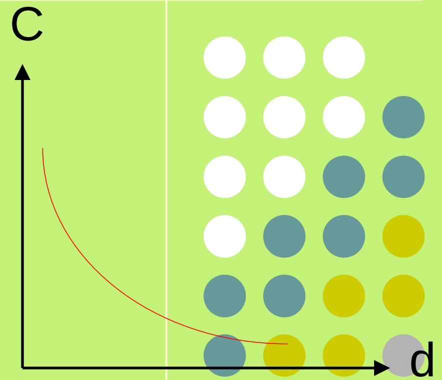
ΔA	Changing the surface area	Δk	Changing the dielectric constant	Δd	Changing the spacing btwn plate



The affective area of the plates will change proportionally to the value of capacitance



Value of C will increased when the dielectric constant increased

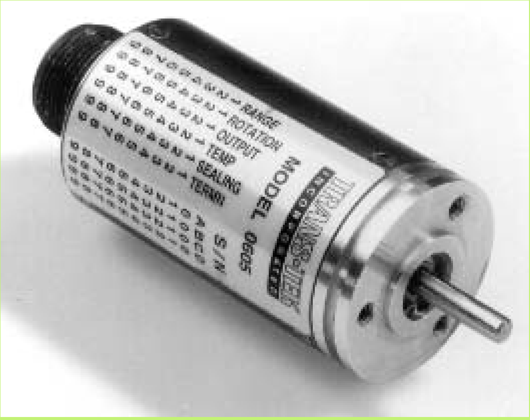


Value of C will decreased when the spacing between plate increased

Advertisement !!!

Series 605 Versatile ADT

The Series 605 Angular Displacement Transducers use capacitive technology to sense the absolute angular movement of an object. Enhancements to the electronics such as an internal voltage regulator, standardized outputs, and 3 kHz frequency response make this unit ideal for most industrial applications requiring an analog DC-in/DC-out angular position sensor. The small size of this transducer makes it an attractive alternative to absolute encoders for strokes to 300°.



http://www.globalspec.com/FeaturedProducts/Detail/transtek/Series_605_Versatile_ADT/110/0

Advertisement !!!

Camille Bauer KINAX rotary transducers

The transducers employ contactless capacitive sensing to provide 0° up to 350° angular measurement. They are available in explosion-proof housings, depending on the model series chosen.

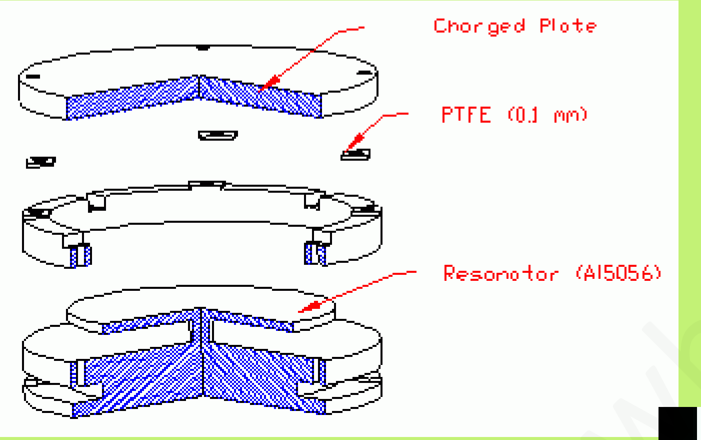
The KINAX SR709 is designed for use measuring the stroke of valves and other actuators. KINAX transducers have a 4-20mA or 0-20mA output, the KINAX 2W2 being provided also with a serial interface.

High resolution angular displacement measurements are catered for by gearbox-equipped KINAX transducers with minimum torque requirements of 0.001Nm or less.

http://www.ferret.com.au/articles/df/0c01cbdf.asp

Capacitive Transducers

- Some examples of capacitive transducers



Capacitive Transducers

Example 3:

An electrode-diaphragm pressure transducer has plates whose area is $5x10^{-3}$ m^2 and distance between plates is $1x10^{-3}$.

Calculate its capacitance if it measures air pressure with k=1.