Pressure Transducers

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Pressure Measurement

Elastic Transducers:

- ✓ **Elastic elements, when subjected to pressure, get deformed. The deformation gives an indication of the pressure.**

- ✓ **These elements may be in the form of diaphragms, bellows, Bourdon tubes etc.**

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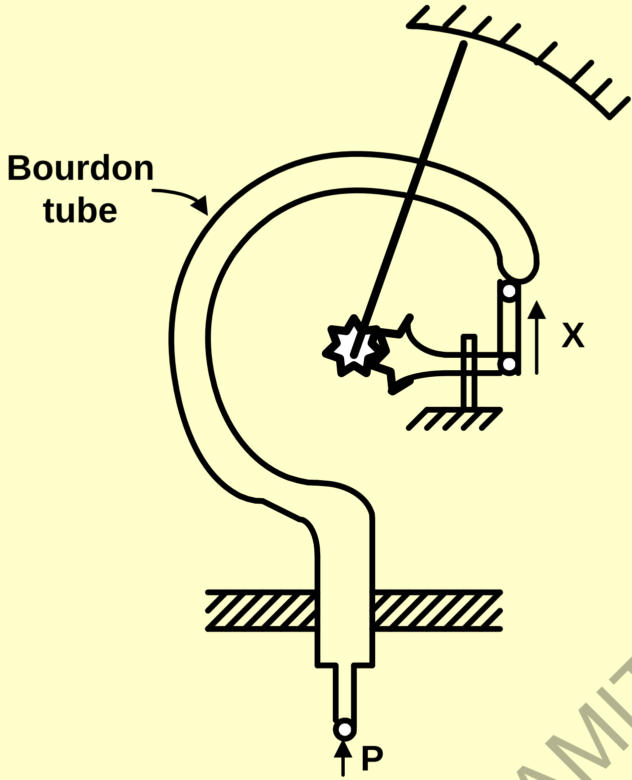
Bourdon Tube Pressure Gauge



Features:

- ✓ The basic element is a tube of non circular cross section.
- ✓ The C-type bourdon tube has been utilized upto about 1,00,000 lb/in^2.
- ✓ They enjoy a wide range of application where consistent, inexpensive measurements of static pressure are desired .
- ✓ The spring-loaded linkage is constructed so that the mechanism may be adjusted for optimum linearity and minimum hysteresis, as well as to compensate for wear which may develop over a period of time.

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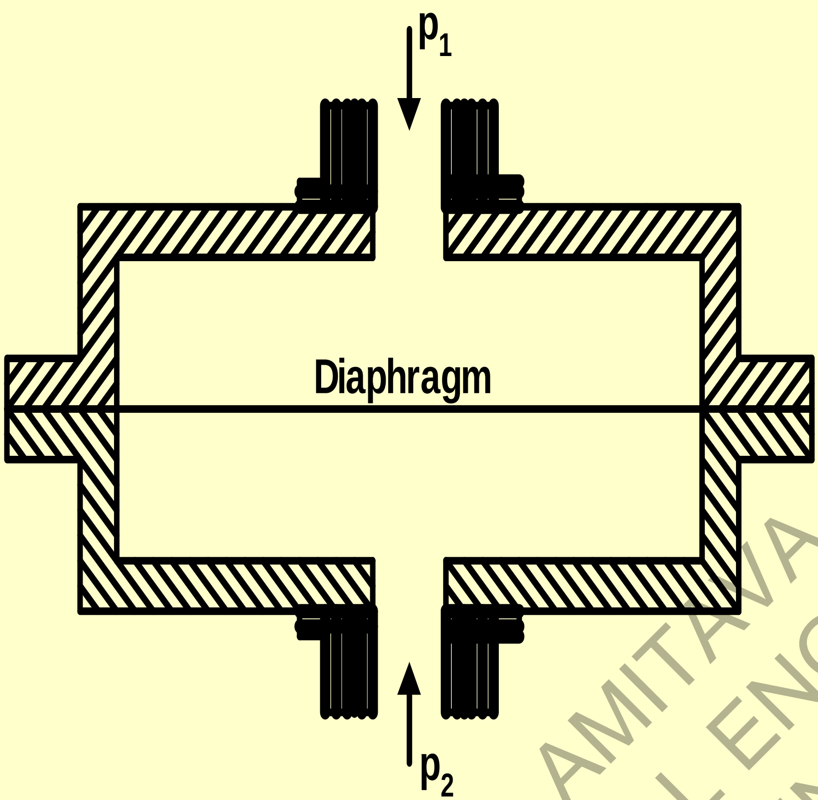
Diaphragm



Features:

- ✓ **The flat diaphragm will be deflected due to the pressure differential $(p_1 - p_2)$.**
- ✓ **The deflection is sensed by an appropriate displacement transducer.**
- ✓ **Electrical resistance strain-gauges may also be installed on the diaphragm.**
- ✓ **The deflection generally follows a linear variation with Δp when the deflection is less than (⅓)rd the diaphragm thickness.**

