实验一：压强测量
Lab 1: Pressure Measurements

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2013-3-27

内容

- 压强
- 平均压强测量方法
  - U型管、布尔顿管、压电材料、金属膜
- 脉动压强测量方法
  - 高频压强传感器

Pressure definition

- 压强=力/面积
- Pressure is the action of one force against another over, a surface. The pressure P of a force F distributed over an area A is defined as:

$$P = F/A$$

How Much is a Pascal (Pa)帕斯卡

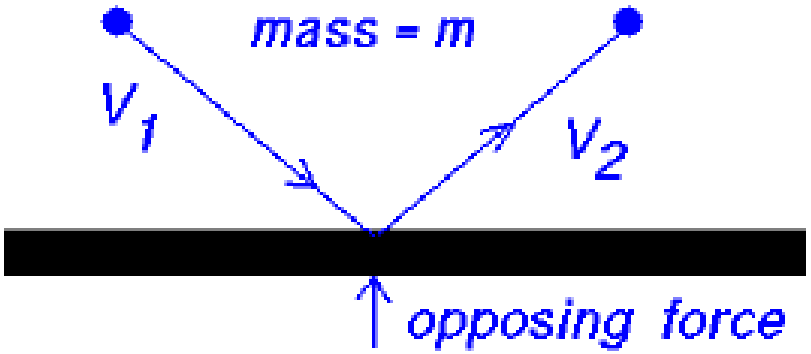
- 1 N/m^2
  - is a very small pressure
  - Therefore kilopascal (kPa)
- 1 atmosphere (14.7 psi, 750mmHg) is approximately 100 kPa = 1 bar
- 1 kPa is about 7 mmHg

Air Pressure

Glenn Research Center

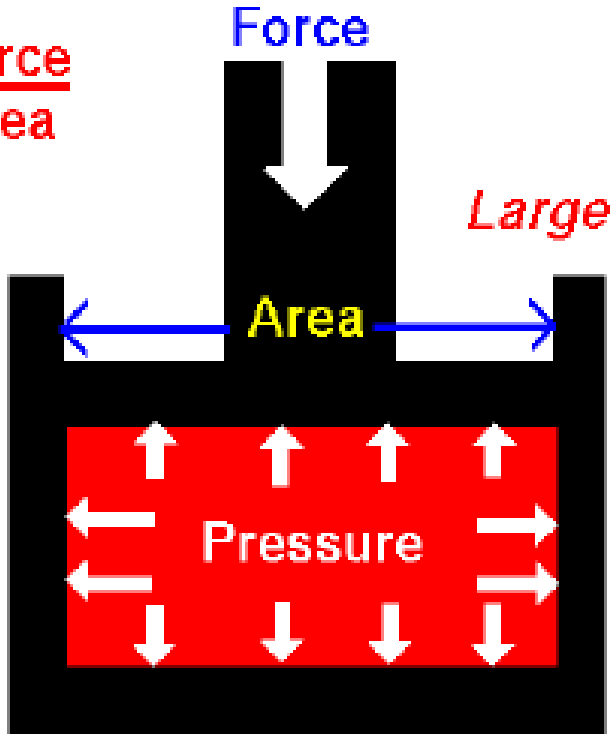
Pressure is $\frac{\text{Force}}{\text{Area}}$

Small Scale



Pressure is a measure of the linear momentum of the gas molecules.

Large Scale



Pressure force acts perpendicular to enclosing surfaces.

Pressure is a scalar quantity.
(magnitude, no direction)

纳维斯托克斯方程

Navier–Stokes equations *(general)*

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \nabla\cdot\mathbf{T} + \mathbf{f},$$

欧拉公式

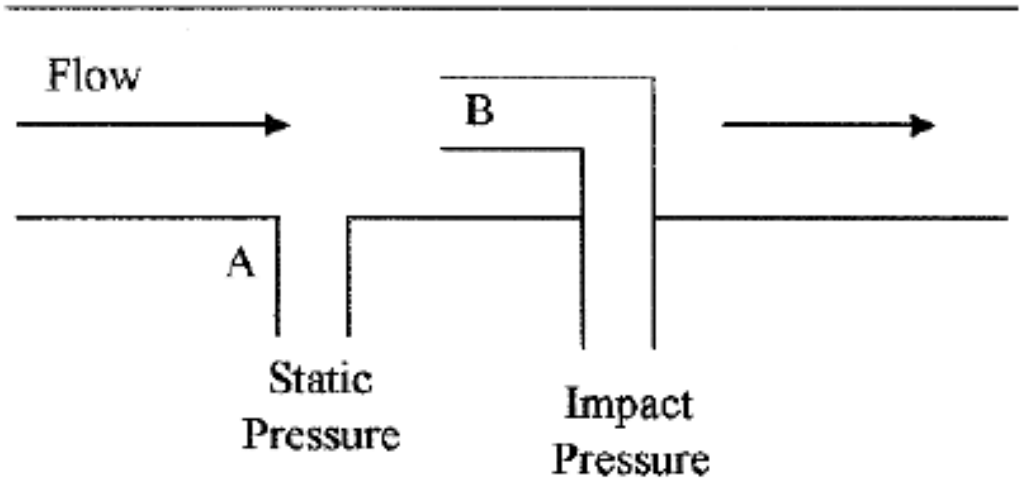
Navier–Stokes equations *(general)*

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \nabla\cdot\mathbf{T} + \mathbf{f},$$

伯努利方程

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$$

静压、动压和总压
Static, dynamic, and impact pressures



- *Static pressure* is the pressure of fluids or gases that are stationary or not in motion. 静压只的是本地压强
- *Dynamic pressure* is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow. In Fig., the dynamic pressure is (*B* – *A*). 动压指的是把运动空气阻挡到静止所要承受的压强
- *Impact pressure* (total pressure) is the sum of the static and dynamic pressures on a surface or object. Point *B* in Fig. depicts the impact pressure. 总压是本地静压和动压之和

Definition Of Pressure

定义

Gauge pressure表压
The pressure is referenced to atmospheric pressure and by convention is measured in the positive direction, i.e. 7 psig.
相对于本地大气压的压强大小

Absolute pressure绝对压强
The pressure is referenced to zero absolute pressure and has units of psia. Absolute pressure can only have a positive value.
某点的绝对压强=测点表压+本地大气压强

Vacuum pressure真空度
The pressure is referenced to atmospheric pressure and by convention is measured in the negative direction, i.e. -50 mm Hg.
相对于本地大气压的压强大小，通常为负值

Pressure Measurement

压强单位

A number of *measurement units* are used for pressure. They are as follows:

