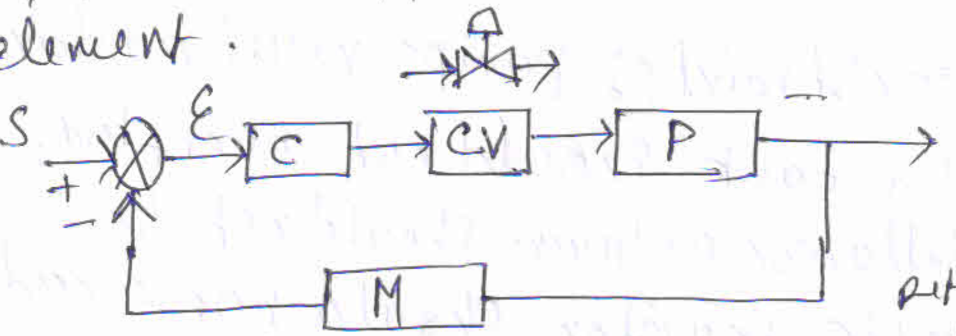
Note PCI 1st Introduction

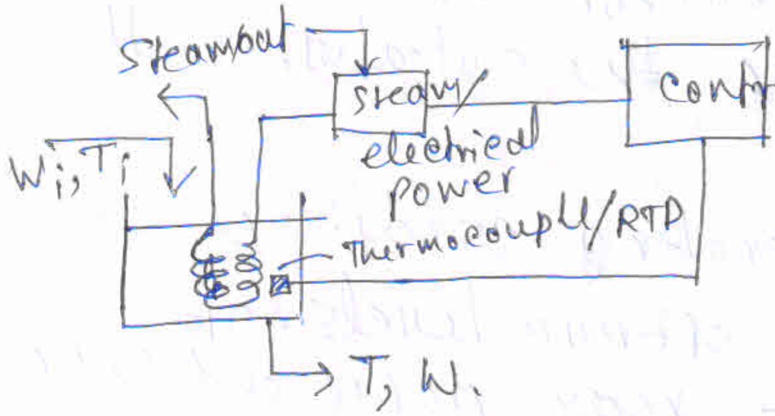
Process control consists of ~~three~~ four elements.

Process 1) measurement, evaluation, and final control element.



3) Coughanowr, D.R. Le Blanc, S.E. process system analysis & control

Feedback control system



1) Intro to Ins, sensors, and process control. William C. Dunn.

2) Stephanopoulos. G. Chemical process control.

Incentives for chemical process: During operation, a chemical plant must satisfy several requirement in the presence of everchanging external influences (disturbances)

i) Safety: operating pressure, temperature and concentration of chemicals, and so on, should always within allowable limits. For ex. if a reactor is designed to operate at a pressure upto 100 psig, ~~the controller~~ we should have control system that will maintain the pressure below this value.

ii) Production specification: Suppose production of ethylene per day is 2 million of 99.5% purity. The control system control flow rate and concentration also.

iii) Environmental regulation: For example amount of SO_2 that plant can ~~reject~~ eject to atmosphere,

iv) operational constraints: pumps must maintain a certain NPSH, tank should not overflow, or go dry, distillation column should not be flooded, catalytic reactor should not exceed an upper limit. since the catalyst will be destroyed.

v) Economics: operating conditions are controlled at given optimum levels. of min operating cost, max. profit and so on.

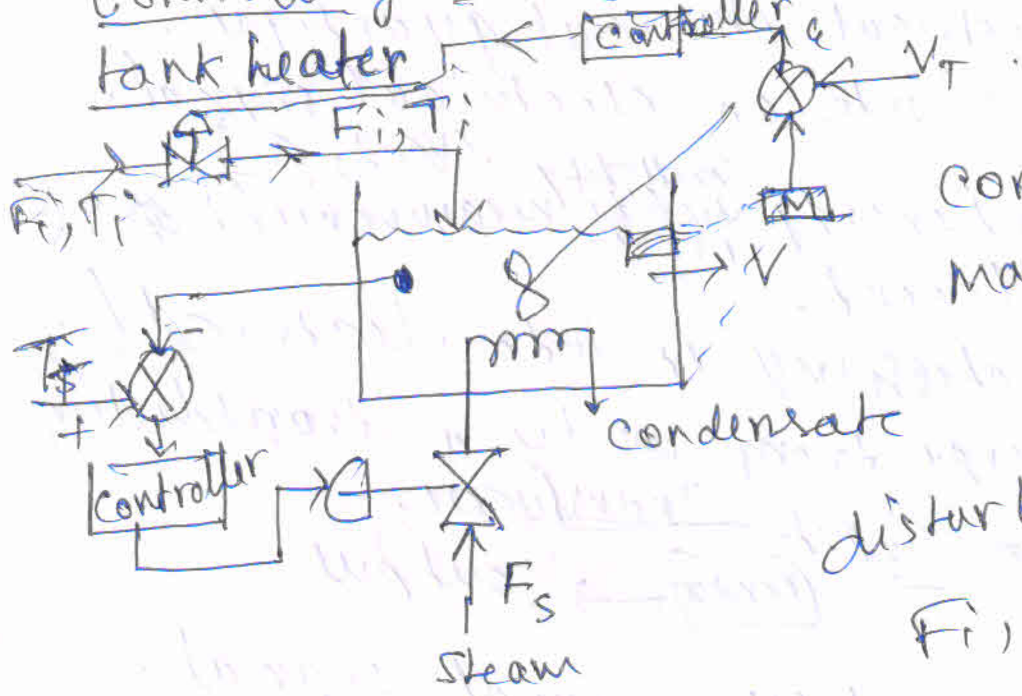
Three general classes of needs that a control system is called on to satisfy.

~~suppressi~~ suppressing the influence of external disturbances.

Ensuring the stability of a chemical process.

optimizing the performance of a chemical process.

Controlling the operation of Stirred tank heater



controlled variable, T, V
manipulated " , F_s

disturbances.
F_i, T_i

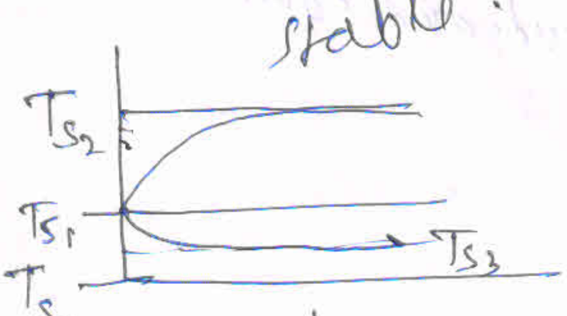
we want to keep at steady state T_{sp}, V_{st}.

If T_i, F_i is changed. $\epsilon = T_T - T$

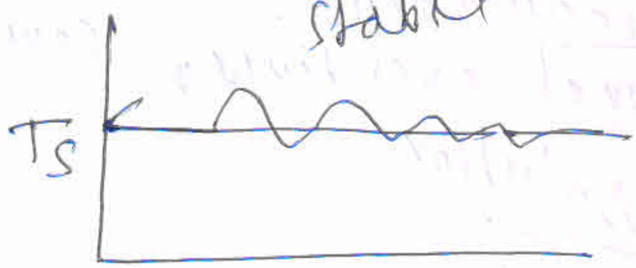
if $T_T > T$. $\epsilon > 0$. controllers open the control valve.

if $T_T \not> T$ $\epsilon < 0$ controller close the control valve.

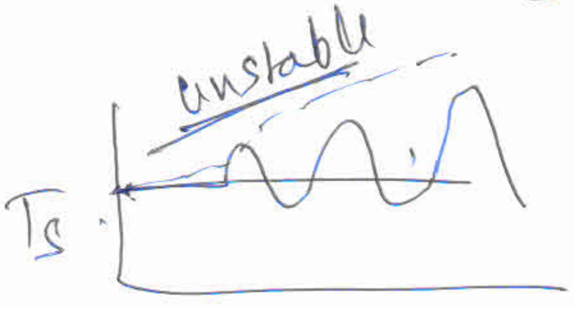
when $\epsilon = 0$. $T_T = T$ controllers stop action.



set point change



effect of disturbance. F_i, T_i



Transducer : It transforms a non-electrical physical quantity (i.e. T, P, C) into an electrical signal (V, I, C).

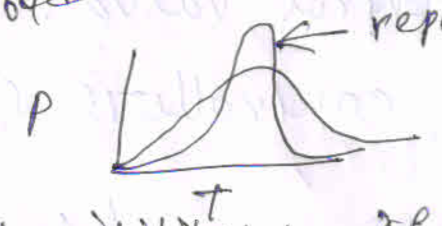
1) sensing input energy by measurement using sensing element.
2) Transforming it into electrical (another energy form) by a transduction element.

input → [sensor] → output (Transducer)

Transmitter : It amplify, format signal to transmit it over long distance with zero or minimal loss of information.

Repeatability : it is a measure of closeness of agreement among a number of reading taken consecutively of a variable.

← repeatability is high : less variation



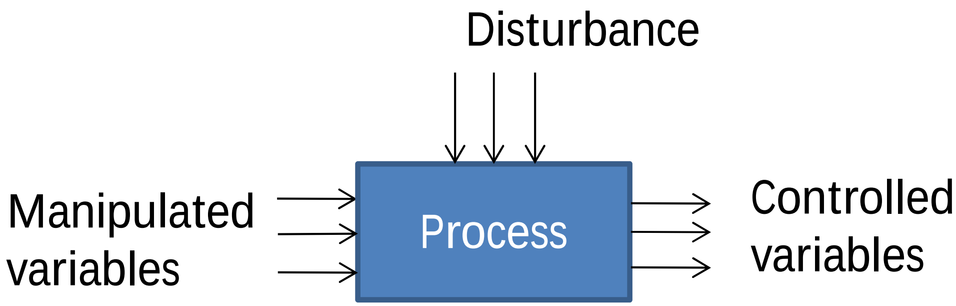
Reproducibility : repeatedly read the same signal over time, same input and same condition.

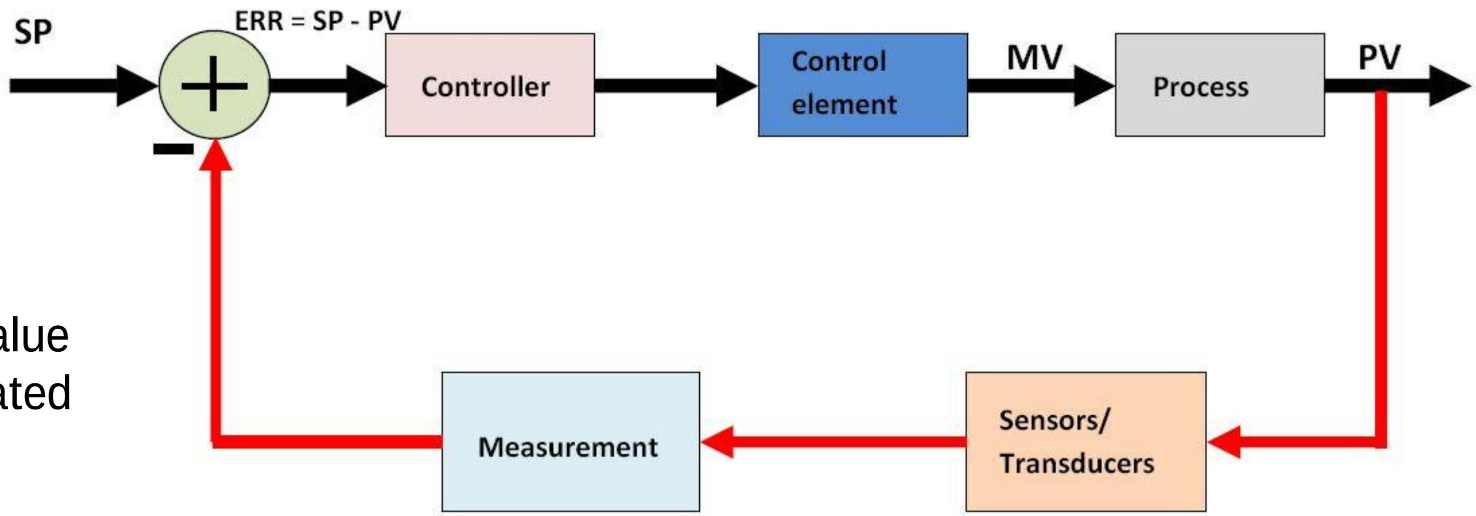
Resolution

Process control Instrumentation

Preliminary concept

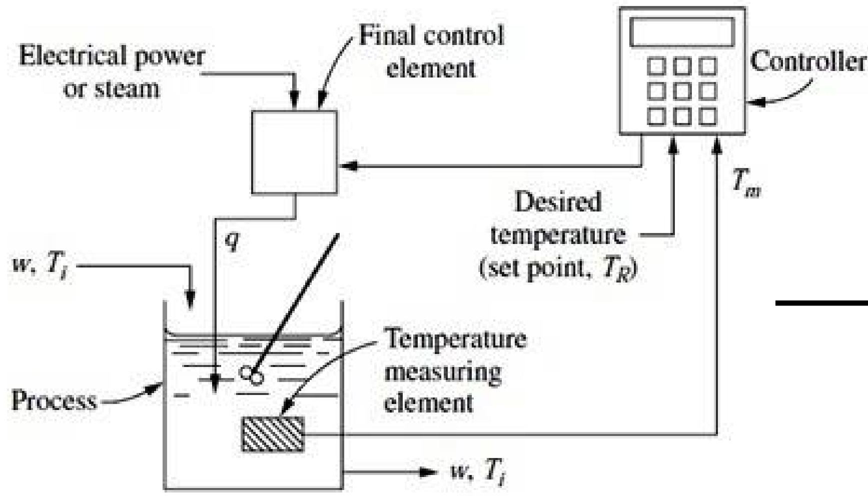
- A process consists of three types of streams: the ***manipulated variables*** (valve position, motor speed), ***disturbances*** (changes in ambient temperature, in demand for product, or in the supply of feed material), and the ***controlled variables*** (temperature, level, position, pressure, pH)**.**