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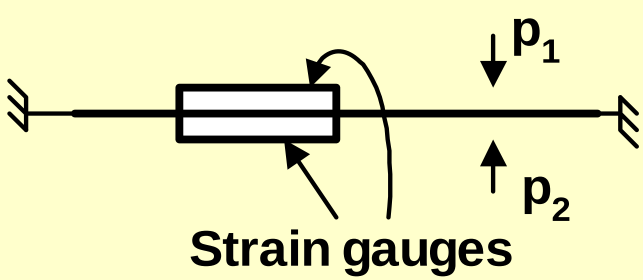
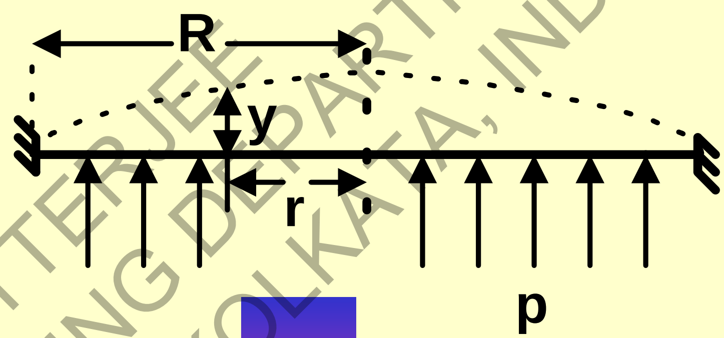
Diaphragm (contd…)





The deflection y at radius r of a circular diaphragm clamped at its outer periphery is given by:

$$y = \frac{3}{16} p \frac{\left(1-\mu^2\right)}{Et^3}\left(R^2 - r^2\right)^2$$

p is the uniform pressure on the diaphragm of radius R and thickness t,
E is Young's Modulus of the diaphragm material,
μ is Poisson's Ratio.

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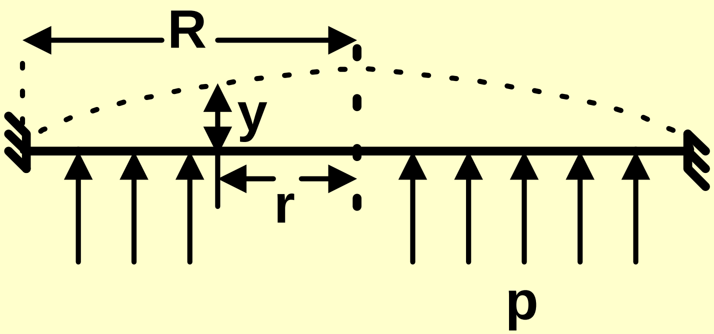
Diaphragm(contd…)



$$y_{max} \text{ (at } r = 0) = \frac{3}{16}.\frac{p}{Et^3}.R^4(1-\mu^2)$$

Important consideration:

For dynamic measurements, the fundamental frequency of the vibrations of the elastic element should be higher than the excitation frequency, due to the fluctuating pressure.

✓**The natural frequency of a circular diaphragm fixed at its perimeter is:**

$$f = \frac{10.21}{R^2}\sqrt{\frac{Et^2}{12(1-\mu^2)\rho}}\ Hz$$

ρ = density of the material (kg/m^3)

E = modulus of elasticity (*Pa*)

[1 Pascal = 1 N/m^2].

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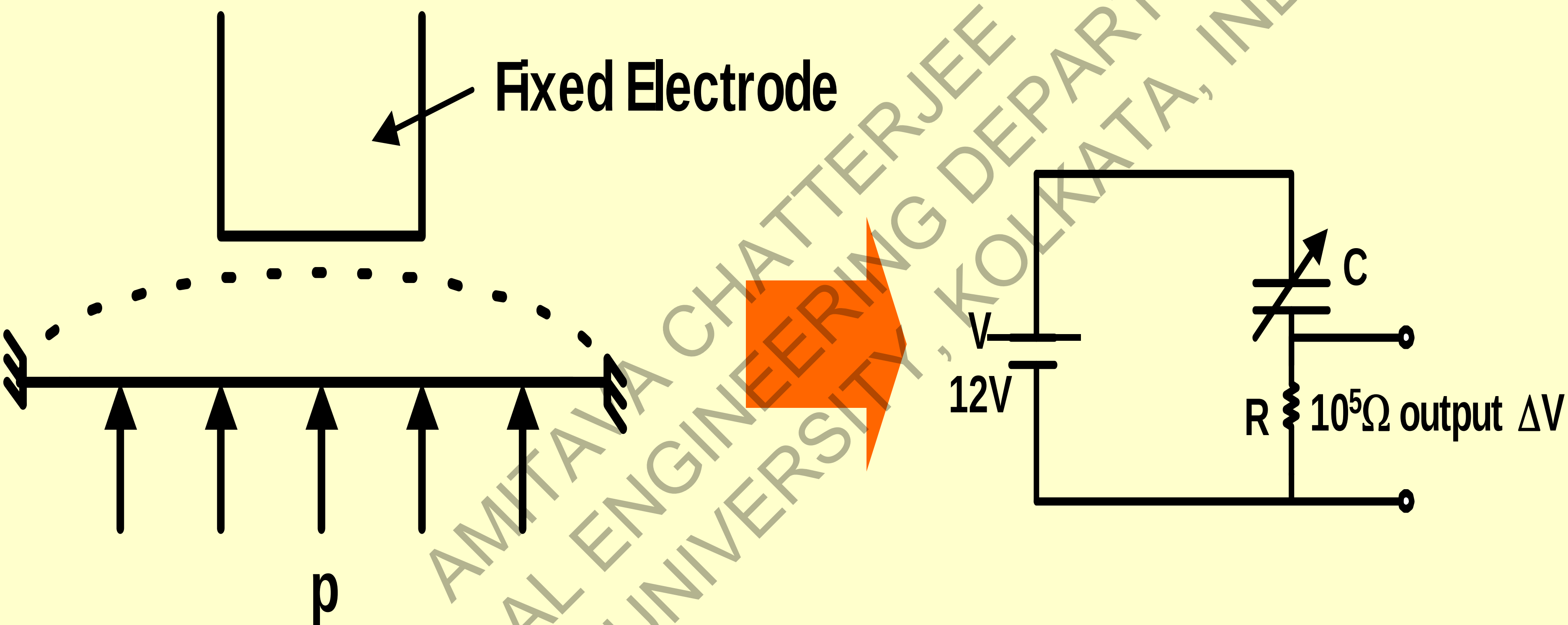
Variable Capacitance Pressure Transducer employing Clamped Diaphragm