1. Pounds per square foot (psf) or pounds per square inch (psi)
2. Atmospheres (atm)
3. Pascals (N/m^2) or kilopascal (1000Pa)*
4. Torr = 1 mm mercury
5. Bar (1.013 atm) = 100 kPa
6. 14.696 lbf/in2 equals 33.9 feet of H2O
7. 14.696 lbf/in2 equals 29.921 inches of of Hg

Pressure Units
単位換算

The following conversion factors should help in dealing with the various units:

1 psi= 51.714 mmHg
= 2.0359 in.Hg
= 27.680 in.H2O
= 6.8946 kPa
1 bar= 14.504 psi
1 atm. = 14.696 psi

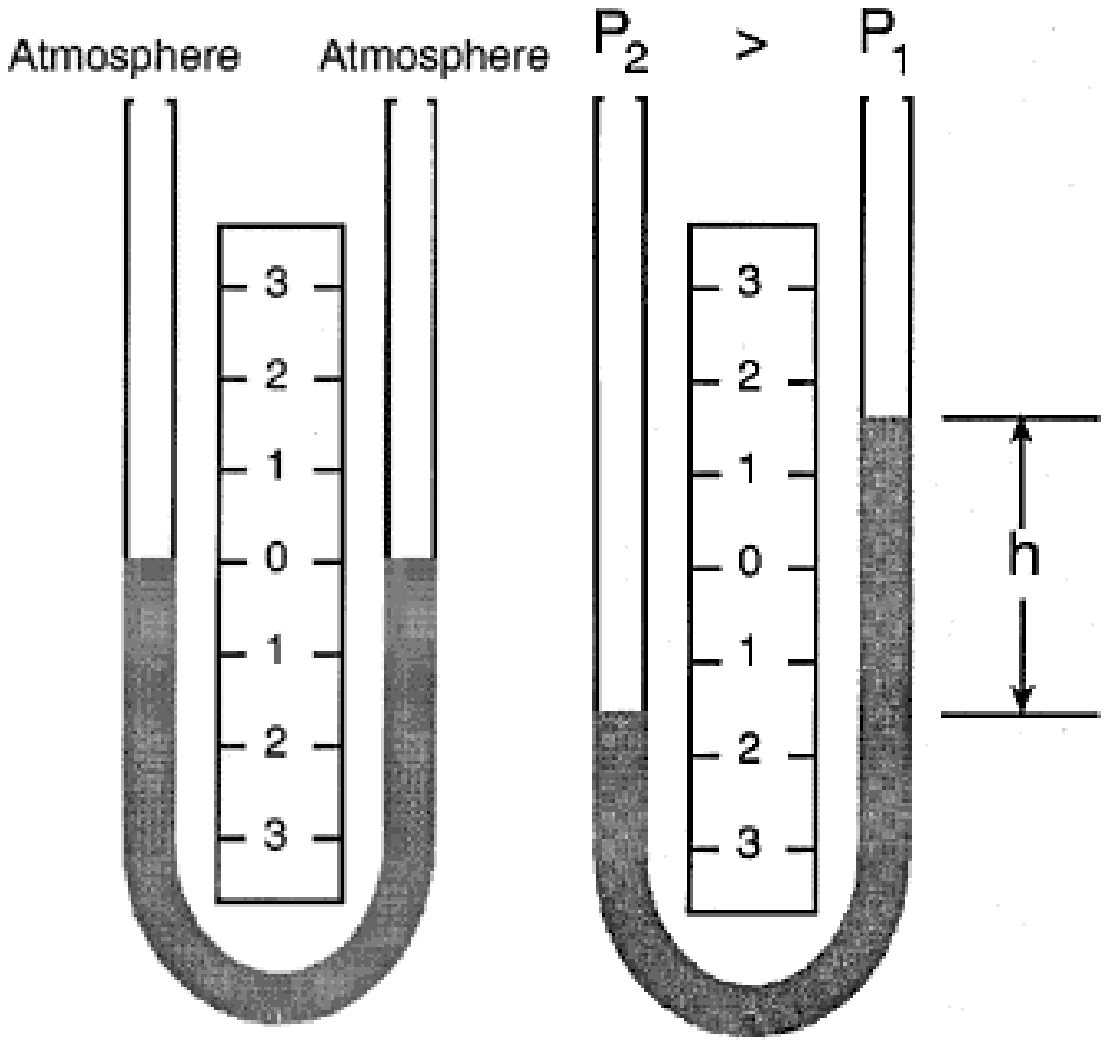
Manometer basics

- Characterized by its inherent accuracy and simplicity of operation. 操作简单
- It's the U-tube manometer, which is a U-shaped glass tube partially filled with liquid. U型管
- This manometer has no moving parts and requires no calibration. 不需标定
- Manometer measurements are functions of gravity and the liquid's density, both physical properties that make the U-tube manometer a NIST standard for accuracy. 受重力和液体密度影响

Manometer

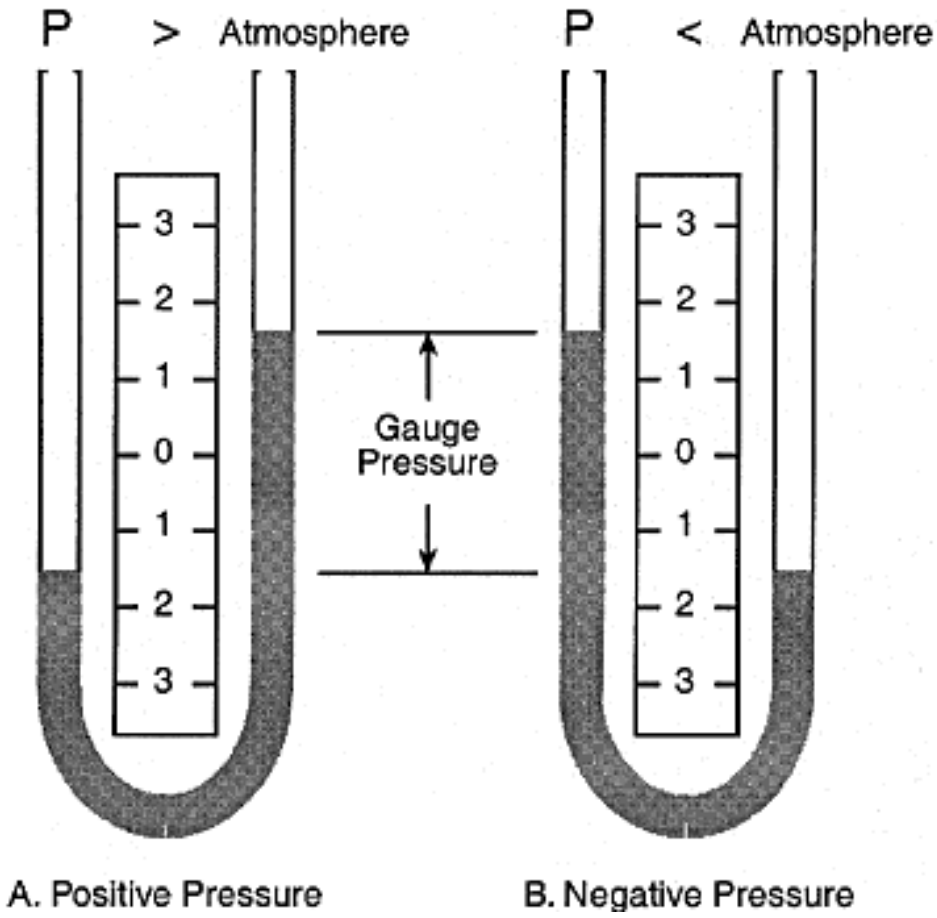
With both legs of a U-tube manometer open to the atmosphere or subjected to the same pressure, the liquid maintains the same level in each leg, establishing a zero reference.