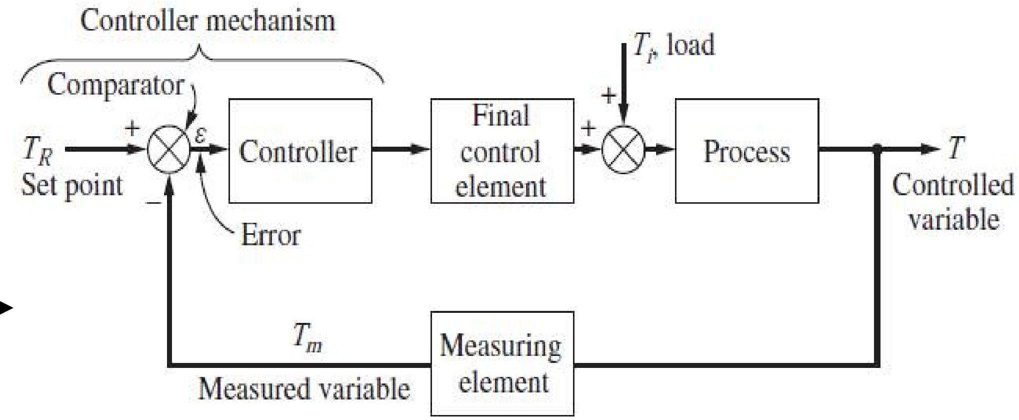




Process control block diagram with its major components

ERR=Error
SP=Set point
PV=Process value
MV=Manipulated variable

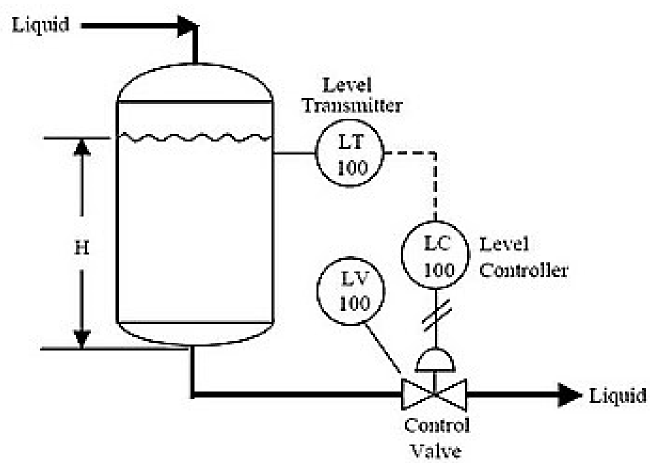




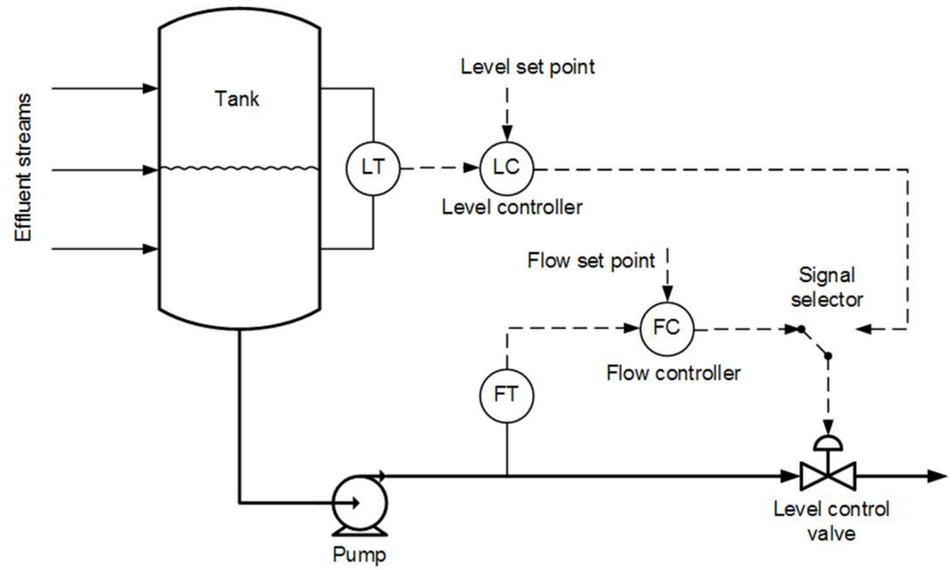
Block diagram of temperature control system

Temperature control in a stirred tank heater

LV: Level control valve
TV: Temperature control valve



Level control in a storage tank



Level and flow control system

LT: Level transmitter
FT: Flow transmitter

- **Accuracy** of an instrument or device is the difference between the indicated value and the actual value. Its absolute value is absolute accuracy. ±1 psig accuracy is equivalent to ±1 psig uncertainty of measured pressure. ±0.5% full scale (FS): if FS is 10 Volt the accuracy is ±10×0.5/100= ±0.05 Volt. The device measuring ±2% of span for 20-50 psig range of pressure, the accuracy= ±0.02×(50-20)= ±0.6 psig. It can be % of actual reading . The reading is 20 mA and accuracy is ±5% of reading = ±1 mA accuracy.
- **Actuators** are devices that control an input variable to the process in response to a signal from a controller. It regulate the manipulated variable of a process to control it.
- **Controlled or Measured Variable** is the monitored output variable from a process, where the value of the monitored output parameter is normally held within tight given limits.
- **Controllers** are devices that monitor signals from transducers and keep the process within specified limits by activating and controlling the necessary actuators, according to a predefined program.
- **Error Signal** is the difference between the set point and the amplitude of the measured variable. Error signal is output of comparator and input of controller.
- **Hysteresis** is the difference in readings obtained when an instrument approaches a signal from opposite directions.
- **Manipulated Variable** is the input variable or parameter to a process that is varied by a control signal from the controller to an actuator.
- **Precision** is the limit within which a signal can be read, and may be somewhat subjective.

- **Range** of an instrument is the lowest and highest readings that it can measure.
- **Repeatability** is a measure of the closeness of agreement between a number of readings taken consecutively of a variable.
- **Reproducibility** is the ability of an instrument to repeatedly read the same signal over time, and give the same output under the same conditions.
- **Resolution** is the smallest change in a variable to which the instrument will respond.
- **Sensitivity** is a measure of the change in the output of an instrument for a change in the measured variable or input variable. For pressure sensor the sensitivity unit is in mV/psi. For temperature sensor the sensitivity unit is mV/^{o}C.
- **Sensors** are devices that can detect physical variables like temperature, pressure, etc.
- **Set Point** is the desired value of the output parameter or variable being monitored by a sensor; any deviation from this value will generate an error signal.
- **Transducers** are devices that can change one form of energy into another.
- **Transmitters** are devices that amplify and format signals, so that they are suitable for transmission over long distances with zero or minimal loss of information.

Temperature measurement

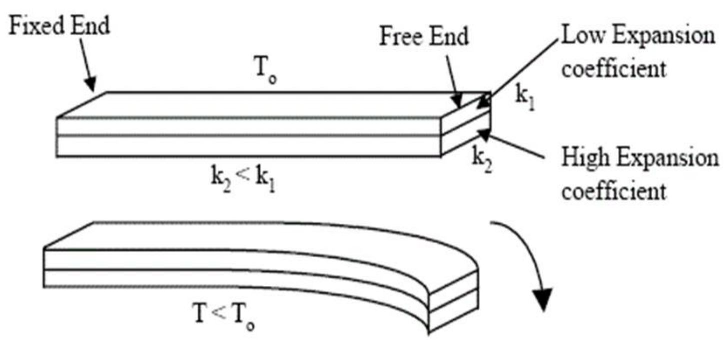
- Temperature measuring devices are based on following methods:

  1. Expansion of materials; 2. Electrical resistance change; 3. Thermistors; 4. Thermocouples; 5. Pyrometers; 6. Semiconductors.

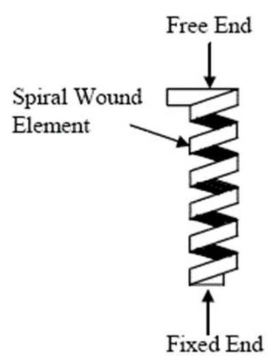
- **Expansion thermometer**

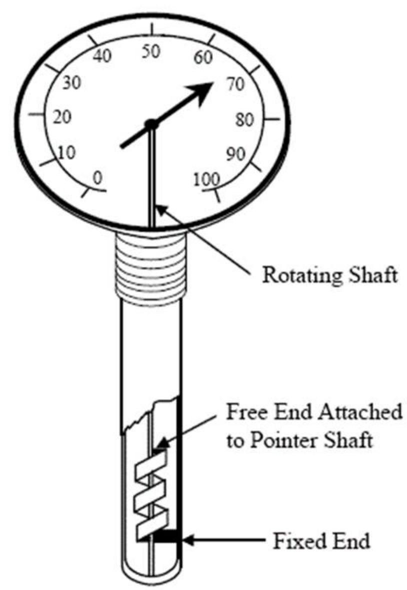
  Liquid in glass thermometers *using mercury were, by far, the most common direct* visual reading thermometer. The operating range is from −30° to +800°F (−35° to +450°C).

  A ***bimetallic strip*** *is a relatively inaccurate, rugged temperature-measuring* device, which is slow to respond and has hysteresis. The device is low cost, and therefore is used extensively in On/Off-types of applications, or for local analog applications not requiring high accuracy.



Bimetallic strip

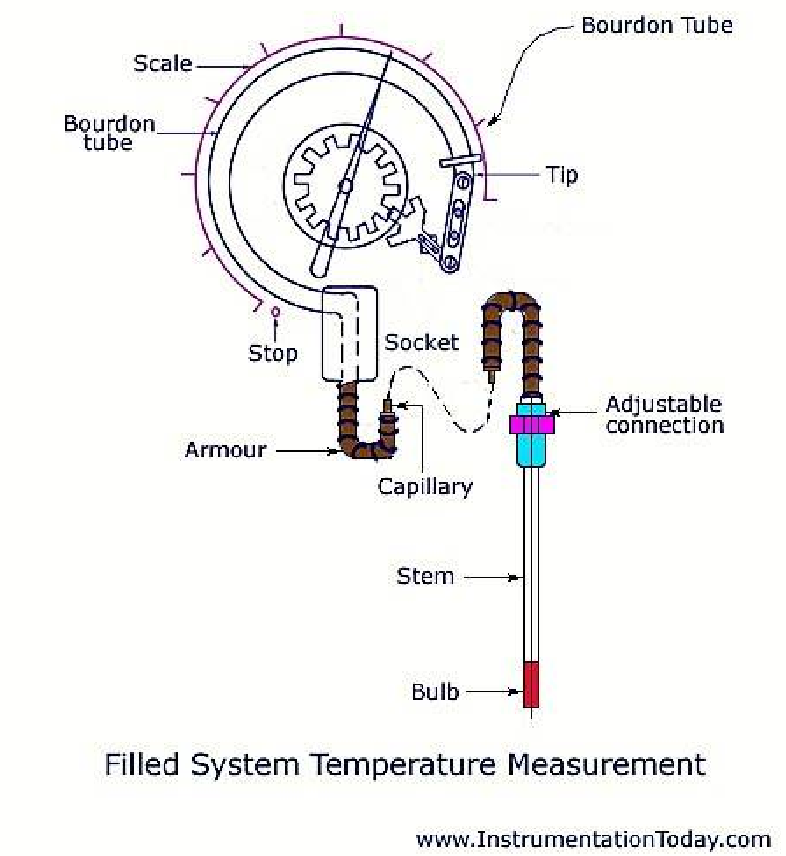




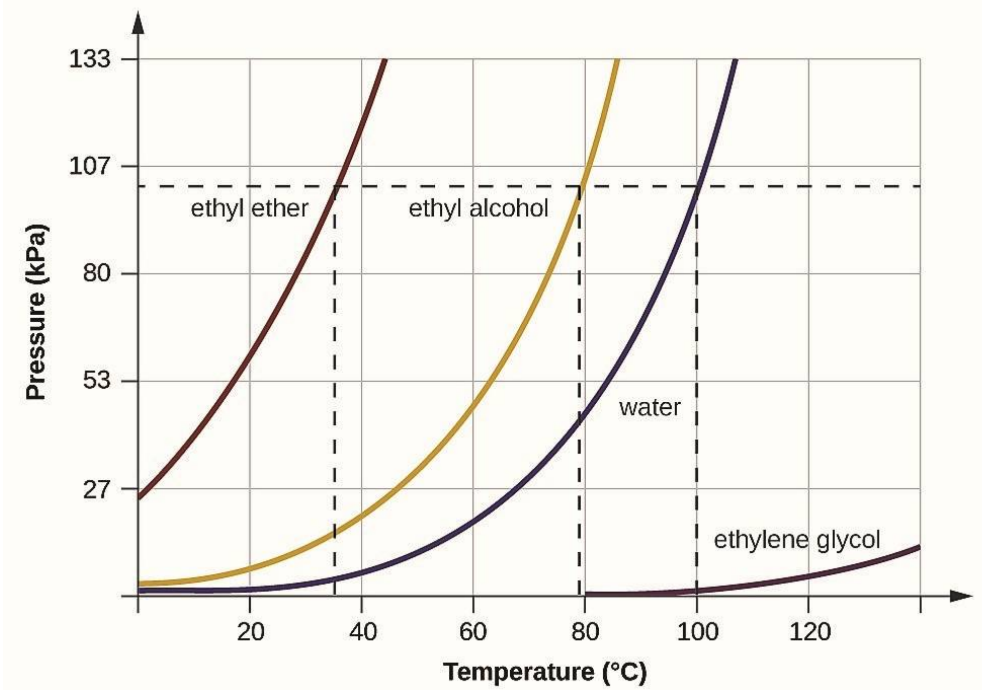
Bimetallic dial thermometer using spiral wound.

