Pressure Measurement

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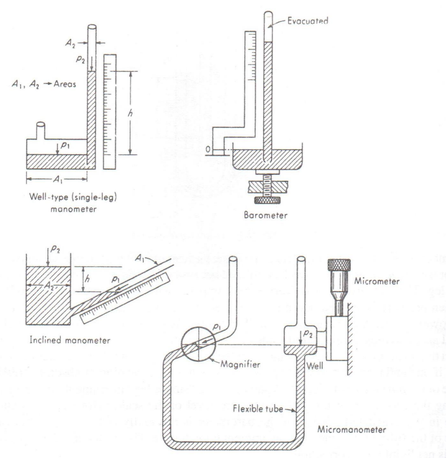
Introduction

- Pressure is not a fundamental quantity (rather derived from force and area)
- However, very accurate instruments are available for calibration of less accurate instruments
- Standards are (as per the range):
  - Several hundred MPa to medium vacuum (~0.1 mm Hg): Precision Hg column (manometer)/ Deadweight piston gauge
  - Low vacuum (10^{-1} to 10^{-3} mm Hg): McLeod gauge
  - Very low to ultra-low vacuum (< 10^{-3} mm Hg): Several accurate orifices + McLeod gauge

Various forms of manometer



P2 – P1 = ρgh

1 atm = 10 m of water column

Manometer

- Unlike deadweight gauge, manometer is deflection type (and not null-type) gauge
- It has continuous (and not step) output
- However, they have comparable accuracies
- Manometers tend to become very long at large pressures, and therefore become unwieldy
- Here, $h = (p_1 - p_2)/\rho g$ where h is difference in height, ρ is density of manometer fluid
- Water and Hg are the most common manometer fluids

Refinements/Corrections in Manometer

For high accuracy:

- Thermal expansion of scale needs to be considered
- Variation of manometer fluid density with temperature needs to be considered
- Local value of *g* should be determined and employed

Additional sources of error include:

- Non-verticality of the tubes
- Difficulty in reading *h* due to meniscus formed by capillarity

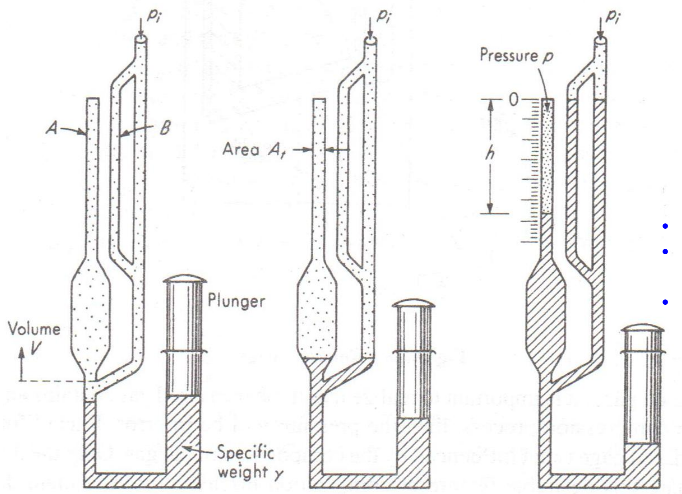
Various forms of manometer (contd.)

- Well-type manometer
  - Well area very large compared to the tube
  - Small change in zero-level is suitably compensated
  - However, compensation is dependent on the variation in cross-sectional area
  - Less accurate as compared to U tube manometer

Various forms of manometer (contd.)

- Barometer
  - Here h gives the absolute pressure, as the inside pressure is essentially zero (actually equals the vapor pressure of Hg, about 0.7 Pa absolute at 21 ^{o}C)
- Inclined manometer
  - Increased sensitivity by inclining
  - Thus, greater motion of liquid for a given change in vertical-height

McLeod Gauge



$$p_i V = p A_t h$$

$$p = p_i + \rho g h$$

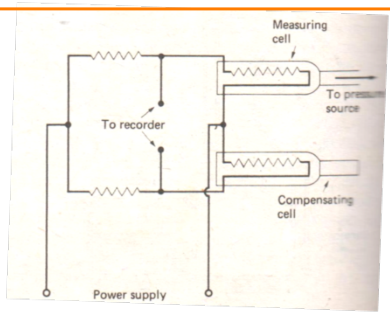
$$p_i = \frac{\rho g A_t h^2}{V - A_t h} \approx \frac{\rho g A_t h^2}{V}$$