- With a greater pressure applied to the left side of a U-tube manometer, the liquid lowers in the left leg and rises in the right leg.
- The liquid moves until the unit weight of the liquid, as indicated by h, exactly balances the pressure.



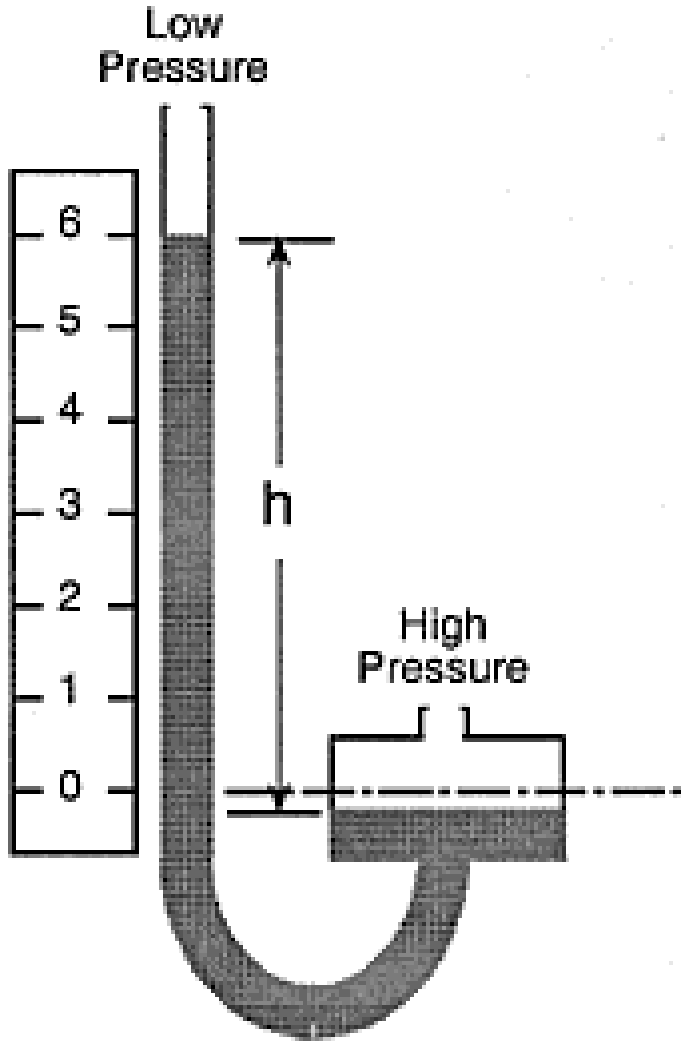
Manometer

- Gauge pressure is a measurement relative to atmospheric pressure and it varies with the barometric reading.
- A gauge pressure measurement is positive when the unknown pressure exceeds atmospheric pressure (A), and is negative when the unknown pressure is less than atmospheric pressure (B).



Reservoir (Well) Manometer

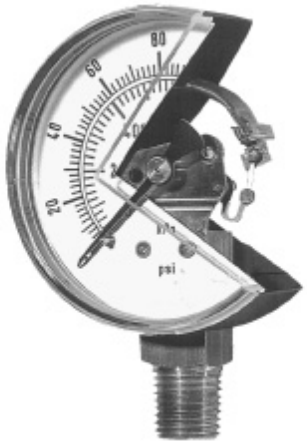
In a well-type manometer, the cross-sectional area of one leg (the well) is much larger than the other leg. When pressure is applied to the well, the fluid lowers only slightly compared to the fluid rise in the other leg.