Pressure-spring thermometers has a metal bulb made with a low coefficient of expansion material along with a long metal narrow bore tube; Both contain liquid/vapor/gas, which are expanded due to temperature sensed by the bulb and used to drive a Bourdon tubes/bellows/diaphragm. The pressure system can be used to drive a chart recorder, actuator, or a potentiometer wiper to obtain an electrical signal. These devices can be accurate to 0.5%, and can be used for remote indication up to a distance of 100m, but must be calibrated.

A *gas thermometer* is filled with a gas, such as nitrogen, at a pressure of between 1,000 and 3,350 kPa, at room temperature. The device obeys the basic gas laws for a constant volume system.

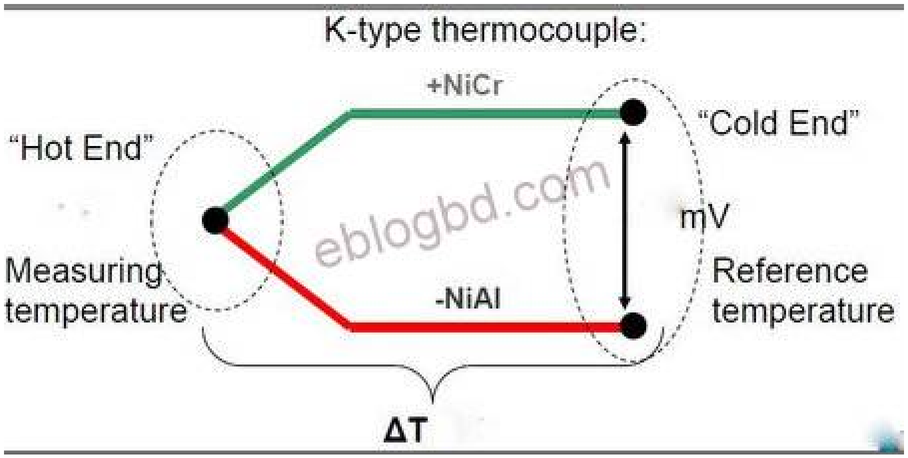


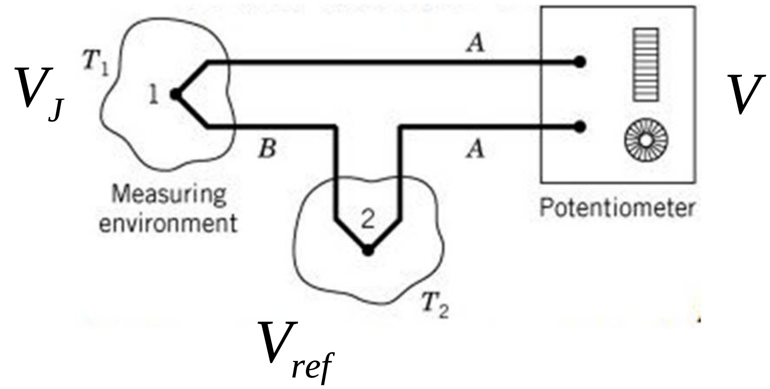
Vapor pressure thermometer



Vapor pressure vs. temperature curve

- **Thermocouple (T/C)** has two wires composed of dissimilar metal are joined at both ends and one end is heated, a continuous current flows in the thermoelectric circuit. This is Seebeck effect. Voltage produced in the thermocouple Vab is proportional to the temperature difference between the two junctions. $V_{ab} = \alpha(T_1 - T_2)$ α is the Seebeck coefficient





$$V_{ref} = f(T_{ref})$$

Electric circuit: i) Resistance of reference junction is measured and reference temperature is evaluated and it is converted to equivalent reference junction voltage Vref. ii) Voltage V of the two end wires is measured by digital Voltmeter (DVM) to measure junction temperature TJ. $V - V_{ref} = V_J$

T/C can be manufactured easily by welding or sholdering. It measures wide range of temperature. In computer based control it exerts small dead time due to calculation of reference junction temperature in a computer.

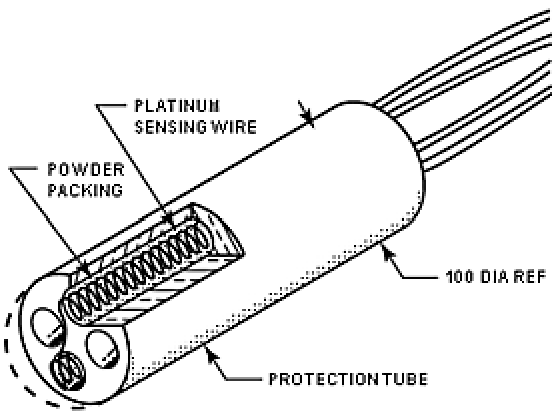
- Different types of T/C

Types	Metal pair	Range	Seebeck coefficient ($\mu V/°C$)
T	Copper—Constantan	−140° to +400°C	40 (−59 to +93 °C)
E	Chromel—Constantan	−180° to +1000°C	62 (0 to 360 °C)
J	Iron—Constantan	30° to 900°C	51 (0 to 277 °C)
K	Chromel—Alumel	30° to 1400°C	40 (0 to 277 °C)
S	Platinum (Rhodium 10 %)—Platinum	30° to 1700°C	7 (0 to 538 °C)
R	Platinum (Rhodium 13 %)—Platinum (R)	30° to 1700°C	7 (0 to 538 °C)

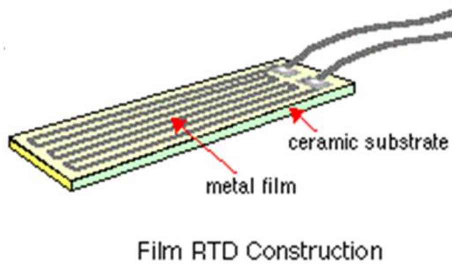
- **Comparison of T/C and RTD**

Types	Advantages	Disadvantages
Thermocouple	Wide temperature range, low cost, rugged, good linearity	Reference temperature need to be measured, low sensitivity.
RTD	Better accuracy, stable, better linearity	Slow response time, low sensitivity, expensive, self heating

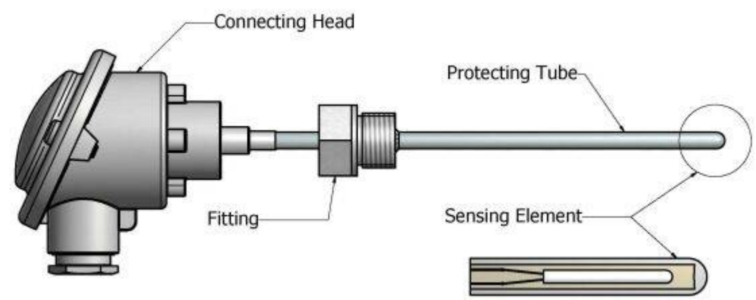
- **Resistance temperature detector RTDs** are of two types i) a metal film deposited on a form ii) wire-wound resistors. The element is sealed in a glass-ceramic composite material. The space between the element and the case is filled with a ceramic power of good thermal conductivity. The noninductive resistive element is platinum (first choice), nickel etc. The RTD is accurate, and positive resistance increases with temperature linearly. It measures temperatures from −300° to +1,400°F (−170° to +780°C). The response time is in between 0.5 s to 5 s.



RTD



Metal-film RTD



Modern RTD construction

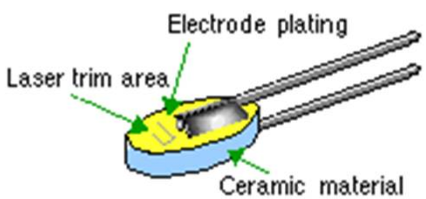
The equation for platinum RTD curve is given by,

$$R = R_o + \alpha R_o \left[T - \delta \left(\frac{T}{100} - 1 \right) \left(\frac{T}{100} \right) - \beta \left(\frac{T}{100} - 1 \right) \left(\frac{T}{100} \right)^3 \right]$$

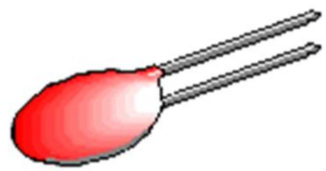
R_o =Resistance at 0°C; R= Resistance at T°C; β=0 if T>0 and β=0.1 if T<0; δ=1.49

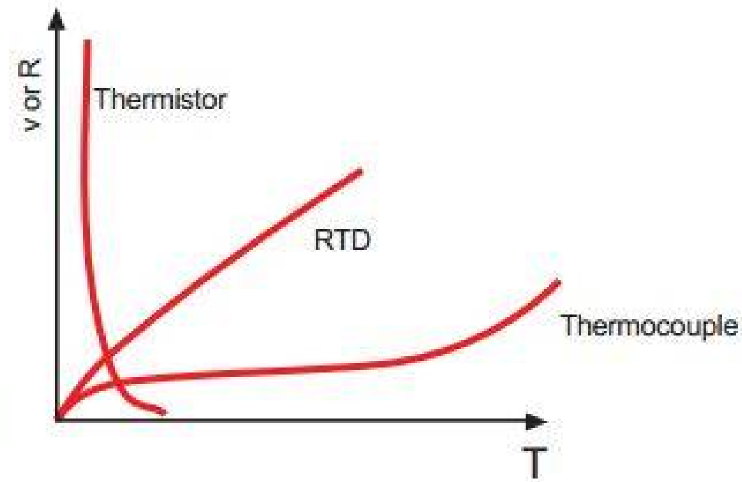
α (temperature coefficient)=0.00392 Ω/ Ω /°C (America) and 0.00385 Ω/ Ω /°C (Europe)

- **Thermistor** is a type of metal oxide/semiconductor material of high negative (can be of positive) temperature coefficient. It has high sensitivity (upto 10% change per ^{o}C); highly temperature sensitive element, highly nonlinear characteristics, response time 0.5 s to 5 s, and operating range from –50° to +300°C. It has low cost, available in a wide range of shapes, sizes. The internal heating effect must be minimized for use. Temperature coefficient is given by, $\alpha = \frac{\Delta R}{R_s}\left(\frac{1}{\Delta T}\right)$ where R_s is the material resistance at reference temperature.