✓ **The arrangement is well suited for dynamic measurements. However, the capacitance pick-up involves low sensitivity and special care must be exerted in the construction of the readout circuitry.**

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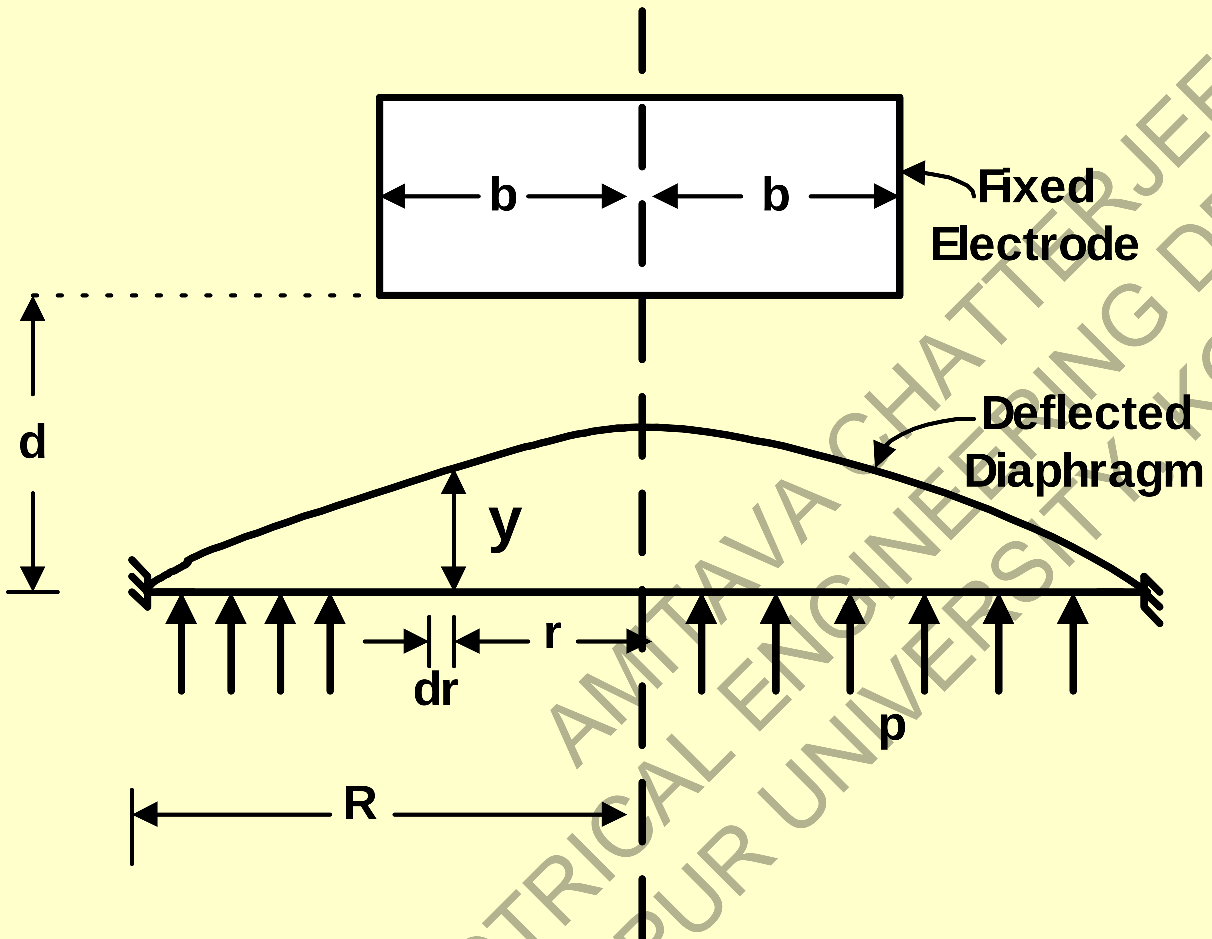
Variable Capacitance Pressure Transducer with a Clamped Diaphragm



✓The change in the gap between the diaphragm and the fixed electrode, due to pressure ***p***, is not uniform but is a function of the radius ***r***.

