Mechanical Sensors

Overview:

- Definitions
- Force and pressure sensors
- Basic pressure sensors
- Medical pressure measurement systems
- Flow and flow-rate sensors.

Mechanical sensors react to stimuli via some mechanical effect

Output may be:

- Mechanical: eg. dial, fluid level
- Electrical: eg. voltage or Current

Force and Pressure Sensors

How do we measure an unknown force?

Acceleration Method

Apply force to known mass, measure acceleration.

Example: Force on Pendulum, apply force measure deflection.

Force and Pressure Sensors

Gravity balance method.

Compare unknown force with action of gravitational force.

Example: Balance scale. (zero-balance method)

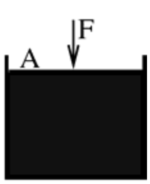
Spring Method

Use force to stretch or compress a spring of known strength, and measure displacement: F=kx , k the spring constant.

Example: Fruit scales at supermarket

Pressure-sensing method.

Convert the unknown force to a fluid pressure, which is converted using a pressure sensor.



$$P = F / A$$

Some pressure sensing elements

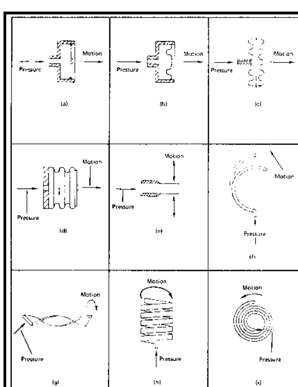
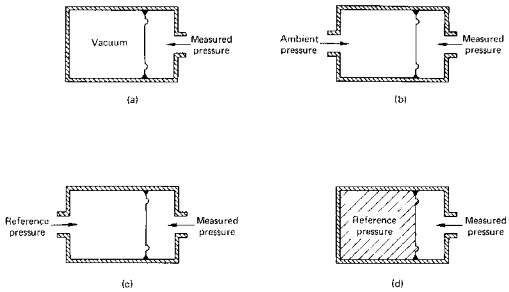


Figure 2-61. Pressure sensing elements: (a) flat diaphragm; (b) corrugated diaphragm; (c) capsule; (d) bellows; (e) straight tube; (f) C-shaped Bourdon tube; (g) twisted Bourdon tube; (h) helical Bourdon tube; (i) spiral Bourdon tube.

From H. Norton, 'Sensor and analyzer handbook'

Note that they all convert a pressure into an angular or linear displacement

Pressure reference configurations



Pressure-sensing method.

If force is constant, pressure is *static* or *hydrostatic:*

- Beer in (untapped) keg
- Butane gas bottle.

If force is varying, pressure is *dynamic* or *hydrodynamic*:

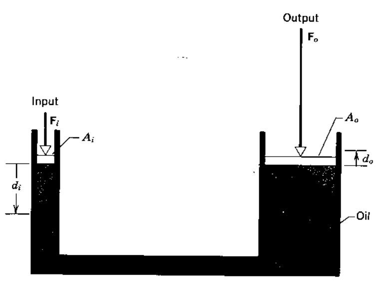
- Arterial blood pressure.

Units of Pressure:

- 1 Pascal = 1 Newton/m^2
- 1 atm (Atmospheric pressure) = 101325 Pa
- 760 torr = 1 atm

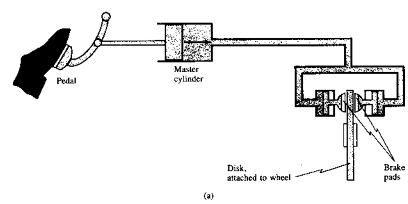
Pascal's Principle

Pressure applied to an enclosed system is transmitted undiminished to every portion of the fluid and container walls.

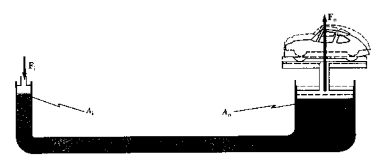


This is the basis of all hydraulics: a small pressure can be made to exert a large force by changing the dimensions of the vessel

Applications of Pascal's Principle



Disk brakes



Car Lift

Notes on Pascal's principle

Pascal's principle is always true in hydrostatic systems.

But, only true in hydrodynamic systems if change is *quasi-static.*

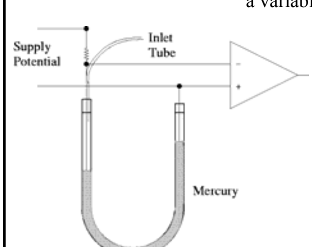
Quasi-static means that after a small change is made, turbulence is allowed to die down then measurement is made.

