IN 221 (AUG) 3:0
Sensors and Transducers
Lecture 8

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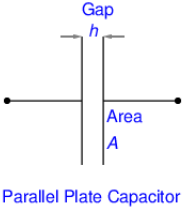
Example: Force in a parallel plate capacitor



$$F_x = -\frac{1}{2}\frac{\epsilon_0 A v^2}{h^2} \tag{1}$$

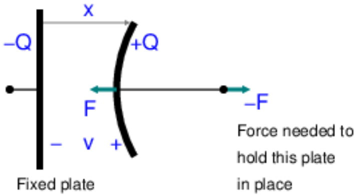
If $A = 1\,\mathrm{m}^2$, $h = 1\,\mathrm{mm}$, and $v = 100\,\mathrm{V}$, then $F_x = -4.4271\,\mathrm{mN}$.
This shows that electrostatic forces in capacitors with macroscopic dimensions are *not* very large.
Here $C = \epsilon_0 A/h = 8.8542\,\mathrm{nF}$.

More Discussion on the Derivation

Formula for forces on the plates of a capacitor:

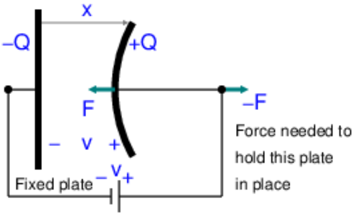
- *Energy method* simplified the derivation.
- Consideration of the detailed charge distribution on the plates would have made the derivation much harder.
- The derivation in the last class was expressed in the language of vector calculus.
- We look again at a scalar version of the derivation.
- The case in which the capacitor is not isolated is also to be discussed.

Isolated Plates



- Q is a constant, C and $v = Q/C$ are functions of x.
- If F is the force exerted by the plate on right, then the force needed to hold the plate in place is $-F$.

Plates Connected to a Voltage Source



- v is a constant, C and $Q = Cv$ are functions of x.
- If F is the force exerted by the plate on right, then the force needed to hold the plate in place is $-F$.

Pressure Sensors for Vacuum Systems

- Vacuum System: Uses pumps to remove air from a chamber.
- Very low pressures are needed.
- Some experiments cannot be done unless the pressure is lower than a specified value.
- Sensors which indicate the pressure accurately are needed.

Commonly used Pressure Units

- Pascal (Pa): 1 newton per square metre (SI Unit)
- 1 bar = 10^5 Pa = 100 kPa
- Technical Atmosphere: 1 at = 1 kgf per centimetre squared = 98066.5 Pa
- Standard Atmosphere: 101325 Pa = 760 Torr
- 1 Torr = 133.3224 Pa (approximately 1 mmHg) (named after Torricelli)
- 1 pound force per square inch = 1 lbf $/(\mathrm{in})^2$ = 6894.757 Pa

Terminology: Absolute, Gauge, and Differential

Pressure measurement readings are of three types.

1. **Absolute pressure**: Reading is zero-referenced against a perfect vacuum.
   - Example: Atmospheric pressure, deep vacuum pressure, altimeter pressure
   - BMP280 shows absolute pressure
2. **Gauge pressure**: Reading is zero-referenced against ambient air pressure.
   - Example: Tyre pressure, blood pressure
   - Pressure sensor MPS20N0040D-S
   - Bourdon pressure gauge
3. **Differential pressure**: Reading is the difference of two pressures.
   - Needs two ports
   - Example: Manometer, DP cell
   - ASAIR ADP810

Bourdon Pressure Gauge

- Shape change of a C-shaped Bourdon tube is magnified to move the indicator needle.
- Very commonly used.

Low Pressure Sensors

Low pressure: Pressure less than 1 mbar

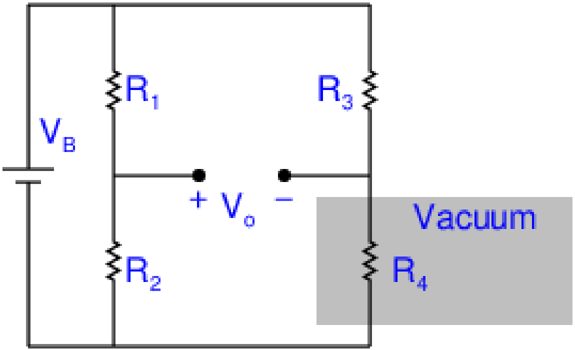
Low pressure sensors are called pressure *gauge*s.

Three Important Low Pressure Gauges:

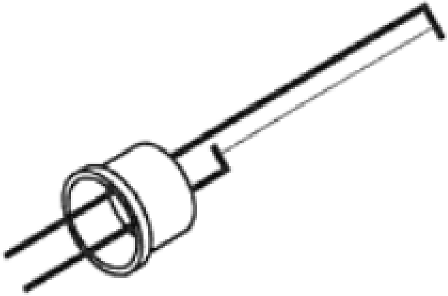
Type	Working Principle	Range
Pirani Gauge	Heat Convection	0.5 Torr to 10^{-4} Torr
Penning Gauge	Ionization: Cold cathode	10^{-2} mbar to 10^{-7} mbar
Bayard-Alpert Gauge	Ionization: Hot cathode	10^{-3} mbar to 10^{-10} mbar

Pirani Gauge

Thermal Convection: Lower pressure ⇒ Less heat carried away ⇒ More heating of resistor ⇒ Higher resistance



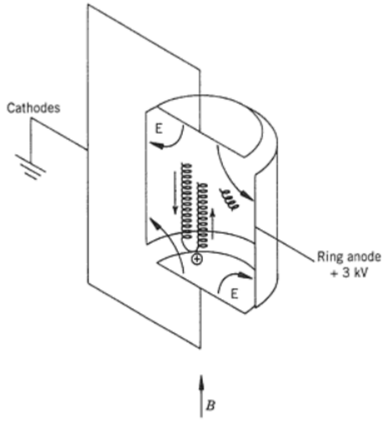
Pirani Gauge



This is used as the R_4 element on the previous slide.

Penning Gauge

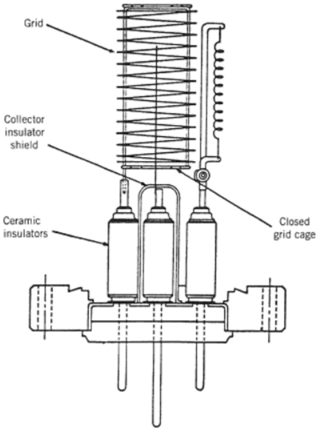
Cold cathode: Requires 2 to 4 kV
Starting problem at very low pressures
Magnetic field often used for longer travel paths of electrons.



Trajectories and fields in the Penning gauge

Bayard-Alpert Gauge

Avoids x-ray ionization problem of the triode gauge.
Hot cathode: Can measure very low pressures.



Bayard-Alpert Gauge

Example potentials at the electrodes:

- Filament at +45 V
- Grid at +180 V
- Collector at 0 V

Vacuum Technology Textbook

J. M. Lafferty: Foundations of vacuum science and technology
Wiley(1998)