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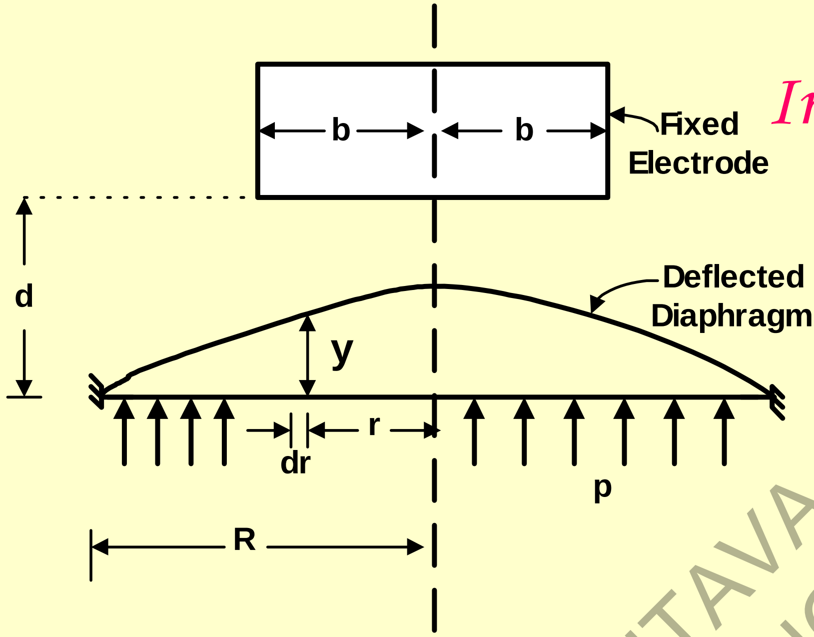
Variable Capacitance Pressure Transducer with a Clamped Diaphragm (contd…)



Initial Capacitance: $C_o = \frac{\epsilon_0 \epsilon_r (\pi b^2)}{d} = \frac{\epsilon_0 \pi b^2}{d}$

where $\epsilon_r = 1$ in air and $A = \pi b^2$.

After application of pressure p:

Let y be the diaphragm deflection.
Then air gap at radius $r = d - y$.

$$\therefore y = \frac{3}{16} \cdot \frac{p}{Et^3} \left(1 - \mu^2\right)\left(R^2 - r^2\right)^2$$

New capacitance C between the diaphragm and the fixed electrode:

$$C = \int_o^b \frac{\varepsilon_0 2\pi r . dr}{(d - y)}$$

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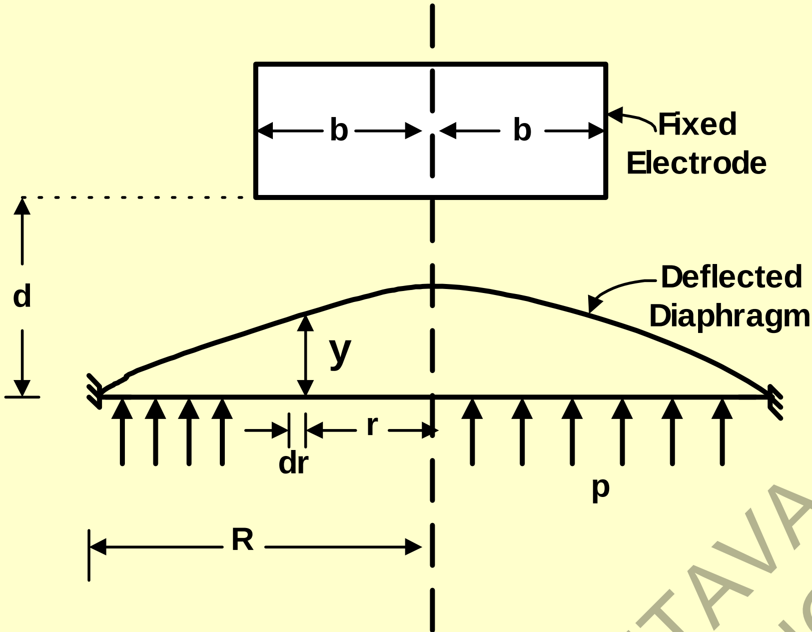
Variable Capacitance Pressure Transducer with a Clamped Diaphragm (contd…)



$$C = \int_o^b \frac{\varepsilon_0 2\pi r dr}{(d-y)} \approx \frac{\varepsilon_0 .2\pi}{d} \int_o^b \left(1 + \frac{y}{d}\right) r dr$$

$$C = \frac{2\pi\varepsilon_0}{d} \int_o^b r dr + \frac{2\pi\varepsilon_0}{d^2} \int_o^b \frac{3}{16} \cdot \frac{p}{Et^3} (1-\mu^2)(R^2 - r^2)^2 r dr$$

$$C = \frac{\varepsilon_0 \pi b^2}{d} + \frac{0.1963\varepsilon_0 p(1-\mu^2)}{Et^3 d^2} \left[b^6 + 3R^2 b^2 \left(R^2 - b^2\right)\right]$$

$$\frac{\Delta C}{C_o} = \frac{C - C_o}{C_o} = \frac{0.0625 p(1-\mu^2)}{Et^3 d} \left[b^4 + 3R^2\left(R^2 - b^2\right)\right]$$