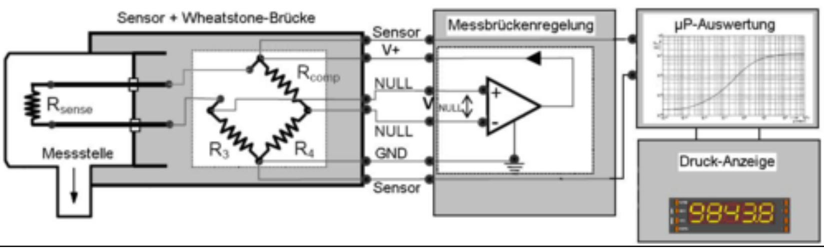
- 1st equation: Boyle's law
- 2nd equation: pressure equation for manometer
- 3rd equation: From 1st & 2nd equations (approx. applies if V >> A_th)

Pirani Gauge
(Thermal Conductivity Gauge)

- Basic Idea: Change in gas pressure will affect heat loss from a heated wire (because of change in density of the surrounding gas). Heat loss affects the wire temperature and therefore its electrical resistance. Pick-up change in electrical resistance by using a resistance bridge.
- Construction: Platinum filament enclosed in a chamber. Change in wire resistance calibrated in terms of chamber pressure. A compensating arm used to minimize variations due to ambient temperature changes, etc.

Pirani Gauge
(Thermal Conductivity Gauge)





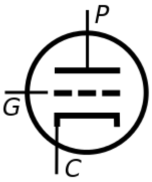
Thermal Conductivity Gauge

Two variants possible of thermal conductivity gauge possible:

- Resistance change picked up by a resistance bridge – Pirani gauge
- Temperature gauge picked up thermocouples welded on the wire – Thermocouple-type conductivity gauge

- Capable of measuring pressures in the range of 1 to 1000 torr ($10^2 – 10^5$ Pa)
- 1 torr = 1/760 of atmospheric pressure = 133.3 Pa

Triode



- Ionization gauge similar to a triode
- In triode, electrons are released into tube from cathode (C) by heating (thermoionic emission)
- Air is removed from tube, so electrons can move freely
- Electrons are attracted to positively charged plate (P)
- Magnitude of current can be controlled by a voltage applied between cathode and grid (G) (made of wire-mesh). The grid acts like a gate for the electrons.
- **Note:** a low power varying (AC) signal applied to the grid can control a much more powerful plate current, resulting in amplification

Ionization Gauges

- Consists of heated filament, positively biased grid, negatively biased plate in an envelope evacuated by the pressure to be measured
- Grid draws current from the heated filament; collision between electrons and gas molecules cause ionization of molecules
- Positively charged molecules are attracted to the plate of the tube
- This causes current flow in the external circuit
- Magnitude of current depends on gas pressure

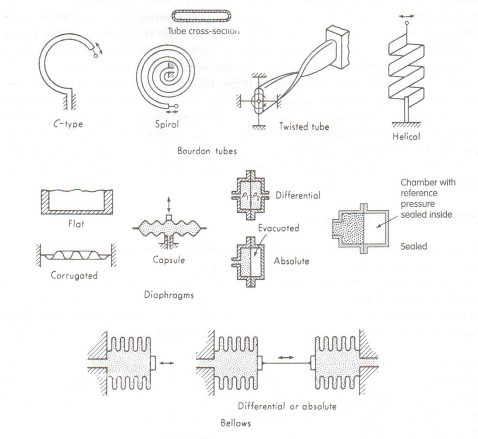
Ionization Gauges

- Used for measuring extremely low pressures (1 – 10^{-6} torr or 100 – 10^{-4} Pa)

- Disadvantages of ionization gauge:
  - Pressure of more than 1 torr causes rapid deterioration of filament, resulting in short life
  - Electron bombardment is a function of filament temperature, which therefore requires careful control of filament current

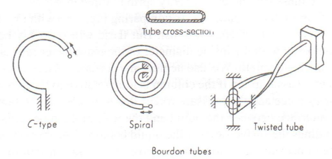
Elastic Transducers for Pressure Measurement

- Flexible metallic elements of the form Bourdon tube, diaphragm, bellow is used as the sensitive element in pressure transducer
- Deflection of the element is connected to pointer/ scale readout through linkages/gears



Elastic Transducers for Pressure Measurement (contd.)