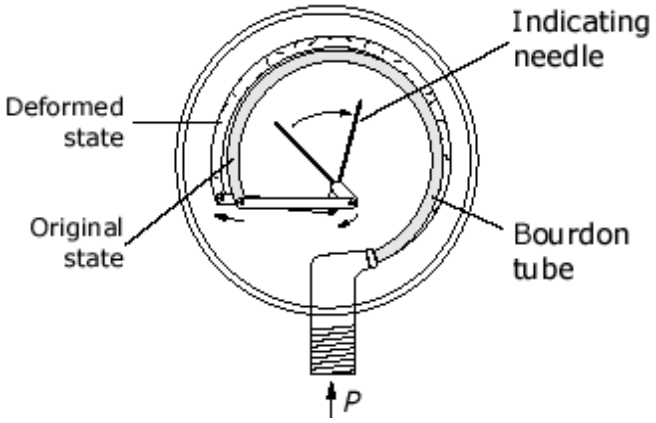
压强测量装置Pressure Measuring Devices

Bourdon Gage:布尔顿管

http://www.cpigauges.com/images/gauges/WeldGageStlCsBM400psi.jpg



http://www.hydraulicspneumatics.com/FPE/images/sensors1_1.jpg

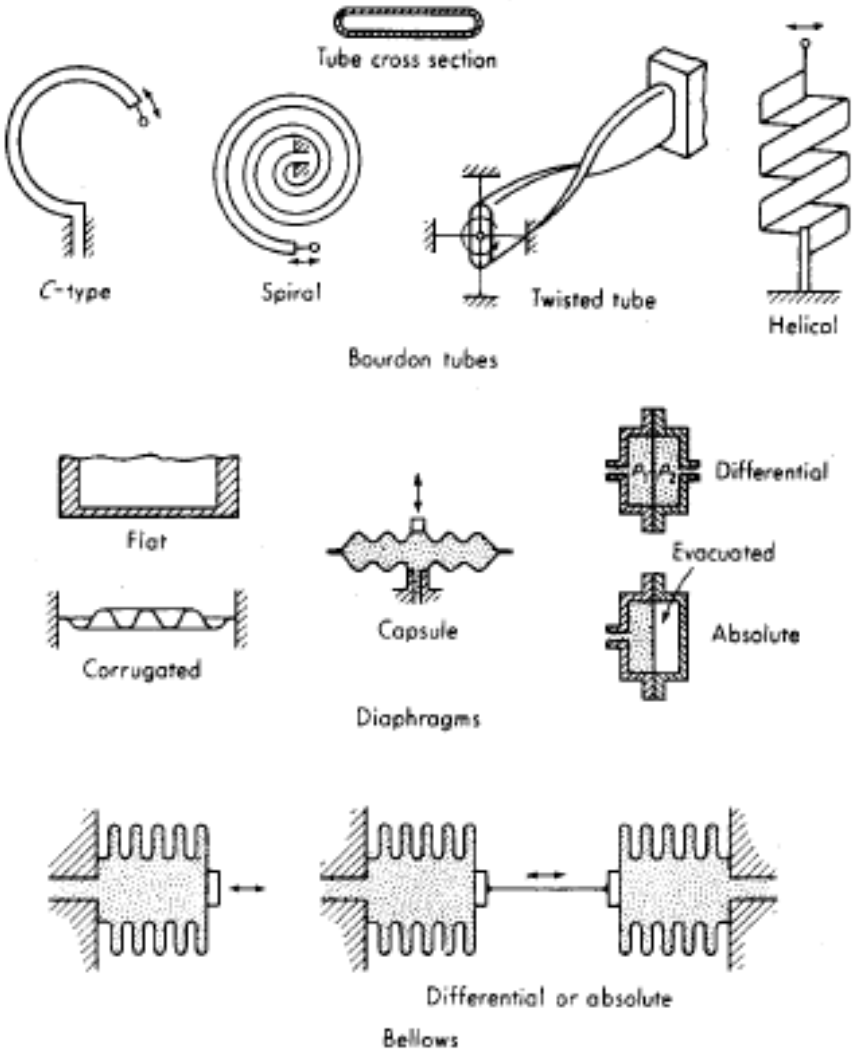


http://www.efunda.com/DesignStandards/sensors/bourdon_tubes/images/Bourdon_tube_A.gif

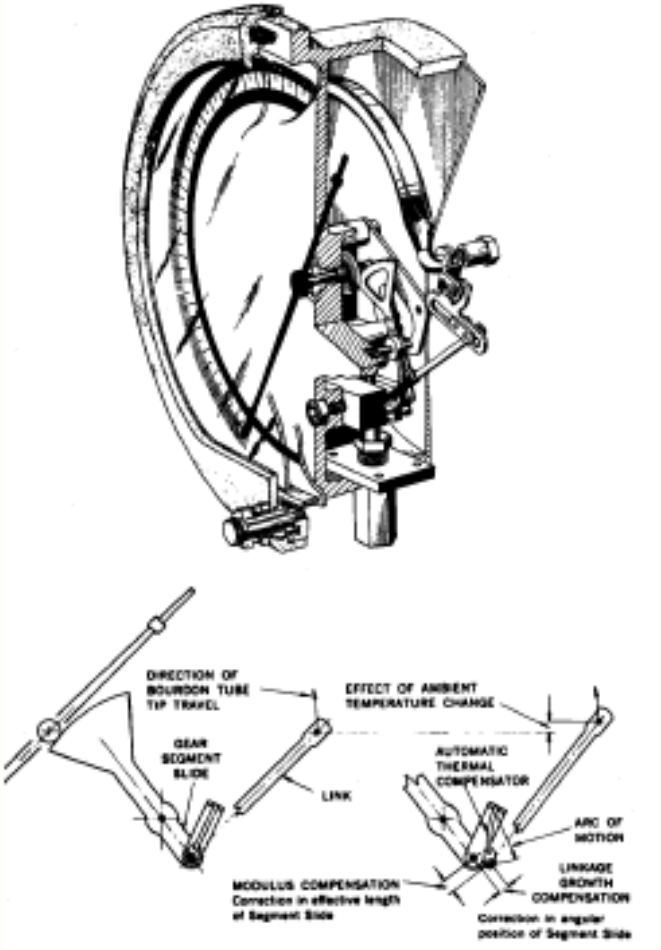
Principles: change in curvature of the tube is proportional to difference of pressure inside from that outside the tube
原理：压强增加、管曲率变化

Applications: tire pressure, pressure at the top or along the walls of tanks or vessels 用途：压力容器

• Elastic pressure transducers



Bourdon-tube gage (0.1% accuracy)