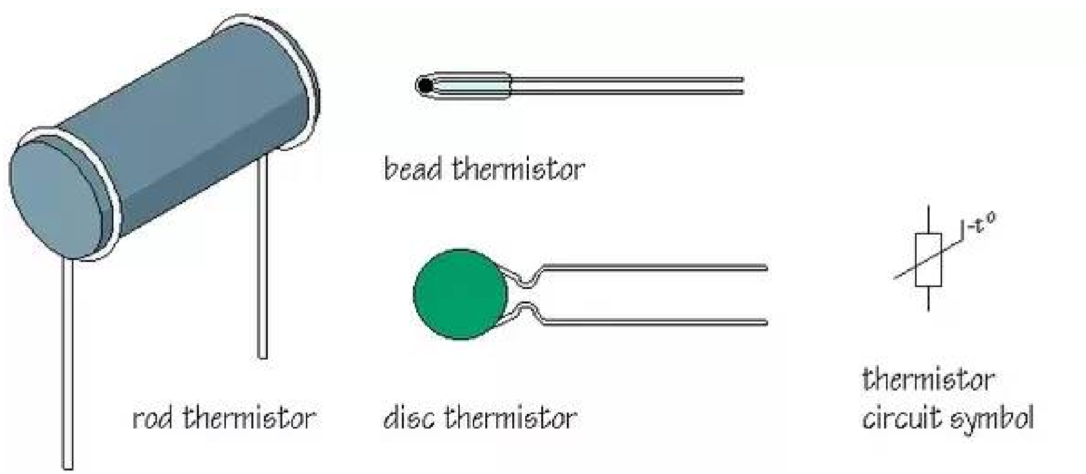


Thermistor without Encapsulation

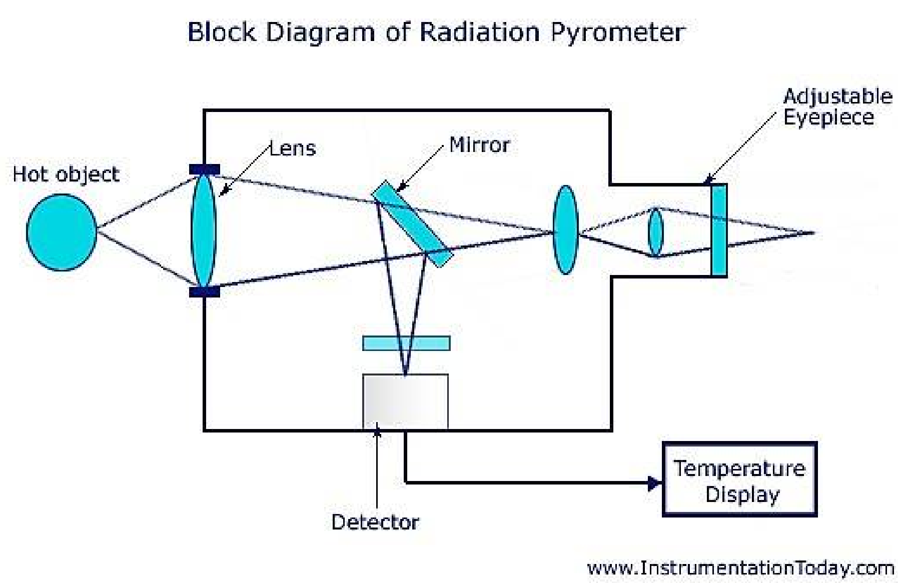

Thermistor with Encapsulation

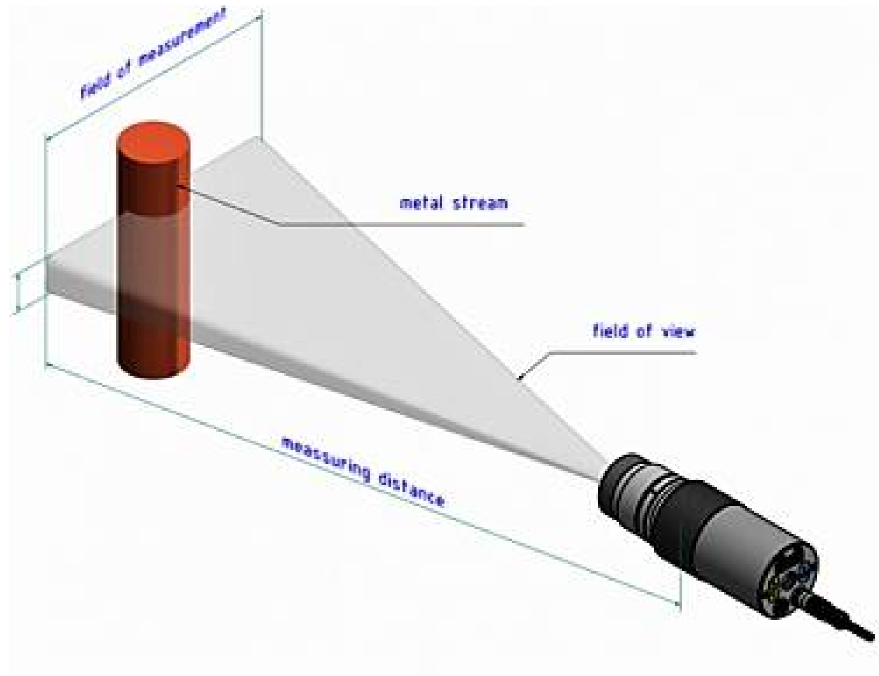


Voltage or resistance vs. temperature for different temperature sensor



- **Radiation pyrometer** is a noncontact temperature sensor that infers the temperature of an object by detecting its naturally emitted thermal radiation. An optical system collects the visible and infrared light from an object and focuses it on a detector which converts the collected energy to a measurable electrical signal and temperature is displayed. the Two types of detectors are used- thermal or thermopile detector and photon detector or photomultiplier tube.



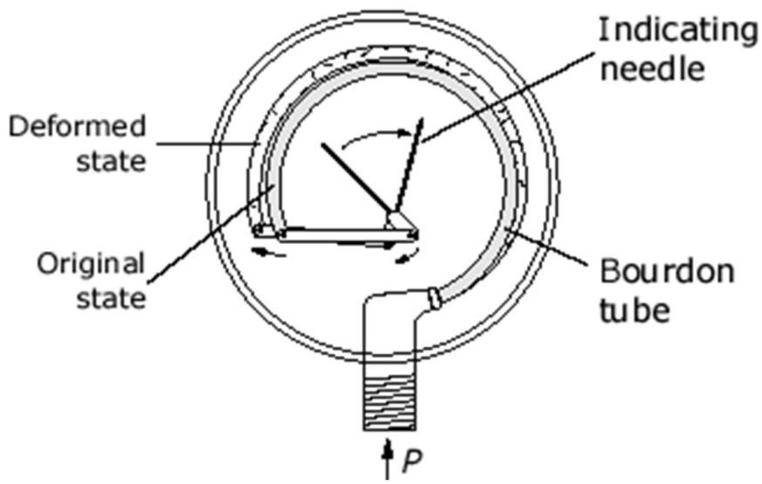


Radiation pyrometer

Pressure measurement

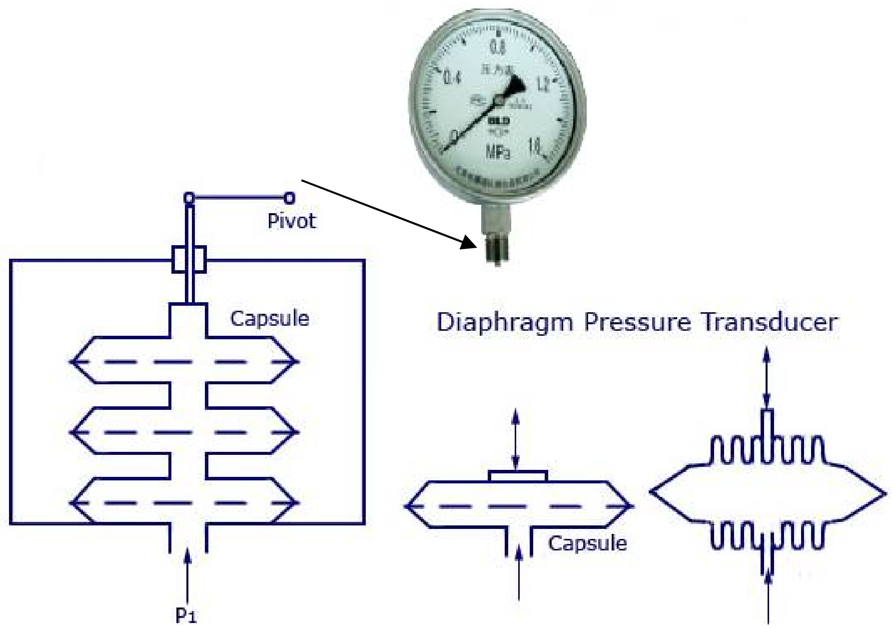
- **Pressure gauge:** It consist of pressure element and dial or indicator. Pressure element converts pressure into a mechanical motion to indicate by dial. These are most common in process industries.

  Bourdon tube pressure gauge is close at one end and open at other end. When pressure is applied to open end, the Bourdon tube uncoils. The tube is mechanically linked to a pointer on a pressure dial which indicate pressure with the movements of the coil.



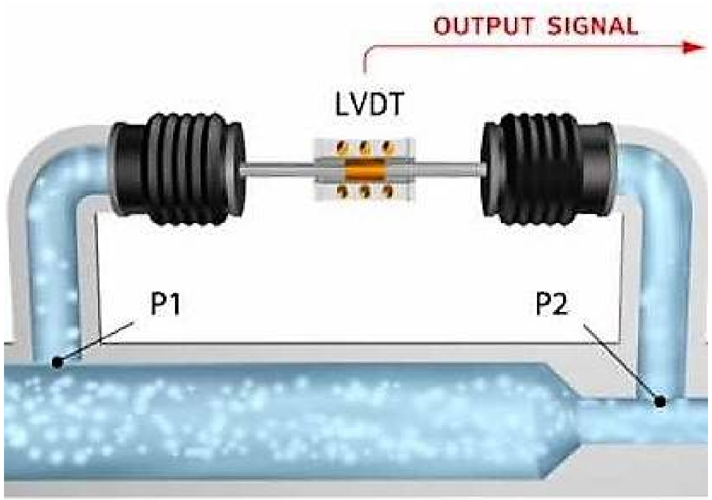
Bourdon tube pressure gauge

Diaphragm-type pressure gauge consist of diaphragm which is a flexible membrane; Two metal elements are fastened together to form a container or capsule. Pressure is applied inside the capsule through pressure line that causes it to expand and produce vertical motion along its axis to indicate pressure through a indicator. Diaphragm materials are brass, beryllium-copper, stainless steel, etc. To amplify motion several capsules are connected together. It measures gauge, absolute or differential pressure in the range of 0-330 psig. It can be built for use in vacuum service.

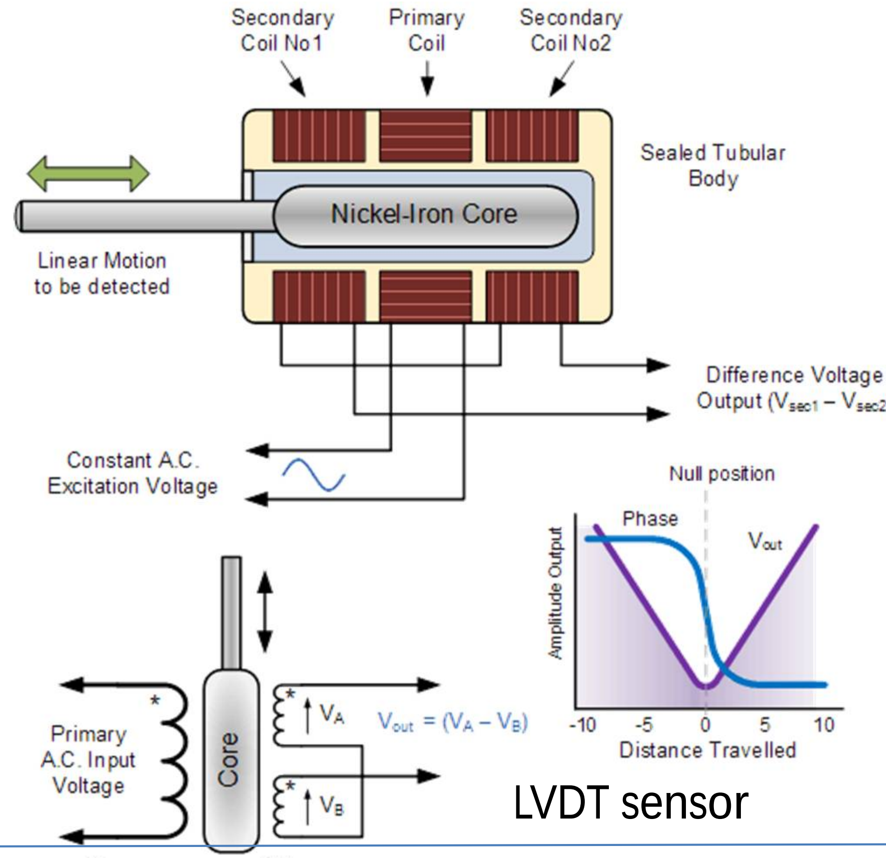


Diaphragm-type pressure gauge

Capsules are two diaphragms joined back to back. For differential pressure measurement, the movement of arm caused by a counter-balanced pressure between two capsules is converted to an electrical signal and it is maintained in a neutral position by a force balance system. Movement of the arm is sensed by linear variable differential transformer (LVDT) signal which is amplified and drives an electromagnet to pull back the arm to its original position. Applied pressure is proportional to current required to drive the electromagnet and it is converted into an output signal of 4-20 mA output current. It is of high resolution, accuracy and stability.