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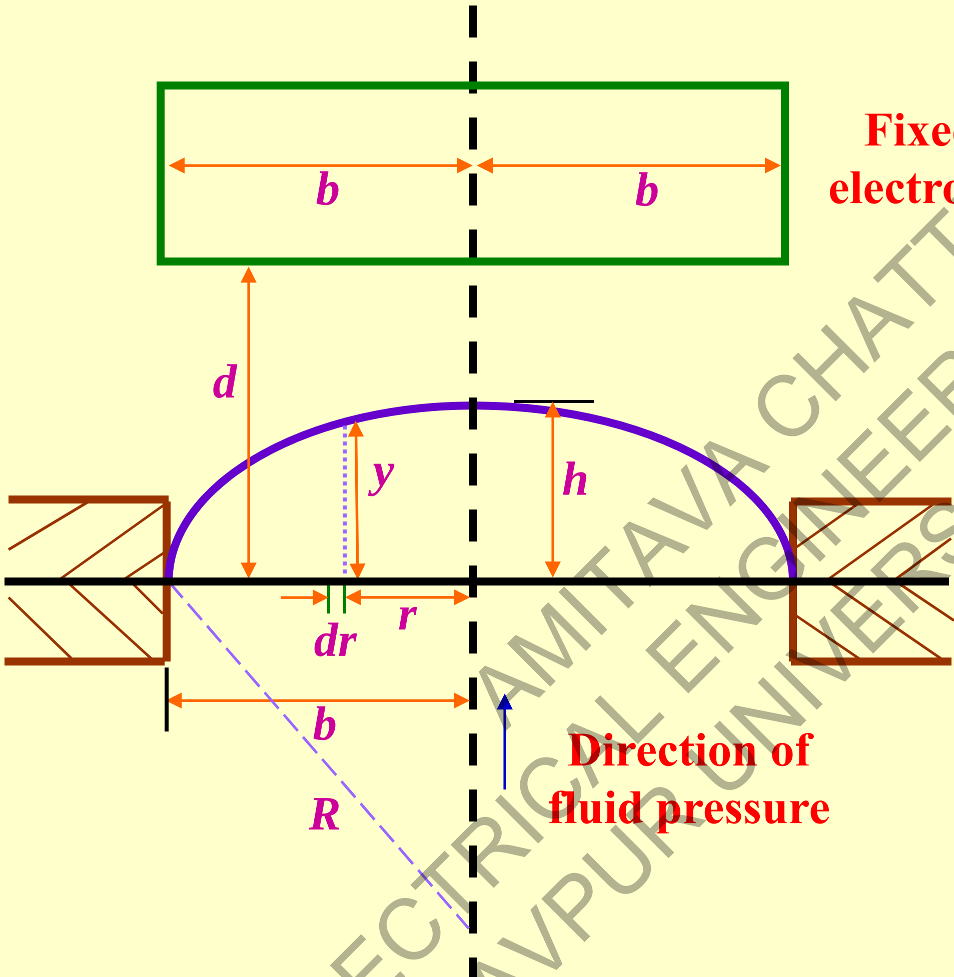
Variable Capacitance Pressure Transducer with a Stretched Diaphragm



- ✓ A change in capacitance will be caused by a flexible diaphragm, deflected by a uniform fluid pressure, in proximity of a stationary rigid plate.

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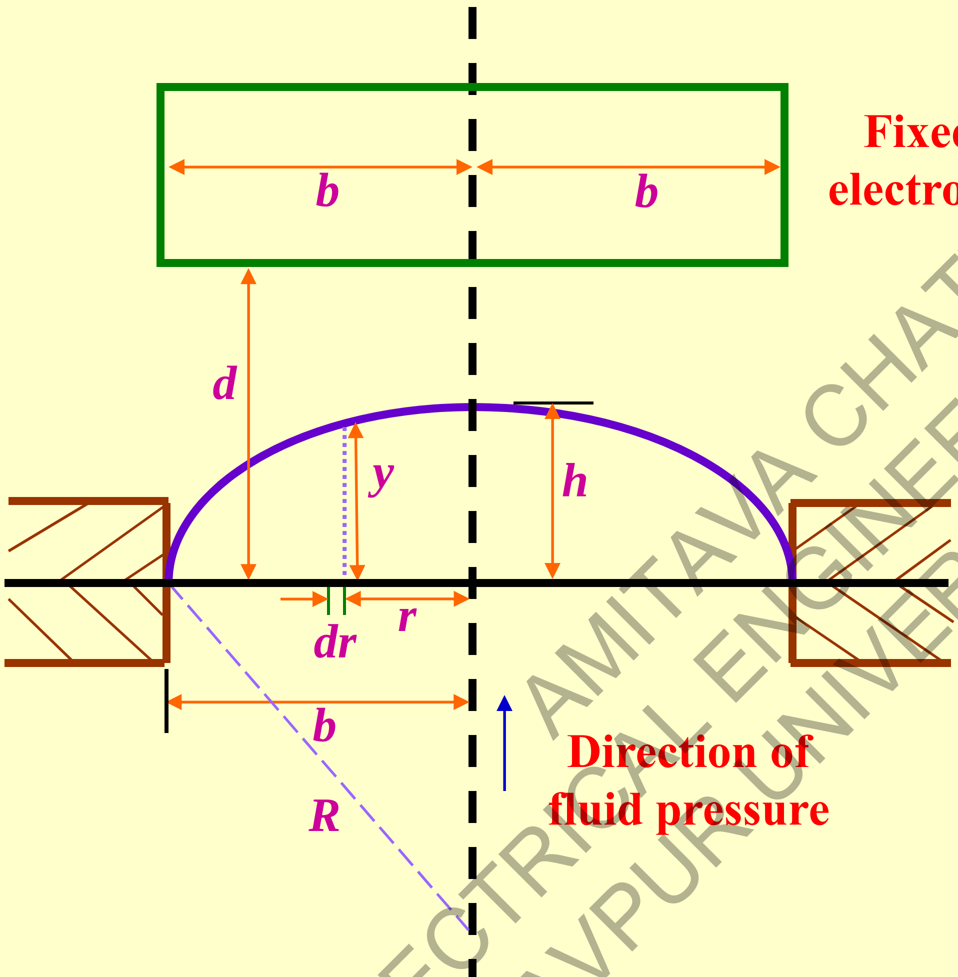
Variable Capacitance Pressure Transducer with a Stretched Diaphragm (contd…)



The Deflection y (cm) of the Circular Membrane at a radius r (cm) is:

$$y = \frac{2S}{p}\left[\sqrt{\left\{1-\left(\frac{rp}{2S}\right)^2\right\}}-\sqrt{\left\{1-\left(\frac{bp}{2S}\right)^2\right\}}\right]$$

S = tension in the diaphragm (kg/cm)

at the circumference and

p = fluid pressure (kg/cm^2).