Examples are hydodynamic systems where flow is non-turbulent and the pipe orifice is small compared with its length.

Bourdon tube sensor

Bourdon tube pressure sensor: curved or twisted tube, sealed at one end.

As pressure inside changes, tube uncurls; this displacement can be transduced using a variable sliding resistior



Measure resistance change as the pressure in the active tube is changed

$$Vout = V\frac{\Delta R}{R} = V\beta\Delta P$$

Can be directly calibrated in Torr

Membrane pressure sensors

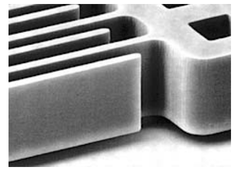
Subdivided into bellows, thin plate and diaphragm sensors.

All work by measuring the deflection of a solid object by an external pressure.

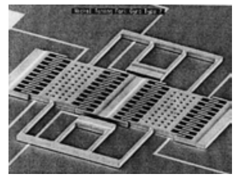
This displacement is then measured, and converted into a pressure reading

Membrane sensors can be made very small using micromachining; called microelectromechanical systems (MEMS).

Some MEMS sensors



- 1 µm high MEMs capacitive accelerometer: such devices are at the heart of car airbags.
- Machined out of single silicon wafer
- ‘Proof mass’ is freer to move in response to acceleration forces



MEMs gyroscope based on ‘tuning fork’ design

Images from www.sensorsmag.com/articles/0203/14/

Medical pressure measurement.

This is a major application for sensor technology.

Most common measurement is for blood pressure. More fully:

- Arterial blood pressure
- Venous blood pressure
- Central venous pressure
- Inter-cardiac blood pressure
- Pulmonary artery pressure
- Spinal fluid pressure
- Intraventricular brain pressure

The difference in these measurements is the range of measurement; we can often use the same sensor for different measurements

Medical pressure sensors

Medical sensors should be:

- minimally invasive
- sterile
- electrically insulated

Medical students are often told there is an “Ohm’s law for blood”

$P=F.R$,
Where:

- P is pressure difference in torr.
- F is flow rate in millilitres/second.
- R is blood vessel resistance in “periphial resistance units” (PRU) where 1 PRU allows a flow of 1 ml/s under 1 torr pressure.

This is misleading: in fact, blood vessels change diameter from systemic adjustments and from pulsatile pressure wave.

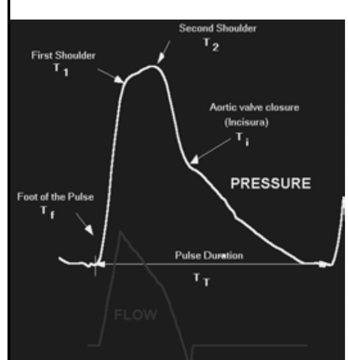
In fact, the flow rate is better given by *Poiseuille’s Law:*

$$F = \frac{P\pi R^4}{8\eta L}$$

Where:

- F is flow in cubic centimetres/second
- P is Pressure in dynes per square centimetre
- η is coefficient of viscosity in dynes/square centimetre
- R is vessel radius in centimetre
- L is vessel length in centimetres

Blood Pressure Waveform



http://themodynamics.ucdavis.edu/mustafa/Pulse.htm

Four kinds of pressure:

T_2 : Peak Pressure (systolic)

T_f: Minimum pressure (diastolic)

Dynamic Average (1/2 peak minus minimum)

Average pressure (arterial)

Blood Pressure Analysis

Mean arterial pressure is given by:

$$\overline{P} = \frac{1}{t_2 - t_1}\int_{t1}^{t2} P \cdot dt$$

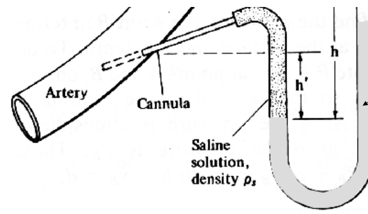
But clinically (for doctors and nurses in a hospital or sleep lab setting) a much simpler approximation is used:

$$\overline{P} = P_1 + (P_2 - P_1)/3$$

Where P_1 is diastolic Pressure and P_2 is systolic pressure

Direct measurement of blood pressure is most accurate but also more dangerous (involves poking tubes into arteries, very invasive.)