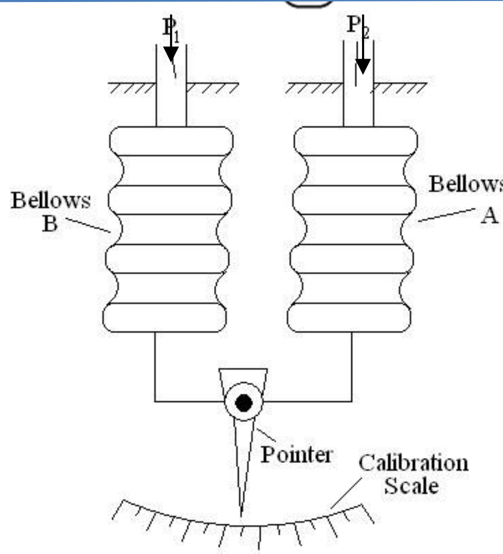


Differential pressure measurement using capsule pressure sensor



LVDT sensor

Bellows is similar to capsule except that instead of is being joined directly together, the diaphragm is separated by corrugated tube or a tube with convolutions.



Bellows

Differential pressure measurement using two bellows

- **Vacuum instrument** is used to measure pressure less than atmospheric pressure.

  Ionization gauge is used to measure pressure in the range of 10^{-3} atm to 10^{-12} atm. In a pressure chamber gas is ionized with a beam of electrons and the current is measure by two electrodes in the gas. The current is proportional to electron density in the chamber and hence the applied pressure.

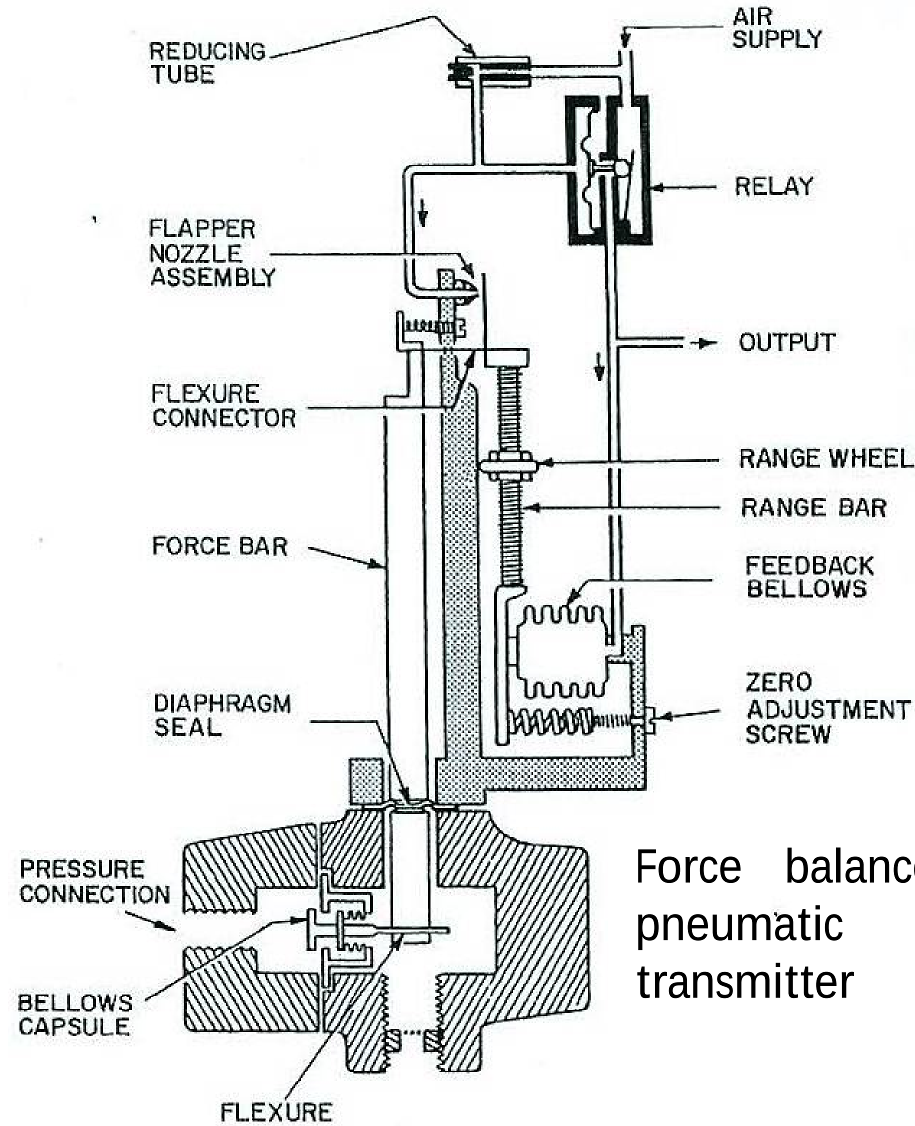
  Pirani gauge measure pressure in the order of 10^{-3} atm. Measurement is based on the heat conduction and radiation from a heating element to the gas molecule density in the low pressure region that determine pressure.

  McLeod gauge is the device that compress the gas in the low pressure region and change in volume and pressure are used to determine original gas pressure for a non condensing gas.

- **Pressure transmitter**

  In control application pressure value must be transmitted some distance (to control room) where it is converted into usable pressure. Pressure transmitter converts a pressure signal into scaled signal like, electric, pneumatic or mechanical.

Pneumatic pressure transmitter is a force balance pneumatic transmitter. Pressure is applied to a metal diaphragm that is welded to the sides of a chamber. The force developed on the diaphragm is taken out of the chamber by rigid rod or force bar attached to it. A balancing force developed by a pneumatic feedback bellows opposes the force. The imbalance between two counter force is sensed by a pneumatic nozzle-baffle. The nozzle pressure reestablishes by feed back mechanism and it is proportional to applied pressure. The pneumatic pressure generates the output signal of 3-15 psig. The most pneumatic pressure transmitters are used to measure differential pressure

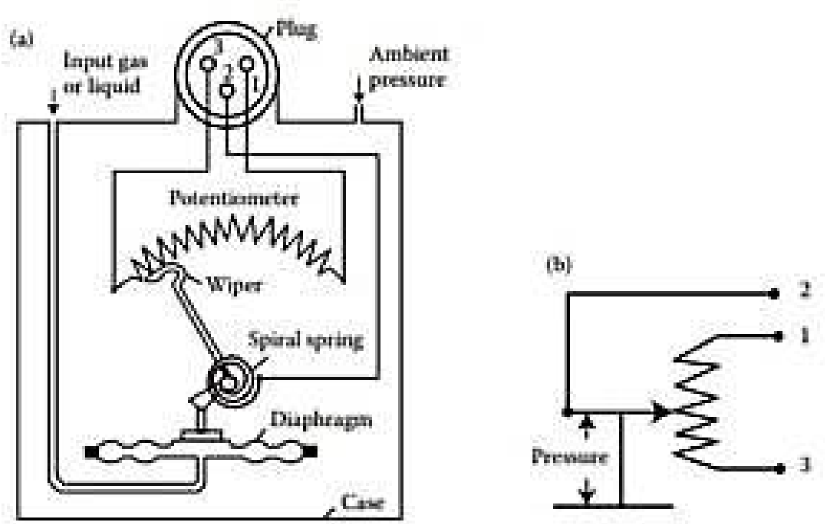


Force balance pneumatic transmitter

- **Electronic pressure sensor**

  The electrical properties used to measure pressure displacement are like, potentiometric, piezoelectric, capacitive, photoelectric, strain gauge, thermoelectric, etc.

  Potentiometric-type sensor converts applied pressure into variable resistance. It is oldest type. Mechanical devices like, diaphragm, capsule are used to move the wiper arm of a potentiometer as the input pressure changes. A DC voltage is applied to the top of the potentiometer, and the voltage drop from the wiper arm to the bottom of the potentiometer is sent to the electronic unit. The output of the electronic unit is 4-20mA DC current that is proportional to input pressure. It measures pressure in the range of 5-10,000 psi. The output signal is generally noisy.

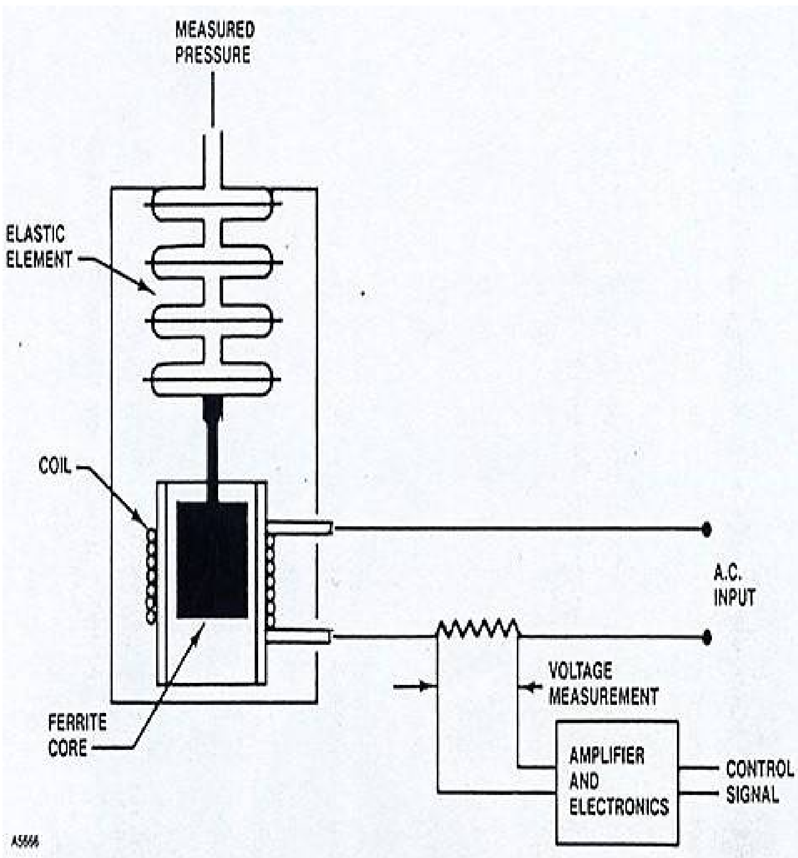


Potentiometric-type sensor

Piezoelectric-type sensor contains certain class of crystal called piezoelectric that produce an electrical signal when it is mechanically deformed. The material is attached to a metal diaphragm. Applied pressure from fluid line in contact with diaphragm is transferred through a link to the crystal which generates output voltage in the order of micro volt. The voltage is amplified by high input impedance amplifier and it is proportional to applied pressure. The crystal can tolerate temperature upto 400 ^{o}F. The pressure measurement should be temperature compensated.

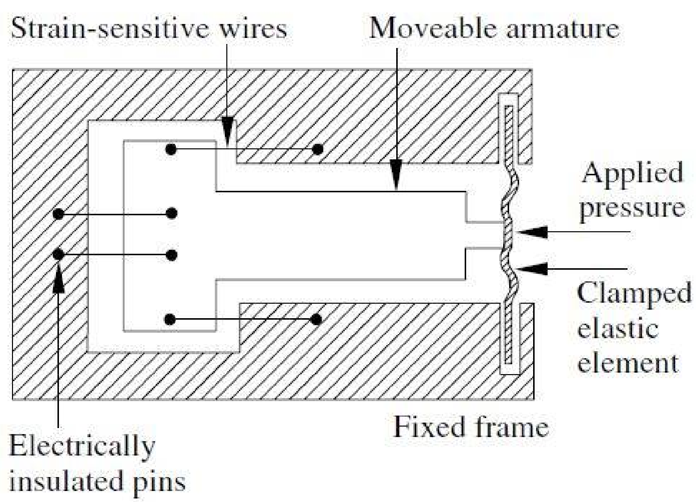
Capacitance-type sensor contains a capacitor and its capacitance changes with input pressure. A diaphragm is moved by input pressure and the movement is transferred to a movable capacitor plate. The change in capacitance occurs with the change in distance between two capacitor plates (one movable and other one fixed). The capacitance signal is then converted into an electrical signal and it is calibrated into input pressure signal.

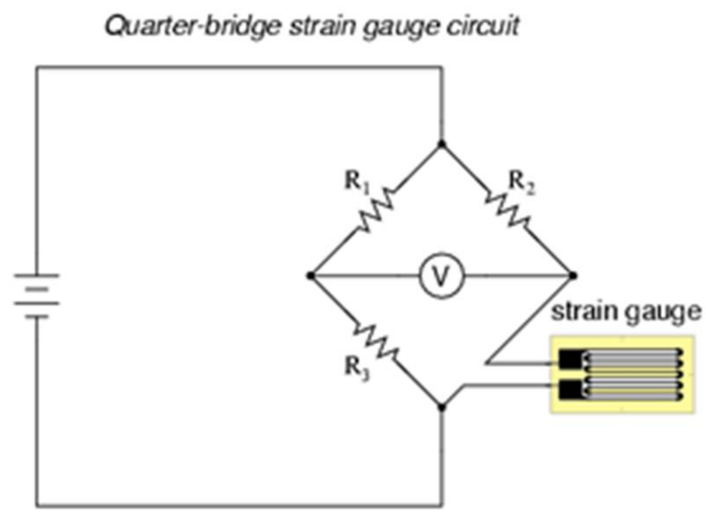
Variable inductance sensor contains pressure sensing diaphragm and a variable length wire of coil connected to the diaphragm. Surrounding the wire there is magnetic core and inductance sensing coil. With the change in pressure, wire length changes and the inductance of the wire changes. The long wire has higher inductance than short wire due to cutting of more conductor length by magnetic flux. The magnetic flux generated from the coil produces higher amount of induced voltage. The inductance is measure by a sensing coil, which is proportional to applied pressure.