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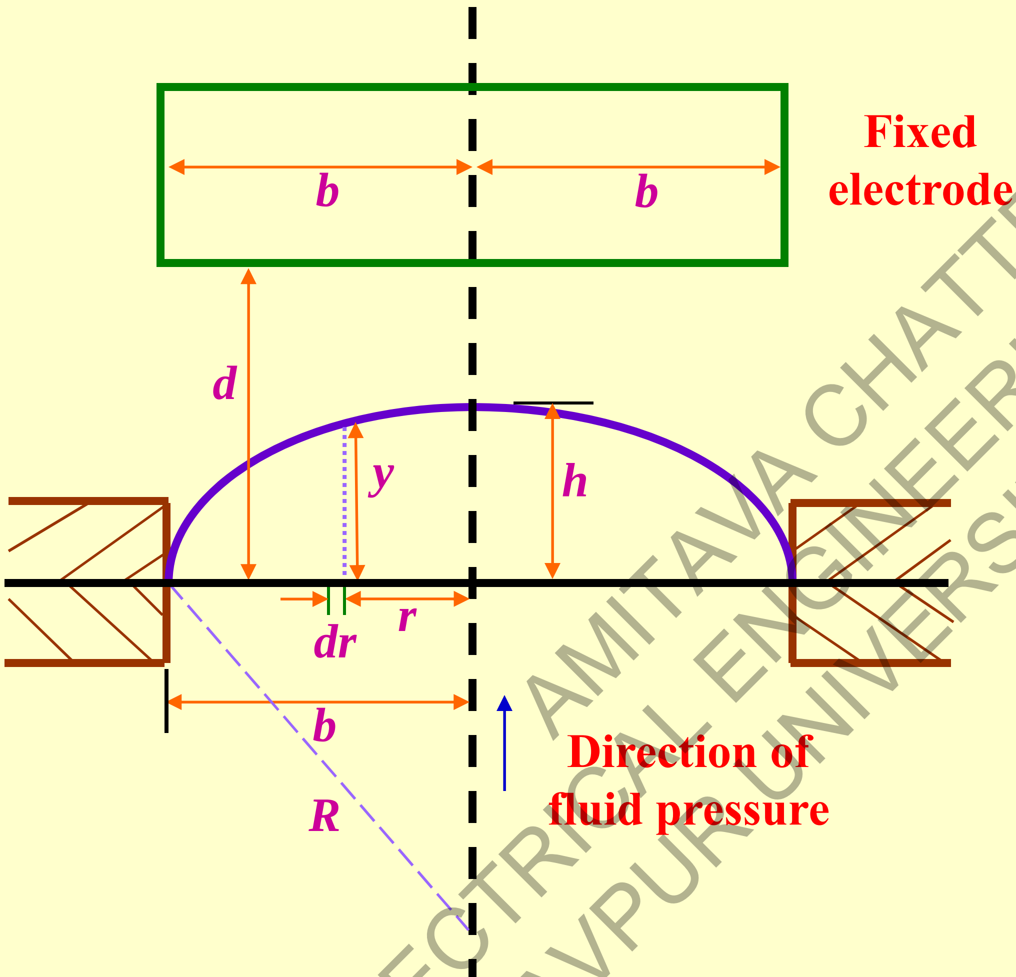
Variable Capacitance Pressure Transducer with a Stretched Diaphragm (contd…)



Expanding y in form of a series and neglecting higher terms, for small deflections :

$$y = \frac{2S}{p}\left[\sqrt{\left\{1-\left(\frac{rp}{2S}\right)^2\right\}} - \sqrt{\left\{1-\left(\frac{bp}{2S}\right)^2\right\}}\right]$$

$$y \approx \frac{p}{4S}\left(b^2 - r^2\right) \quad \left[\because \left(\frac{h}{b}\right)^2 << 1\right]$$