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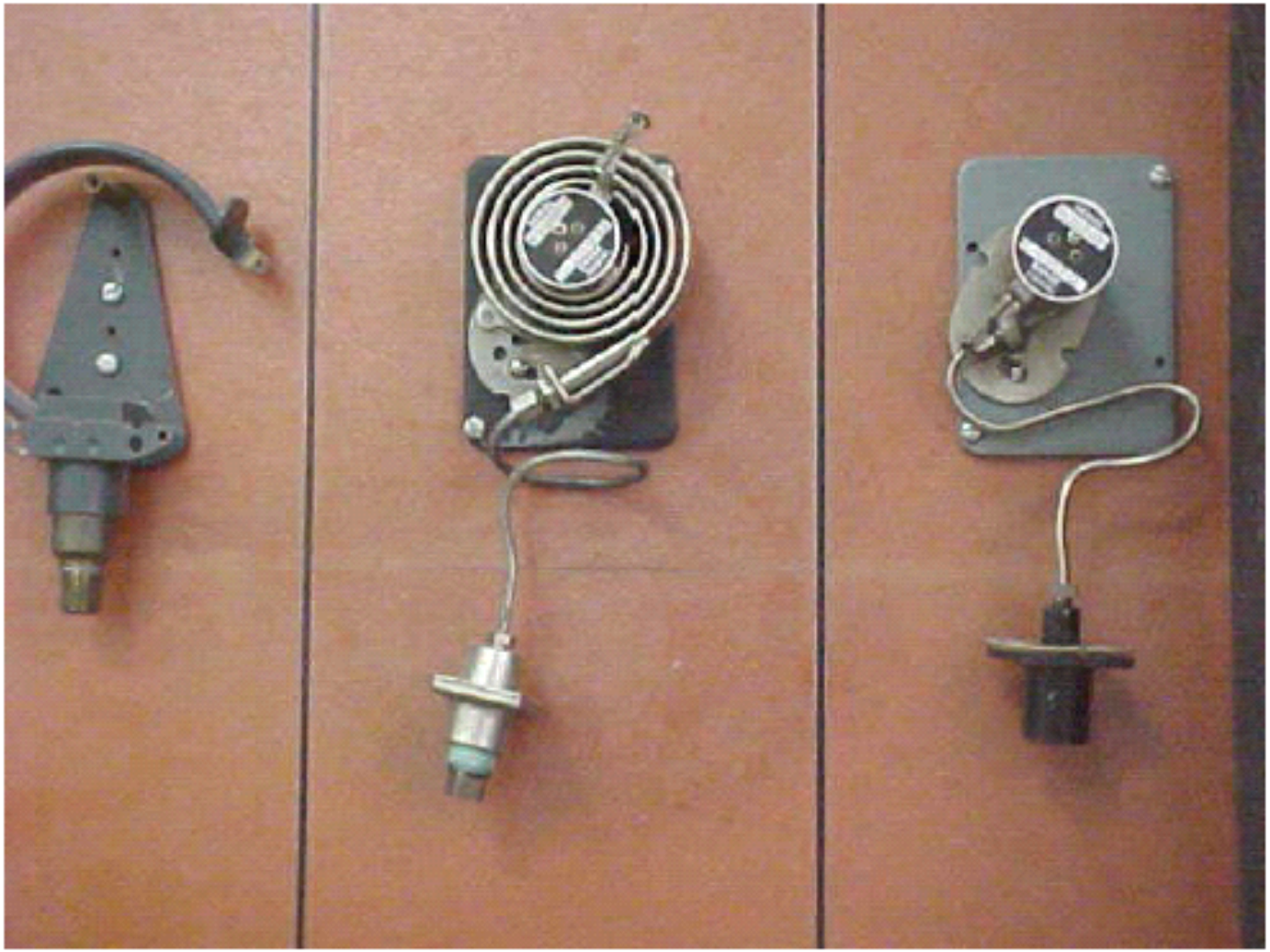
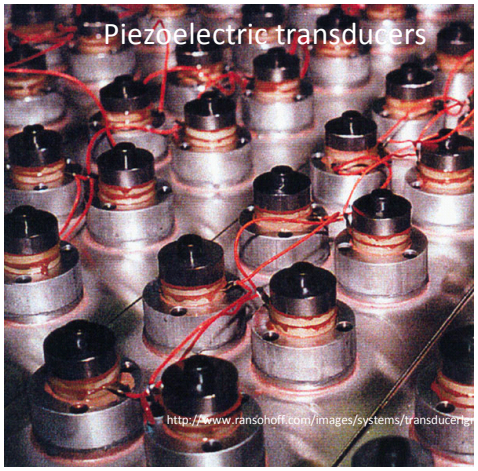
Bourdon Tube Gauge

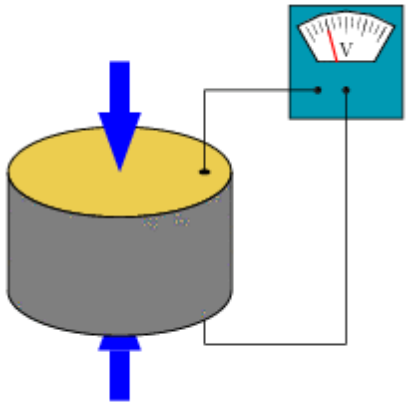
Bourdon Tubes



压强测量装置Pressure Measuring Devices

Quartz Gage





http://upload.wikimedia.org/wikipedia/commons/c/c4/SchemaPiezo.gif

Principles: Δ Pressure → Δ Charge → Δ Voltage

Applications: measurements with high accuracy, good repeatability, high resolution.
e g. Quartz Clock

压强测量装置Pressure Measuring Devices

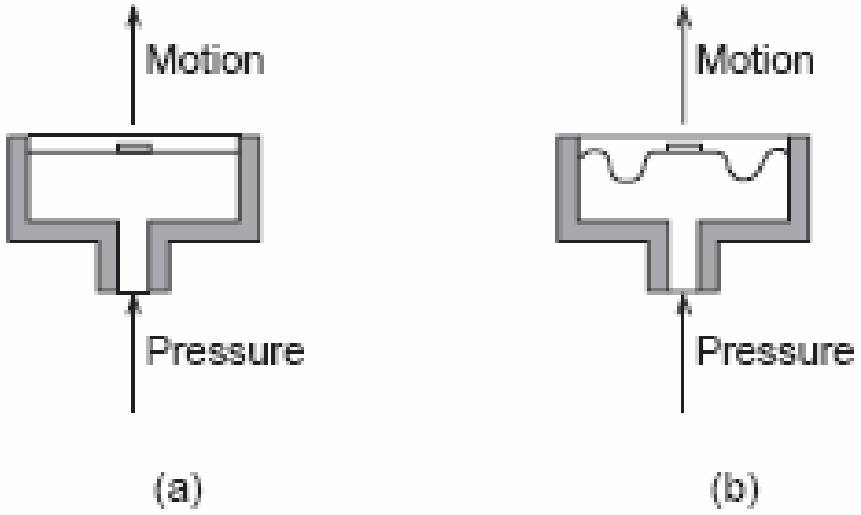
Piezoresistive Gage

Digital Manometer

Principles: Δ Pressure = Δ Charge = Δ Resistance = Δ Voltage

Applications: Very accurate for small pressure differentials
e.g. Difference between indoor and outdoor pressure