Variable inductance sensor

Strain gauge pressure sensor is made of strain gauge that changes its resistance when stretched. Multiple runs of a fine wire are mounted to a stationary frame on one end and a movable armature on the other end. The movable armature is connected to a pressure sensing diaphragm or bellows. A small pressure changes causes the wire to elongate sufficiently in its multiple runs to change its resistance. The change in resistance is measured electrically and converted to output electrical signal which is proportional to input pressure.





Strain gauge pressure sensor

Level measurement

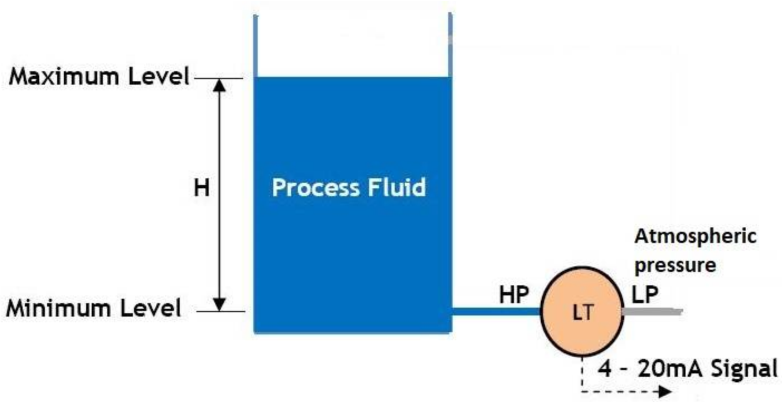
- **Sight type instrument**

  These are glass gauge, displacer, tape float etc.

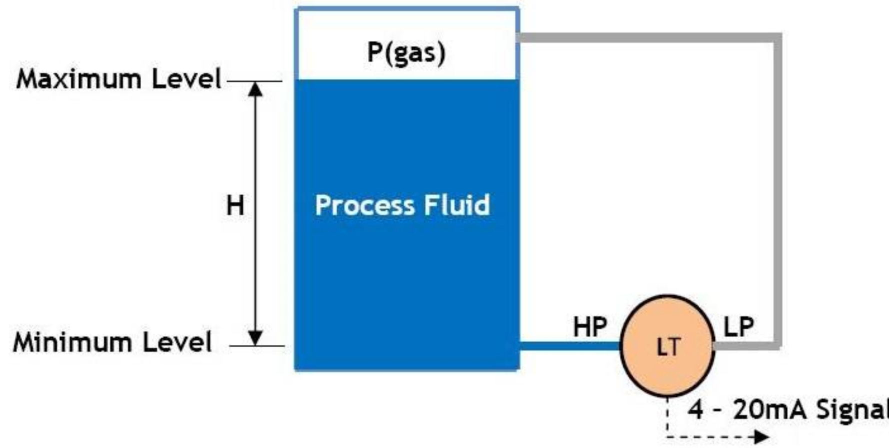
- **Pressure type instrument**

  These are differential pressure, bubbler, diaphragm

Differential pressure



Level measurement in an open tank based on differential pressure

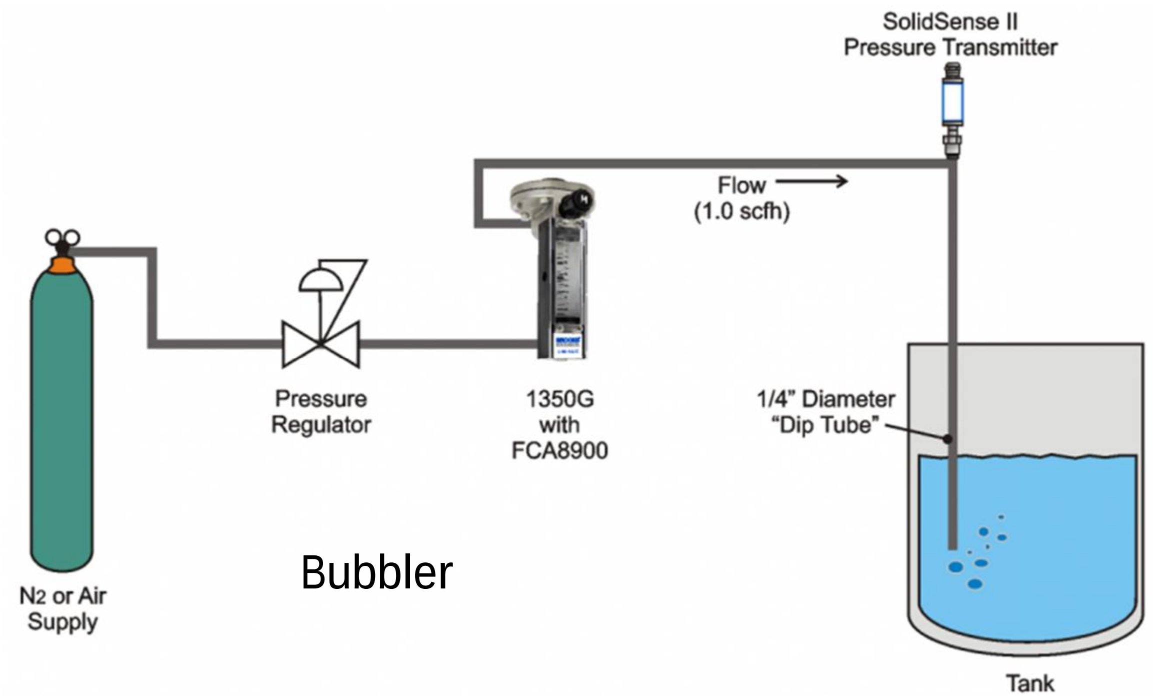


Level measurement in a closed tank based on differential pressure

LT=Level transmitter
HP=High pressure
LP=low pressure
HP-LP= $H\rho g$

DP level transmitter

Bubbler is a level measurement system with bubbling air line and pressure transducer. At the starting of bubbling in the tank through the air supply line, pressure in the line is equal to the pressure of the liquid column. Hence the liquid level is proportional to output current of the pressure transducer at the start of the bubbling (formation of bubbles).



Bubbler

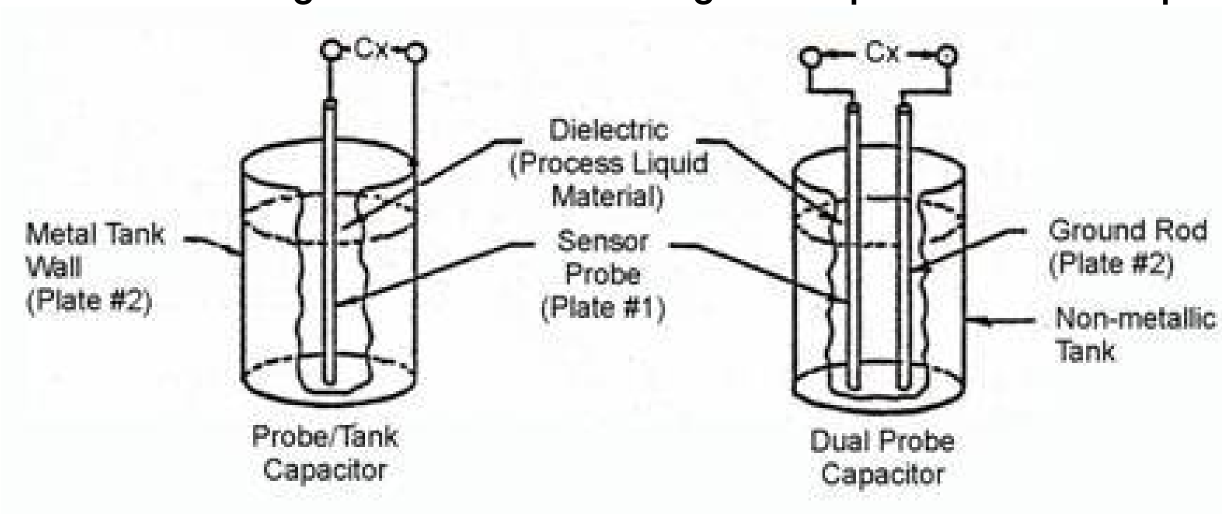
Diaphragm is a level transducer. With the increase of liquid level, the captive air inside the diaphragm is compressed and it is converted into pressure signal proportional to the liquid level.

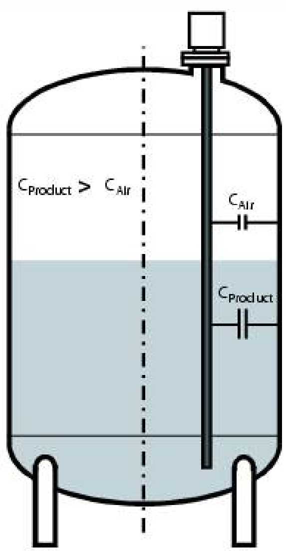
Diaphragm type level transmitter

- ***Electrical type level transducer***

These are capacitance probe, resistance tape, conductivity probe

Capacitance probe converts variation of level into changeable capacitance due to change in surface area in contact with electrodes. A level transmitter transmits electrical signal with the change in liquid level or capacitance.





C = Capacity of the cylinder condenser

$\varepsilon = \varepsilon_0 \varepsilon_r$ = Permittivity, relative permittivity

ε_0 = Electrical field constant

ε_r = Permittivity number

r_1 = Radius of the inner cylinder jacket (sensor radius)

r_1 = Radius of the outer cylinder jacket (container radius)

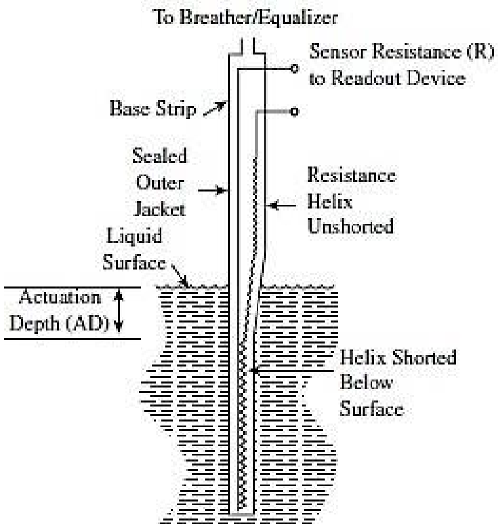
l = Length of the cylinder

$$C = \frac{2 \cdot \pi \cdot \varepsilon \cdot l}{\ln\left(\frac{r_2}{r_1}\right)}$$

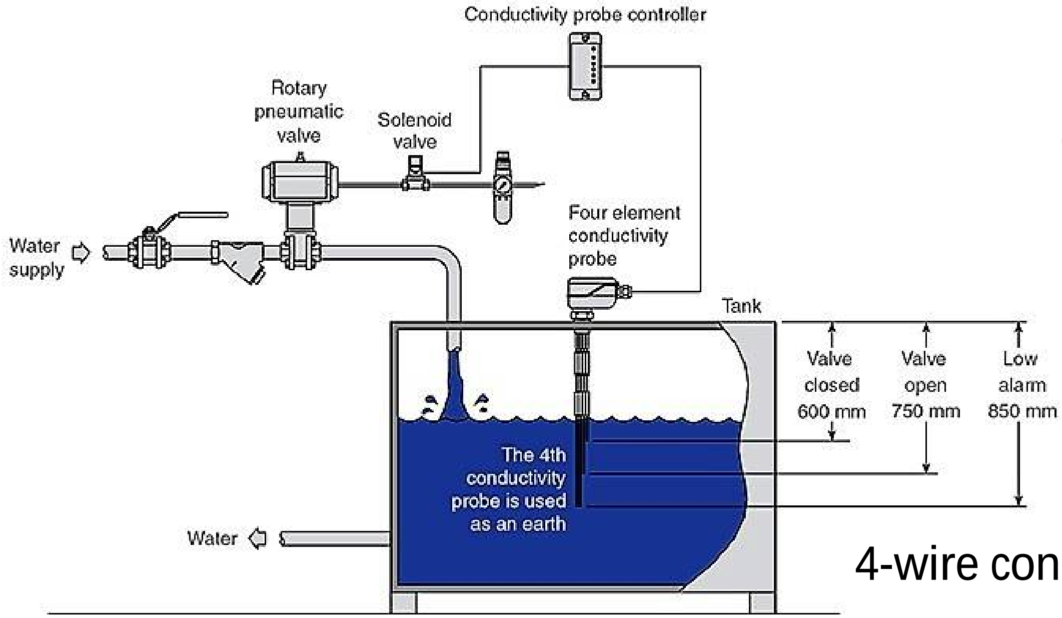
Capacitance type level measurement

Capacitance type level transmitter

Resistance tape is made of resistive material that is spirally wounded around a steel tape. It is short circuited due to pressure of the fluid and the resistance changes. The resistance is converted to an electrical signal that is proportional to the level of liquid.