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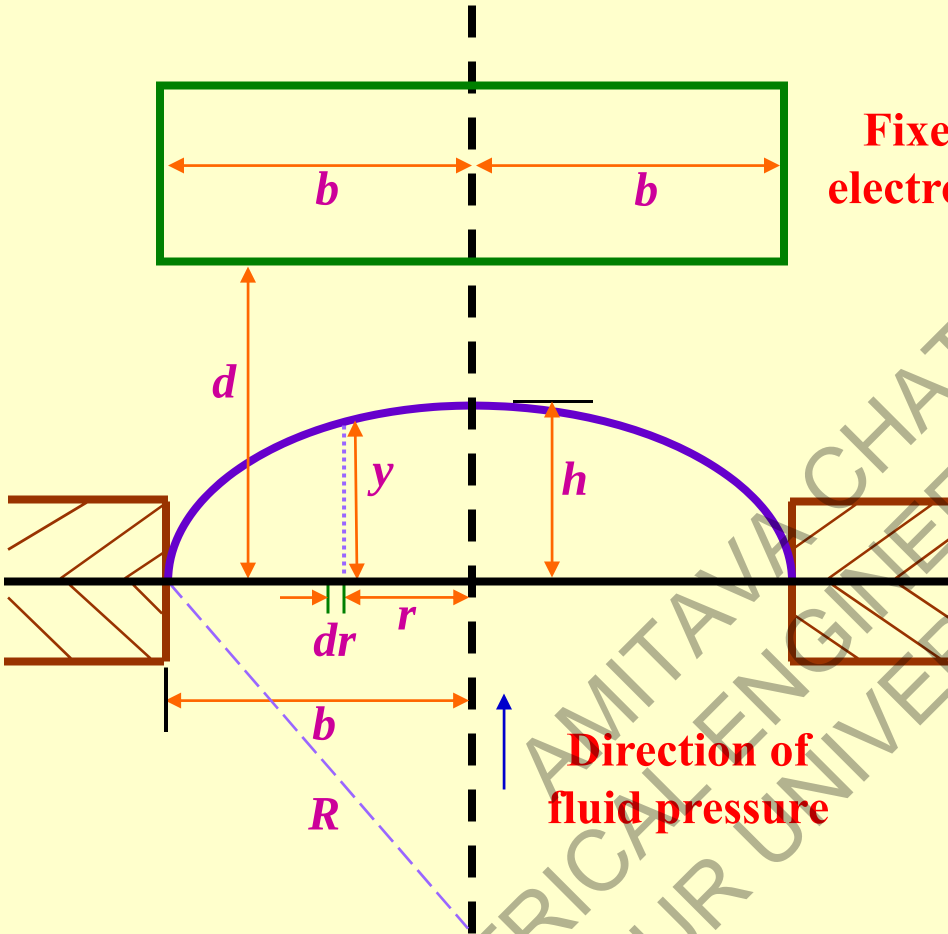
Variable Capacitance Pressure Transducer with a Stretched Diaphragm (contd…)



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After application of pressure p:

Let y be the diaphragm deflection.

Then air gap at radius $r = d - y$.

$$y = \frac{p}{4S}\left(b^2 - r^2\right)$$

New capacitance C between the diaphragm and the fixed electrode:

$$C = C_0 + \Delta C = \int_o^b \frac{\varepsilon_0 2\pi r dr}{(d-y)}$$

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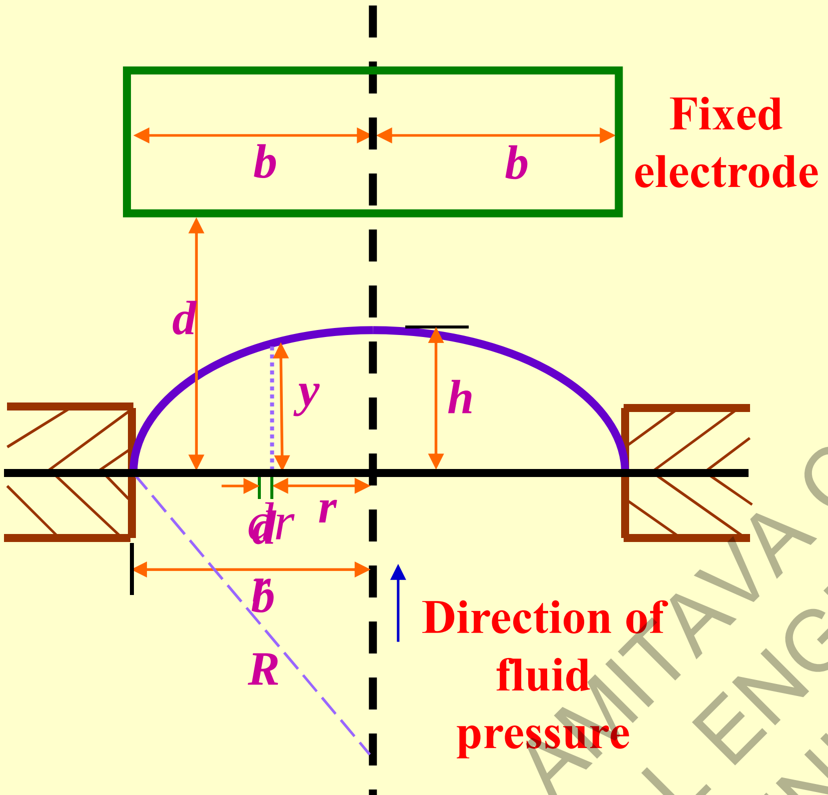
Variable Capacitance Pressure Transducer with a Stretched Diaphragm (contd…)



$$C = \int_o^b \frac{\varepsilon_0 2\pi r dr}{(d-y)} \approx \frac{\varepsilon_0 .2\pi}{d}\int_o^b \left(1+\frac{y}{d}\right) r dr$$

$$C = \frac{2\pi\varepsilon_0}{d}\int_o^b r dr + \frac{2\pi\varepsilon_0}{d^2}\int_o^b \frac{p}{4S}\left(b^2 - r^2\right) r dr$$

$$C = \frac{\varepsilon_0 \pi b^2}{d} + \frac{\varepsilon_0 \pi p b^4}{8d^2 S}$$

Sensitivity of the transducer:

$$\frac{\Delta C}{C_o} = \frac{C - C_o}{C_o} = \left(\frac{\varepsilon_0 \pi p b^4}{8d^2 S}\right)\Big/\left(\frac{\varepsilon_0 \pi b^2}{d}\right) = \frac{pb^2}{8dS}$$