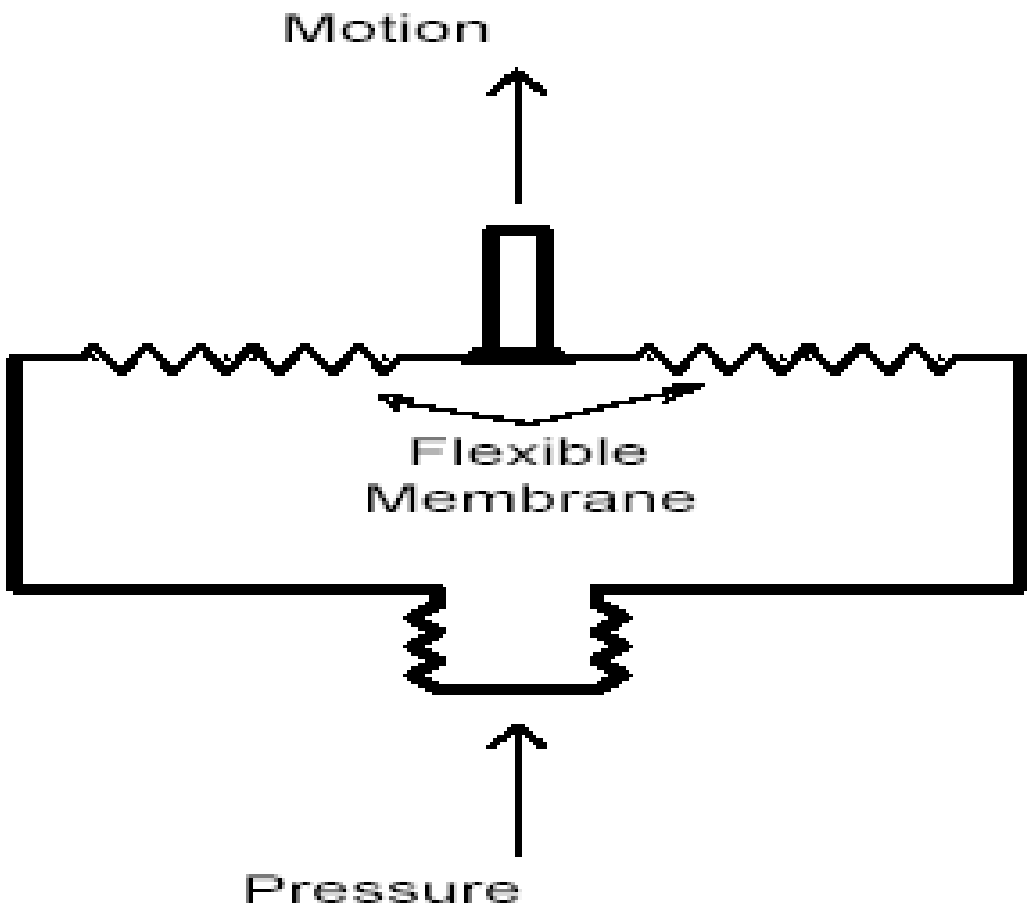
压强测量装置Pressure Measuring Devices



(a) flat diaphragm; (b) corrugated diaphragm

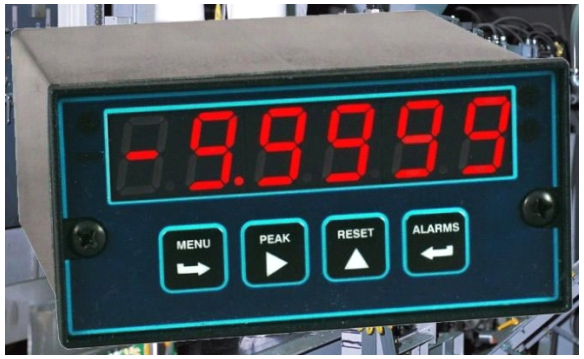
- A diaphragm usually is designed so that the deflection-versus-pressure characteristics are as linear as possible over a specified pressure range, and with a minimum of hysteresis and minimum shift in the zero point.

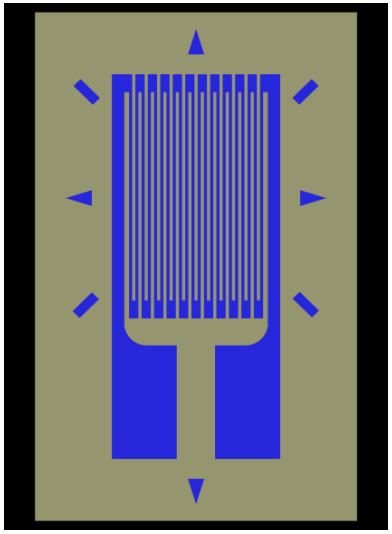
Diaphragm

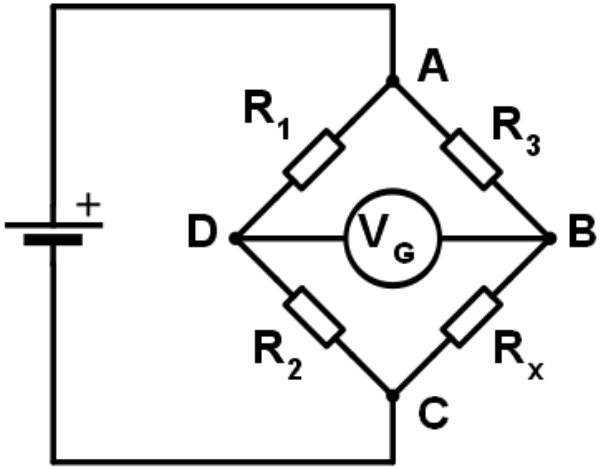


压强测量装置Pressure Measuring Devices

Strain Gage



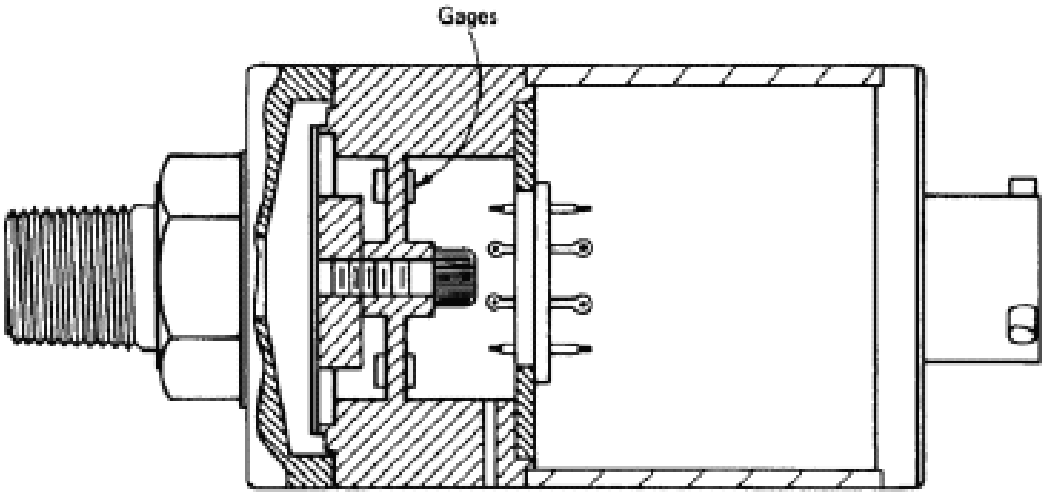




Principles: Δ P → Δ Resistance → Δ Voltage

Applications: Sensors for internal combustion engines, automotive, research etc.