Resistance tape level measurement

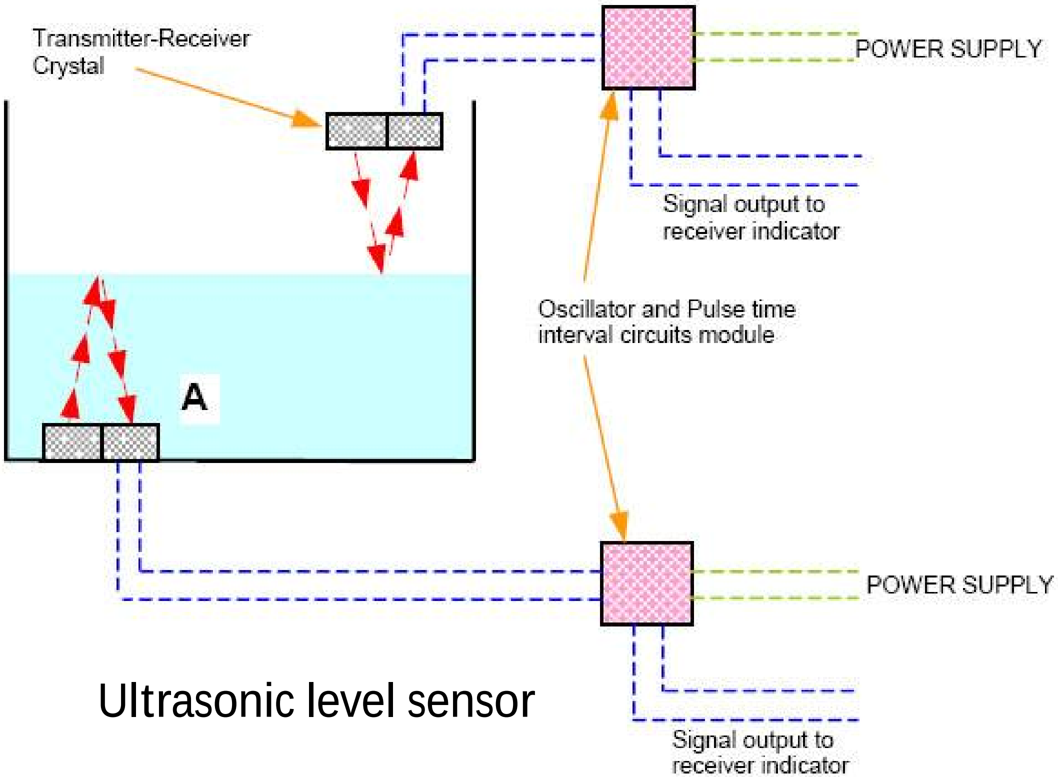


Conductivity probe relay system for closing, opening and alarming of control valve.

4-wire conductivity probe

Conductivity probe is made of more than one electrodes. The figure shows a four wire conductivity probe. When the rising liquid level touches 1st electrode (from right) the circuit between 1st and 2nd electrodes closes through conductance of liquid and it sends a current signal through relay system (controller and solenoid valve) to a rotary valve actuator to close it. In a same manner when rising liquid level touches 2nd and 3rd electrodes the valve opens and an alarm rings respectively. The 4th probe is used as a ground element.

Ultrasonic level sensor utilizes two ultrasonic transducers (one generator and other one receiver) made of piezoelectric crystal. An electrical pulse is converted into ultrasonic wave of few thousand Watt by a ultrasonic transducer and it is reflected from the liquid surface to 2nd ultrasonic transducer (receiver). Pulse timings of the transmitted and received signals are analyzed and time delay between two signals are evaluated and it is inversely proportional to the liquid level.

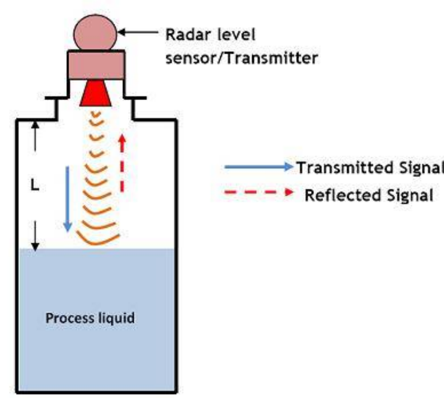


Ultrasonic level sensor

$$t/2 \propto 1/H$$

t=time delay between two pulses
H=Level
$t/2$=Time required to travel wave to reach the liquid surface

Radiation type level sensors are nuclear, microwave and rader based.

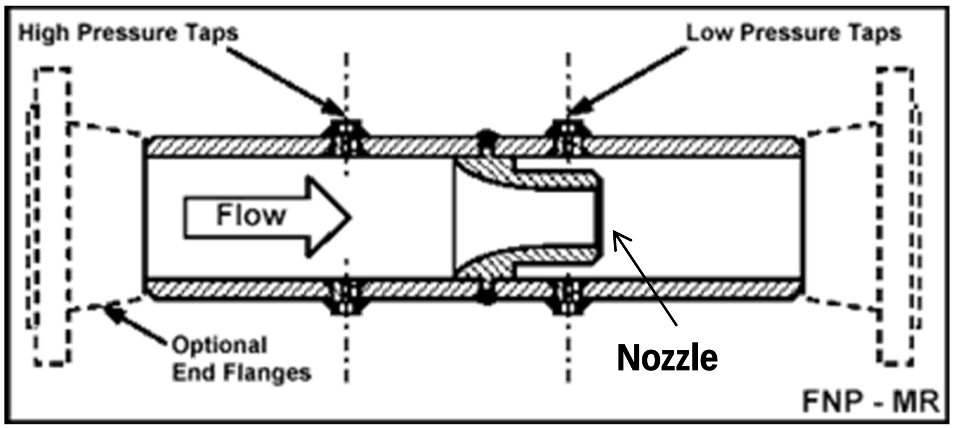


Flow measurement

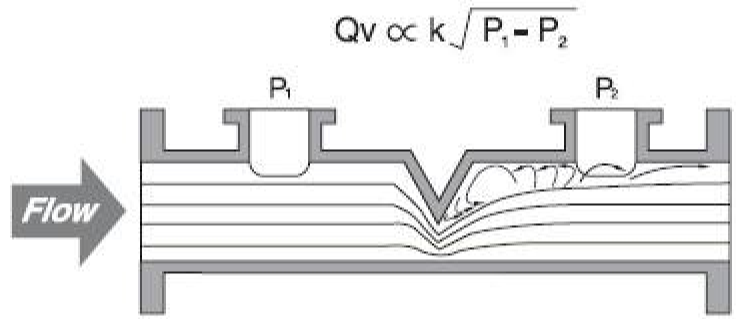
- **Differential pressure flow meter**

These are orifice meter, venture meter, flow nozzle, wedge flow meter, pitot tube, annubar, etc.

flow nozzle measures high velocity flow like steam flow. It is used in erosion environment and not used for measuring fluid containing high amount of solid or suspended particles.



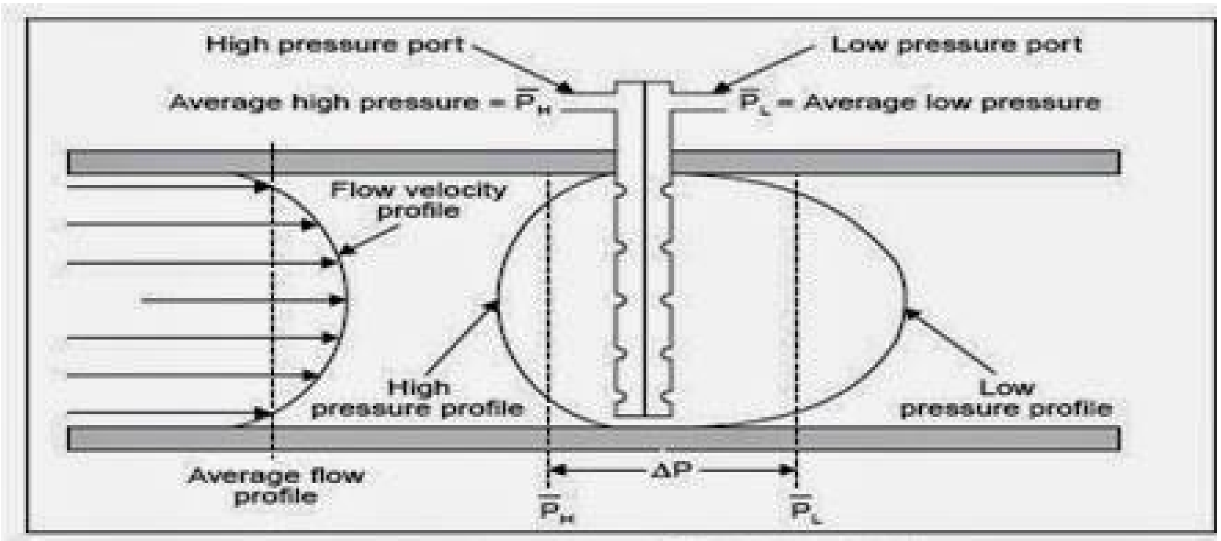
Flow nozzle



Wedge flow meter

Wedge flow meter measures flow rate of slurry and dirty fluid. Pressure drop through wedge or obstruction is proportional to square of flow rate.

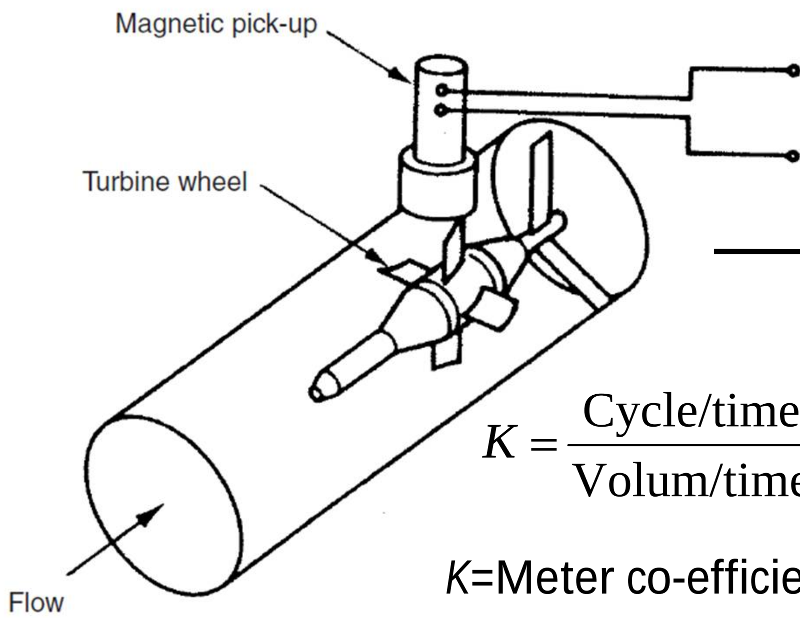
Annubar contains a bar surrounded by perforated wall that creates pressure drop through restriction of flow. Two side (upstream and downstream) of the probe are connected to pressure taps by which pressure difference of restricted flow is measured and it is proportional to square of flow rate.



Averaging pitot tube (Annubar)

- **Velocity type flow meter**

  Turbine flow meter measures flow rate when fluid passes through a rotor, makes it rotating with an angular velocity that is proportional to linear velocity or volumetric flow rate of the fluid. A magnetic pick up coil measures the rotor velocity with the help of an equivalent frequency signal. Turbine blades are made of magnetic material with plastic covering. It is used to measure flow rate of clean fluid such as gasoline. It is accurate but expensive.



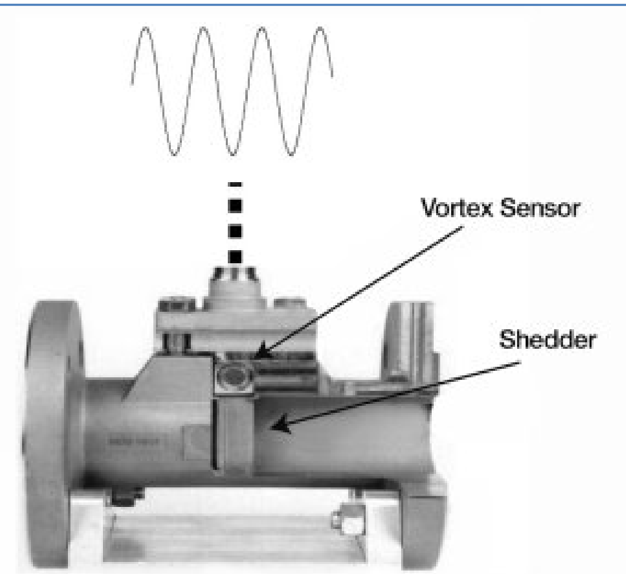
Pulse in
Cycle/time

$$K = \frac{\text{Cycle/time}}{\text{Volum/time}} = \frac{\text{Pulse}}{\text{Volumetric flow rate}}$$

K=Meter co-efficient

Turbine flow meter

Vortex shedding device measures flow rate of fluid based on the turbulence or vortices produced by an obstruction or bluff body in fluid or gas flow. Swirling motion produced by the vortices is measured by ultrasonic or pressure sensor in terms of frequency of the vortices which is proportional to flow rate.