Open Tube Manometer



ρ=density of Manometer fluid

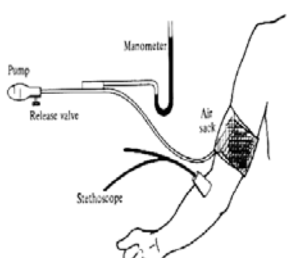
Sensing tube tube inserted *directly* into artery; mercury is poisonous, so need saline buffer

Measure pressure by height of sensing column:

$$P = P_{atm} + \rho g h - \rho_s g h'$$

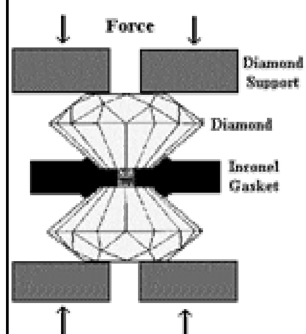
Only used in intensive care units.

Sphygmomanometry (Korotkoff Method)



- Inflatable cuff placed on upper arm and inflated until blood can't flow
- Sound sensor (stethoscope) placed downstream
- Pressure is released
- When can hear blood squirting (Korotkoff sounds), the cuff pressure equals systolic (higher) pressure
- Hear continuous but turbulent flow when cuff pressure equals diastolic pressure

The diamond Anvil



http://ituwebpage.fzk.de/ACTINIDE_RESEARCH/dac.htm

- One way to get huge pressures is to use diamonds to squeeze a sample
- Can achieve pressures up to 80 GPa (or even higher)
- So, like, is that big?

Relative pressure scale

Pressures are given in Atmospheres

10^{-31} |- Non equilibrium "pressure" of hydrogen gas in intergalactic space.

10^{-28} |-

10^{-25} |-

10^{-22} |- Non equilibrium "pressure" of cosmic microwave background radiation.

10^{-19} |- Pressure in interplanetary space.

10^{-16} |-Best vacuum achieved in laboratory.

10^{-13} |- Atmospheric pressure at altitude of 300 miles.

10^{-10} |- Pressure of strong sunlight at surface of earth.

10^{-8} |-

10^{-7} |- Partial pressure of hydrogen in atmosphere at sea level.

10^{-6} |-Best vacuum attainable with mechanical pump. Radiation pressure at surface of sun.

10^{-5} |-Pressure of the foot of a water strider on a surface of water. Osmotic pressure of sucrose at concentration of 1 milligram per liter.

10^{-4} |-Pressure of sound wave at threshold of pain (120 decibels). Partial pressure of carbon dioxide in atmosphere at sea level.

10^{-3} |- Vapour pressure of water at triple point of water.

10^{-2} |-Overpressure in mouth before release of consonant *p*. Pressure inside light bulb.

10^{-1} |- Atmospheric pressure at summit of Mount Everest.

1 |-*Atmospheric pressure at sea level*. Pressure of ice skater standing on ice.

10 |-Maximum pressure inside cylinder of high compression engine. Air pressure in high-pressure bicycle tyre.

10^{2} |-Steam pressure in boiler of a power plant. Peak pressure of fist on concrete during karate strike.

10^{3} |-Pressure at greatest depths in oceans.

10^{4} |-Pressure at which mercury solidifies at room temperature. Pressure at which graphite becomes diamond.

10^{5} |-Highest pressure attainable in laboratory before diamond anvil cell. Radiation pressure of focused beam of pulsed laser light.

10^{6} |-*Highest pressure achieved with diamond anvil cell*. Pressure at centre of Earth.

10^{7} |-Pressure at centre of Saturn.

10^{8} |-Pressure at centre of Jupiter. Radiation pressure at centre of sun.

10^{10} |- Pressure at centre of sun.

10^{13} |-

10^{16} |-Pressure at centre of red-giant star. Pressure at centre of white-dwarf star.

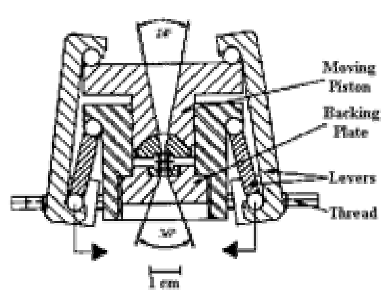
10^{19} |-

10^{22} |-

10^{25} |- Pressure at centre of superdense star.

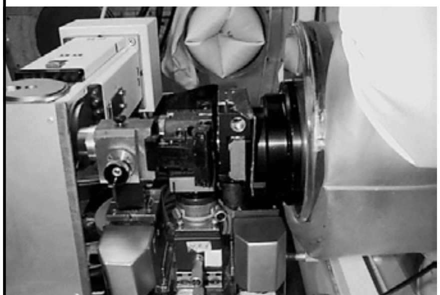
10^{28} |- Pressure at centre of neutron star.

The Holtz cell



- The Holtz cell is a way to achieve huge pressures in a diamond anvil
- Uses a simple lever system to apply pressure

The diamond Anvil



- A photo of a working diamond anvil at the institute for transuranic elements, in Europe