Pressure-diaphragm rosette



• Strain gage pressure sensors

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

where
- $p \triangleq$ pressure difference across diaphragm
- $E \triangleq$ modulus of elasticity
- $t \triangleq$ diaphragm thickness
- $\nu \triangleq$ Poisson's ratio
- $R \triangleq$ diaphragm radius to clamped edge

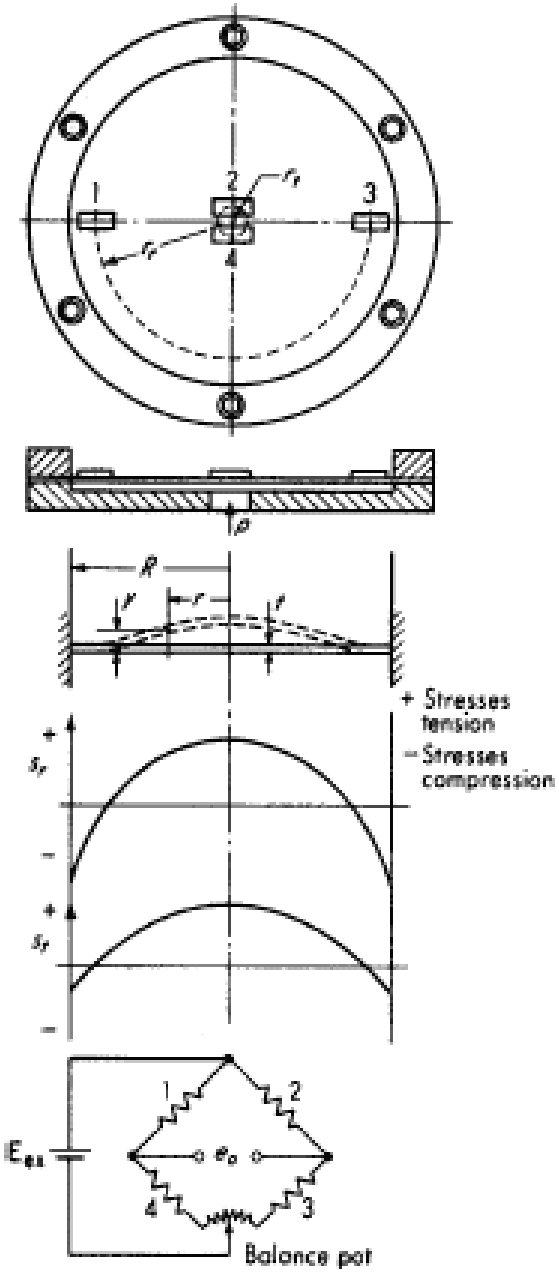
$$s_r = \frac{3pR^2\nu}{8t^2}\left[\left(\frac{1}{\nu}+1\right) - \left(\frac{3}{\nu}+1\right)\left(\frac{r}{R}\right)^2\right]$$

$$s_t = \frac{3pR^2\nu}{8t^2}\left[\left(\frac{1}{\nu}+1\right) - \left(\frac{1}{\nu}+3\right)\left(\frac{r}{R}\right)^2\right]$$

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

$$\omega_n = \frac{10.21}{CR^2}\sqrt{\frac{Et^2}{12\rho_d(1-\nu^2)}} \quad \text{rad/s}$$

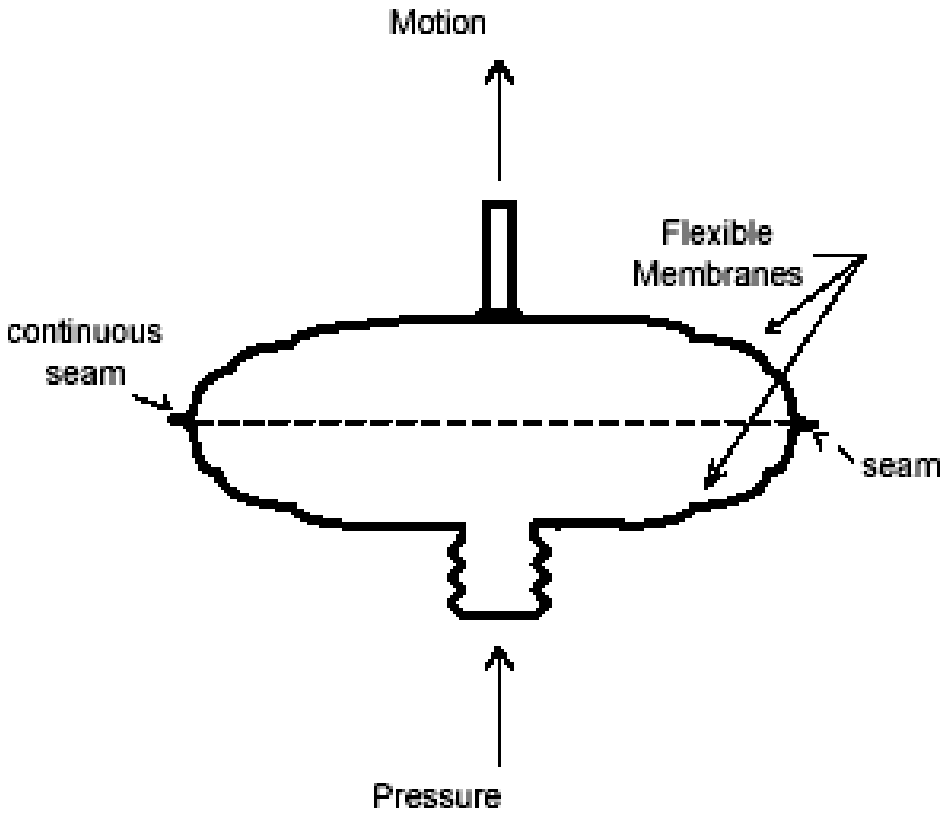
$$C \triangleq \sqrt{1 + 0.669\frac{\rho_f}{\rho_d}\frac{R}{t}}$$