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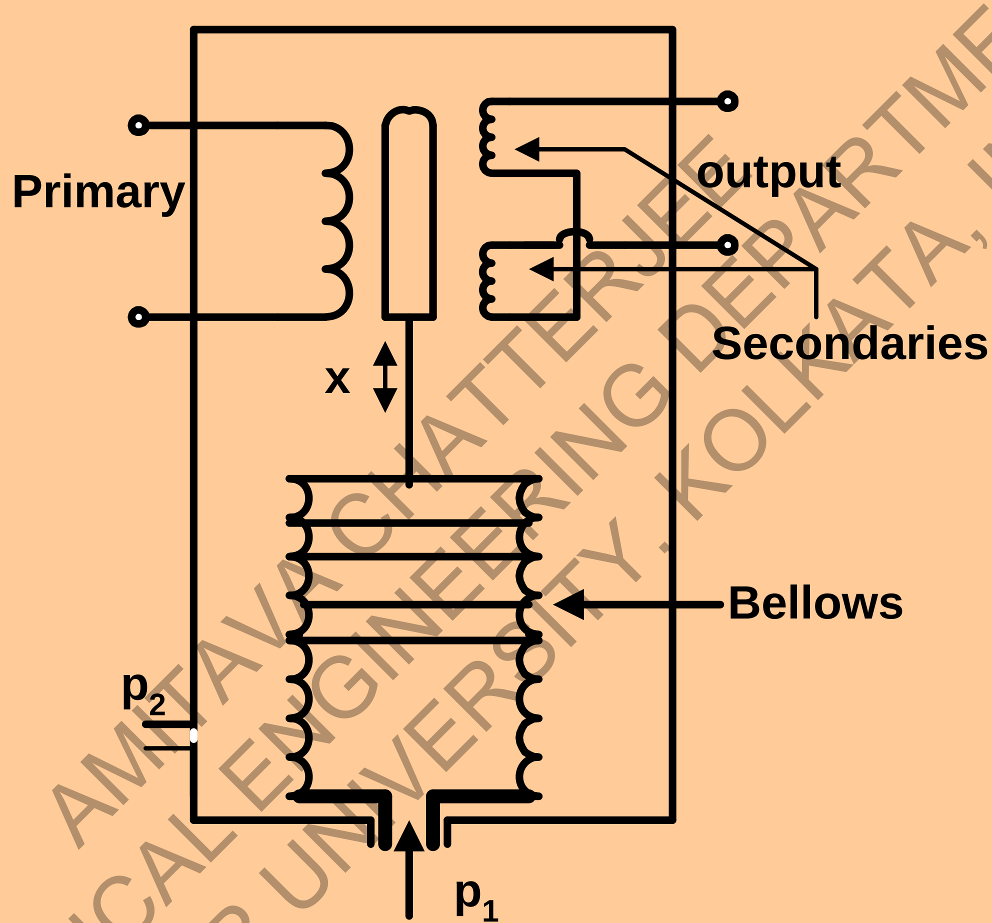
Bellow Gauge



LVDT type pressure transducer

$$p = (p_1 - p_2)$$

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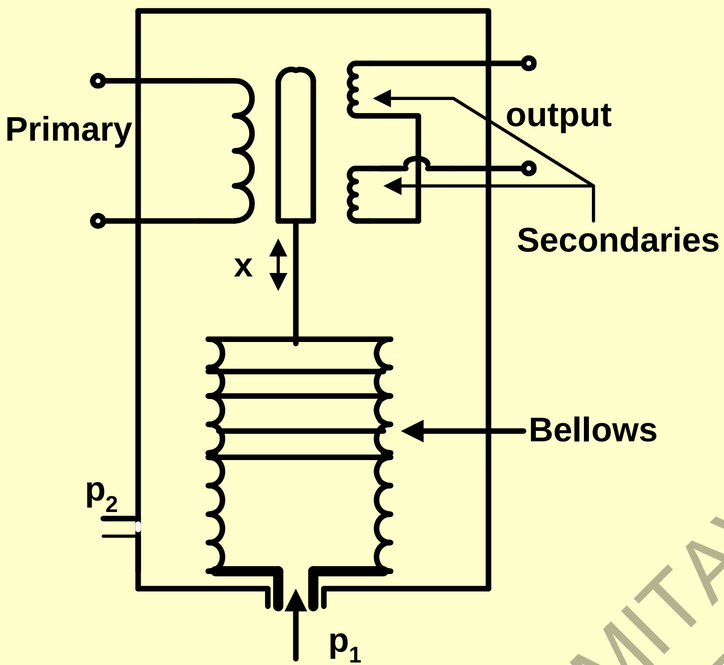
Bellow Gauge (contd…)



LVDT type pressure transducer

$p = (p_1 - p_2)$

- ✓ The displacement of the bellows is converted to an electrical signal with the help of an LVDT type pressure transducer.
- ✓ Since the motion of the bellows is proportional to the pressure differential *p*, the output voltage is also proportional to *p*.
- ✓ Commercial models of this type of gauge permit measurement of pressure as low as 0.25 Pa.

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Thank You

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