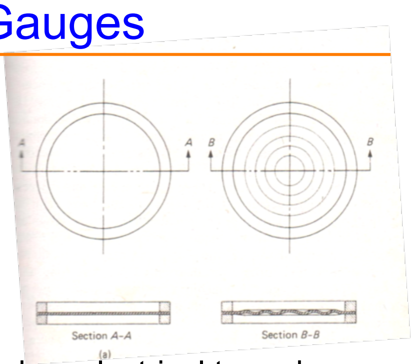
- Bourdon tube has a tube of non-circular cross-section
- Pressure difference causes the tube to attempt to attain a circular cross-section
- This leads to distortion, and curvilinear translation/ rotation of the free end



- Motion of the free end gives the desired output
- Spiral/helical configurations give more output motion for a given pressure
- Twisted tube is soft in rotation, but stiff in radial direction (reduces sensitivity to shock and vibration)

Elastic Diaphragm Based Pressure Gauges

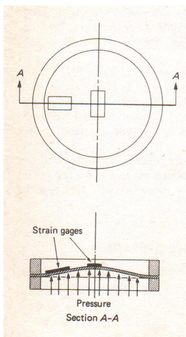
- Many dynamic pressure measuring gauges use an elastic diaphragm as primary pressure transducer
- Diaphragm can be flat or corrugated



- Flat type together with a secondary electrical transducer allows measurement of very small diaphragm deflections
- Corrugated type used when deflections are large
- (Secondary) Electrical transducer can be resistance, capacitance, inductance or piezo based.

Flat Diaphragm Pressure Gauges

- Generally, maximum deflection is limited to 30% of diaphragm thickness
  - To either maintain linear pressure-displacement relation or stress consideration
- Resistance strain gauge can be used to measure strain in terms of pressure
  - Note, small area available for mounting
  - Gauge with small lengths used
  - Change in resistance measured using a Wheatstone bridge



Relevant formula

- Pressure difference versus deflection:

$$p = \frac{16Et^4}{3R^4(1-\upsilon^2)}\left[\frac{y_c}{t} + 0.488\left(\frac{y_c}{t}\right)^3\right]$$

- p: pressure difference across the diaphgram; E modulus of elasticity; t: thickness; R: radius
- The deflection at any point is given as:

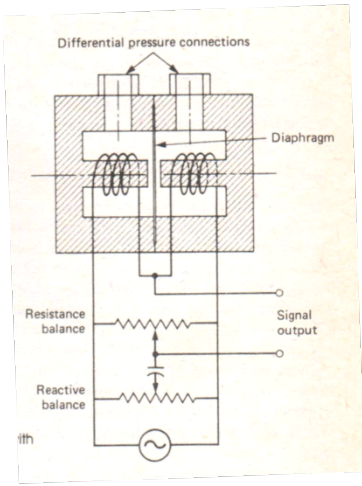
$$y = \frac{3p(1-\upsilon^2)(R^2 - r^2)^2}{16Et^3}$$

Corrugated Diaphragm Pressure Gauges

- Corrugated diaphragm used in larger diameter than flat types
- Convolutions to diaphragm however increases complexity of theoretical design
- Corrugation permits increased linear deflections and reduced stresses
- However, large size and deflections reduce the dynamic response
  - Employed mostly in static applications

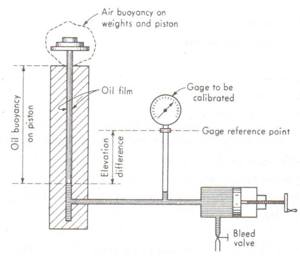
Differential pressure cell with inductance-type secondary transducer

- Variable inductance has been successfully used as a form of secondary transducer
- Flexing of the diaphragm due to applied pressure causes it to move toward one pole piece and away from the other
  - Causes change in relative inductances
  - An inductance bridge circuit used to pick up this change
- Typical range: 0-7 bar



Deadweight Gauge

- The gauge to be calibrated (less accurate gauge) is connected to a chamber filled with liquid
- The chamber pressure is adjusted by pump and bleed valve
- Weights applied on piston-cylinder
- When the piston and weights appear to float, the gauge pressure equals the weight applied divided by piston area



Refinements/Corrections in Deadweight Gauge

- Frictional force between piston-cylinder must be reduced to a minimum
- Small clearance between piston-cylinder leads to axial flow of fluid from high-pressure end to low-pressure end. This movement leads to viscous shear force, which tends to support part of the deadweight
- Small clearance also means that the area to be employed in pressure calculation is not clear
- Corrections needed for:
  - Temperature effect on areas of piston and cylinder
  - Local gravity condition
  - Buoyancy effect