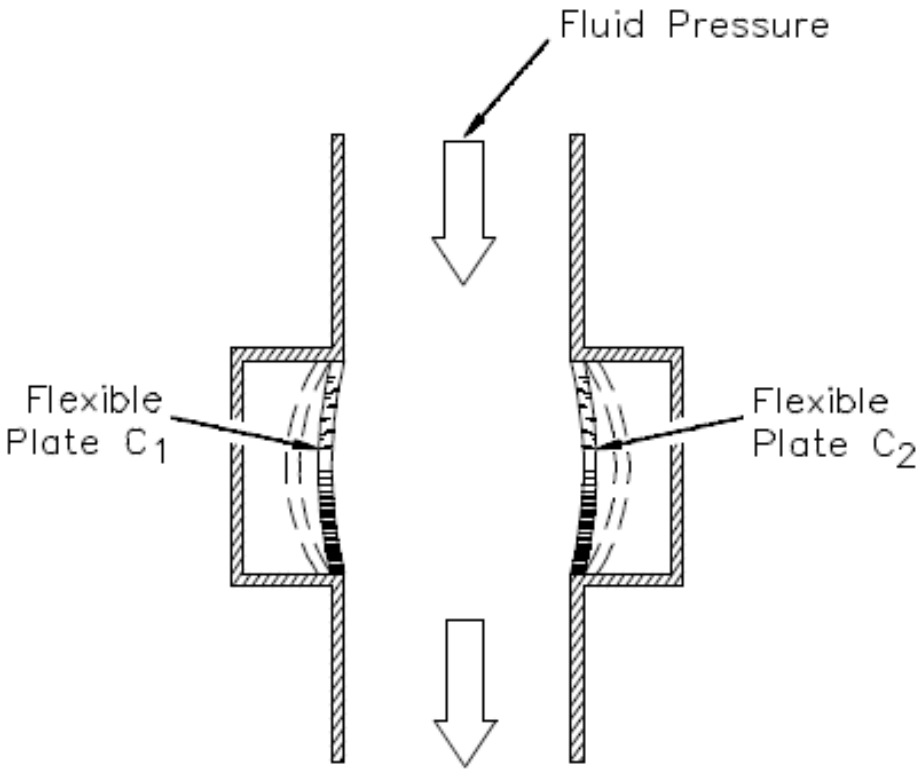
Capsule

A capsule is formed by joining the peripheries of two diaphragms through soldering or welding.

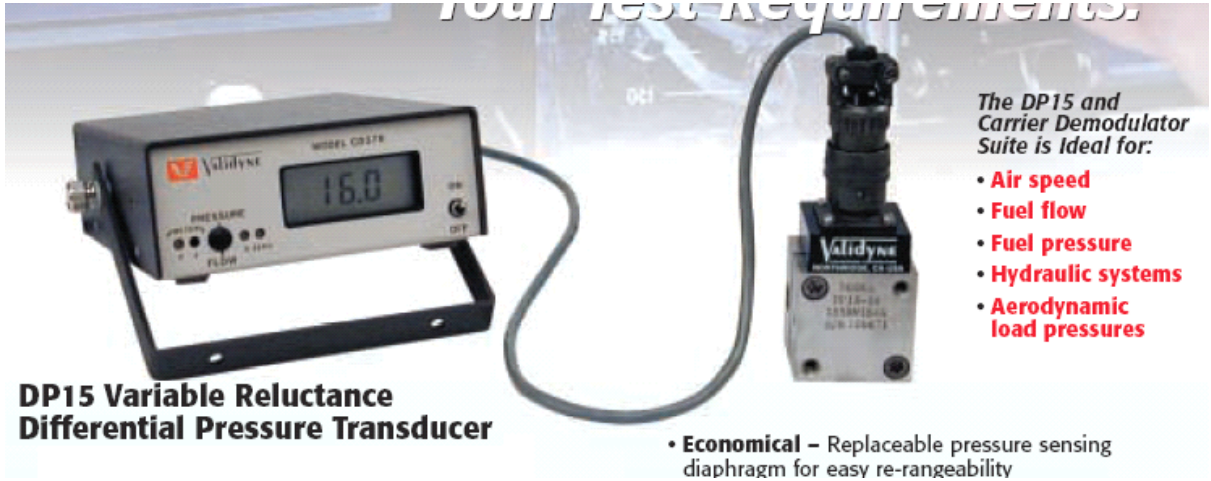
Used in some absolute pressure gages.

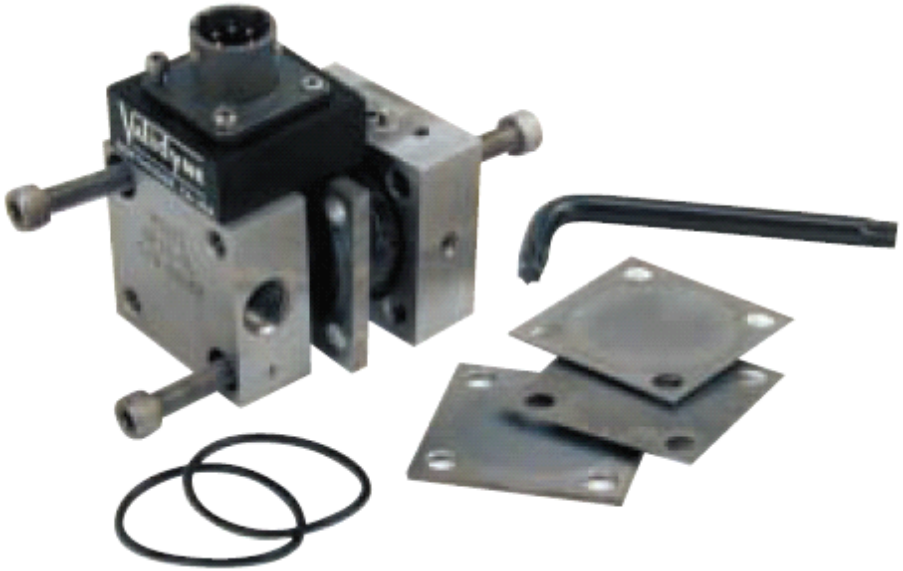


Capacitance



Validyne DP15 压力传感器





脉动压强

- 当压强发生快速变化的时候
  - 压力传感器中存在质量较大的金属片
  - 除金属片外空腔和导管还有大量空气/液体
  - 所以，当被测点压强变化时，金属片不会快速随之发生形变
  - 频率响应低
- 对策
  - 使用小金属片
  - 减小空腔体积，不使用导管
  - 频率响应高
  - Dynamic pressure transducer

Dynamic pressure transducer

- 因为美国Kulite公司的产品最为市场认同，Dynamic pressure transducer有时被称作Kulite transducer
- 选购此种传感器注意事项
  - http://www.advizia.com/v41/Advisor.asp?User=transducers&Rnd=559
  - 频率响应，大小，介质，温度要求，平均压强范围

Omega DPX101传感器

SPECIFICATIONS

Excitation: 2 mA nominal
@ 18 to 30 Vdc, constant current
Rated Output: 5 V nominal FS
Rise Time: 1.0 µs
Resonant Frequency: 500 kHz
High Frequency Range: 170 kHz
(approx. ⅛ of resonant frequency)
Low Frequency Range (-3 dB):
0.08 Hz (101-250), 0.03 Hz (101-500),
0.02 Hz (101-1K), 0.003 Hz (101-5K)
Acceleration Sensitivity: 0.002 psig
Discharge Time Constant:
2 s (DPX101-250)
5 s (DPX101-500)
10 s (DPX101-1K)
50 s (DPX101-5K)
Proof Pressure:
5000 psi (DPX101-250)
10,000 psi (DPX101-500)
10,000 psi (DPX101-1K)
15,000 psi (DPX101-5K)

测量脉动压强的廉价选择:麦克风

Panasonic Microphone Cartridges

Omnidirectional Back Electret Condenser Microphone Cartridge

Series: **WM-62A/62C/62CC/62K**
WM-62B (pin type)

■ **Typical Frequency Response Curve**