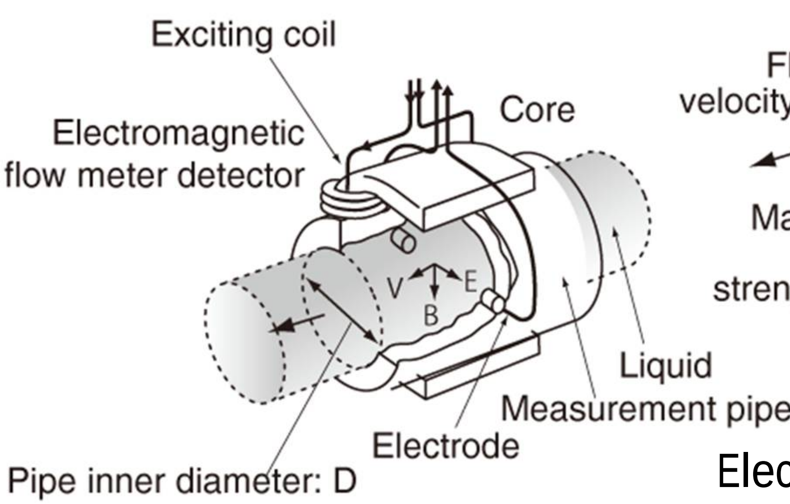


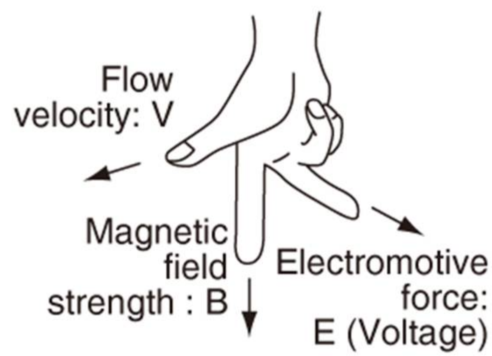
Vortex shedding device

Electromagnetic flow meter is made of a non magnetic measuring tube that contains the flowing fluid of dielectric in nature. A magnetic coil surrounding the tube produces magnetic field across the width of the tube when an electric current is applied. When the dielectric fluid moves through the magnetic field a voltage is generated that is proportional to volumetric flow rate. The voltage is measured by two electrodes placed in diametrically opposite sides of the tube, that is proportional to the magnetic field and direction of the flowing fluid. Negative flow rate or flow rate in opposite direction of the flow can be measured. It measures only the liquid phase flow, no gas or air flow can be measured.

Faraday's law $$Q = \frac{EC}{BD}$$

C=meter constant; *E*= Electric field; *B*=Magnetic field strength
D=Tube diameter; *Q*= Volumetric flow rate of fluid





Electromagnetic flow meter

Ultrasonic flow meter is a transit time flow meter based on Doppler effect. Two transducers and two receivers are mounted diametrically opposite to each other forming two pairs (A & B) which are inclined at an angle of 45° to the axis of the pipe. The transducers transmit ultrasonic beam (frequency 1 MHz) produced by a piezoelectric crystal. The signal is received by an receiver on the other side of the pipe. The difference of transit time of the two beams based on the Doppler effect is used to measure average velocity of the fluid passing through the pipe. It measures velocity of dispersed gas, vapor, and solid, particles in the liquid.

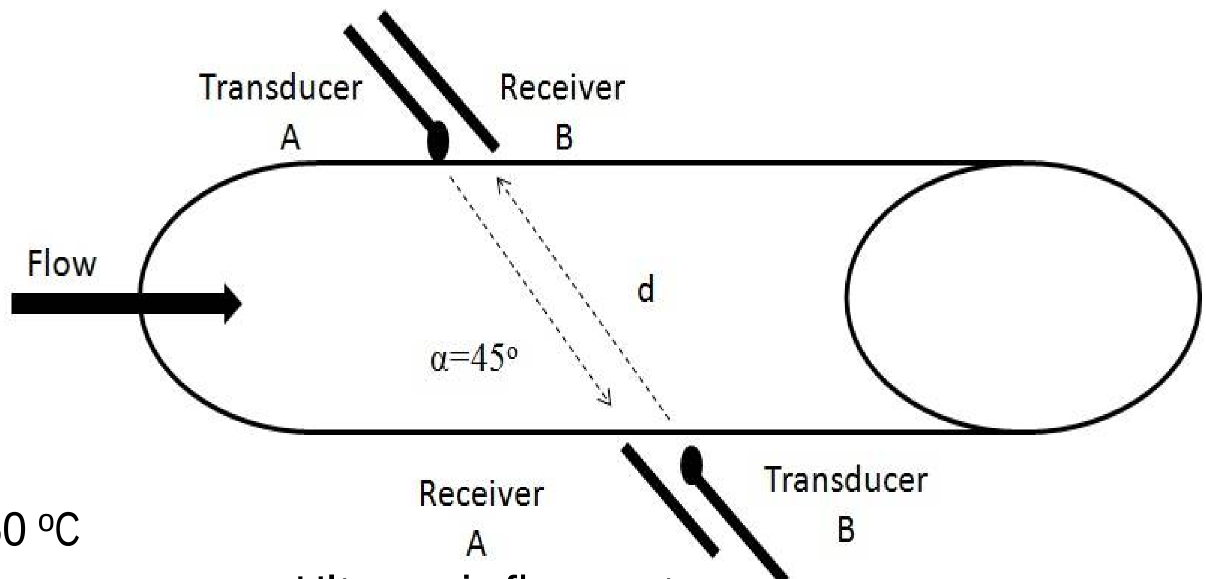
V_s=Velocity of sound
V=Average velocity of liquid

$$f_A = \frac{V_s - V\cos\alpha}{d};\ f_B = \frac{V_s + V\cos\alpha}{d}$$

$$df = f_B - f_A = \frac{2V\cos\alpha}{d}$$

df is bit frequency is converted to an electric signal that is proportional to average flow rate. It nullifies the density and temperature effect on the velocity measurement.

Temperature range -20 °C to +250 °C and accuracy of ±5% FSD.



Ultrasonic flow meter

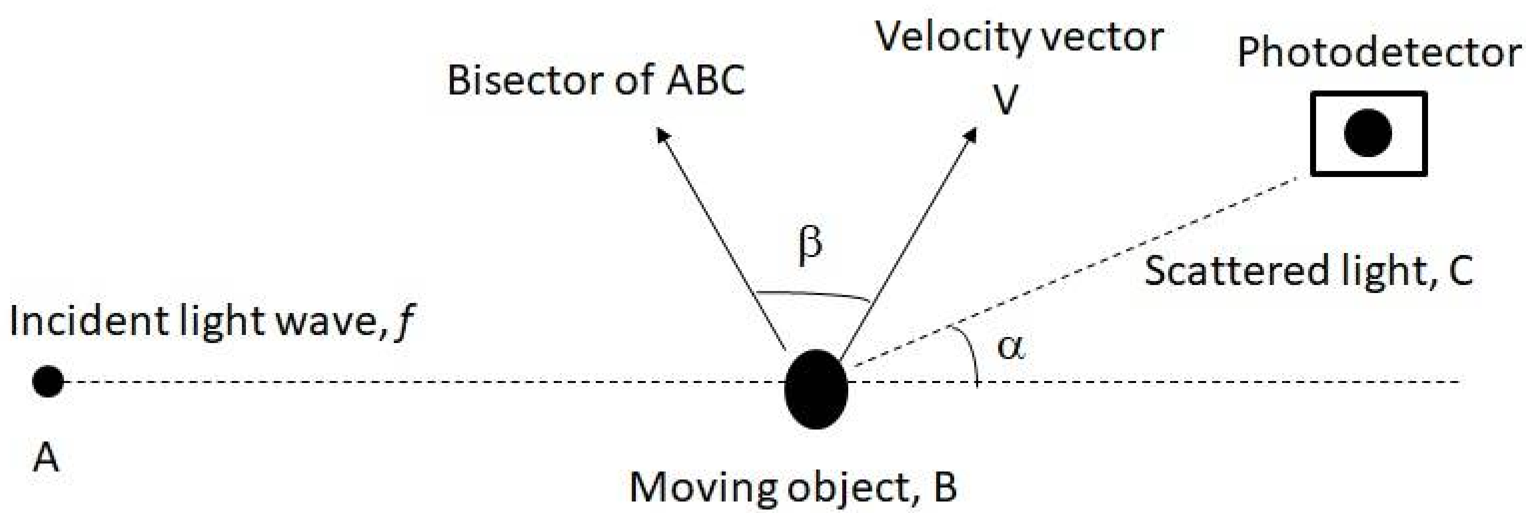
Laser Doppler anemometry measures velocity of a moving object in a liquid medium such as, vapor, gas, solid particles dispersed in a liquid based on Doppler shift that is the difference between incident laser light frequency and scattered (by the moving object) laser light frequency. The frequencies are measured by a photodetector or photomultiplier tube that generates current in proportion with absorbed photon energy.

$$f - f_o = f_d = \frac{2V}{\lambda}\cos\beta\sin\frac{\alpha}{2}$$

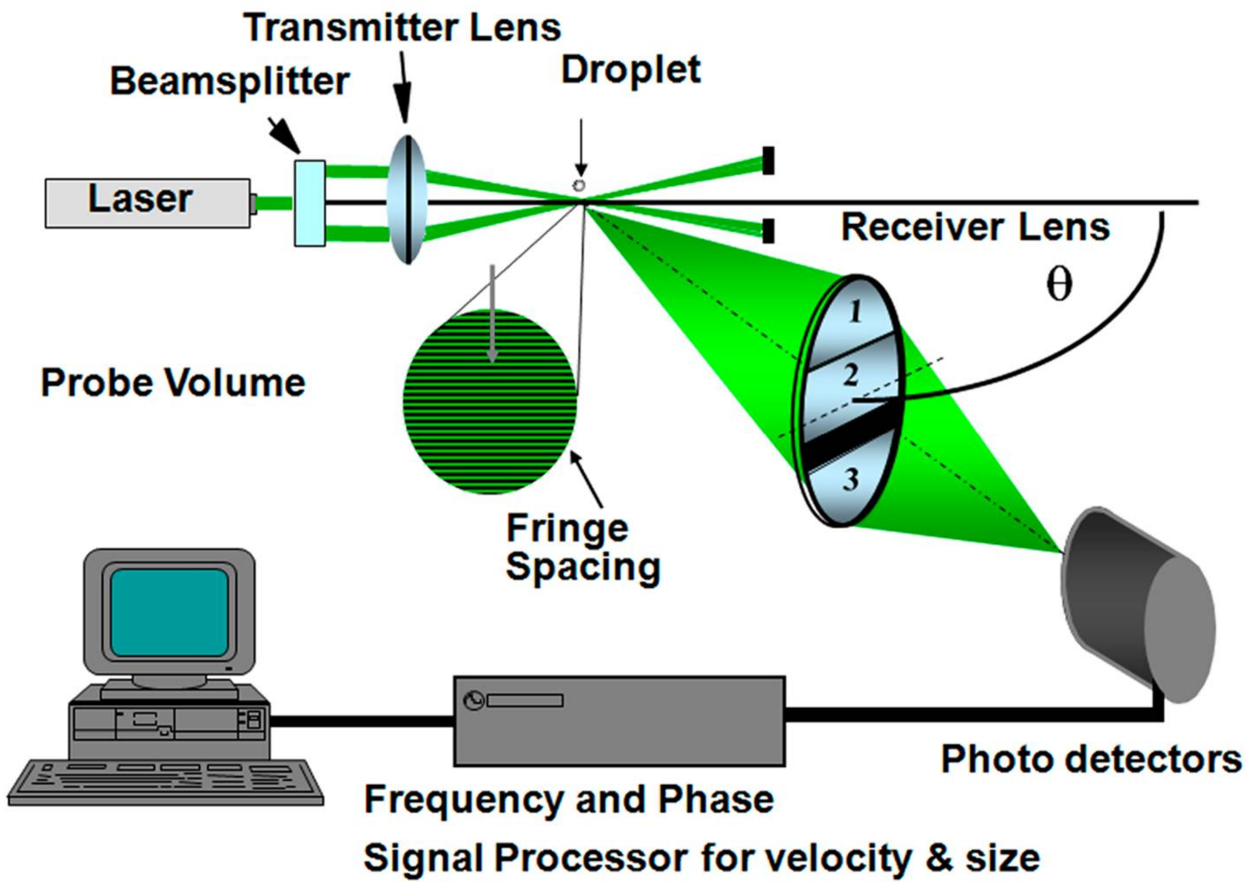
V=velocity of the object; λ=Wavelength of laser light

β= Angle between velocity vector and bisector of ABC.

α=Angle between incident light and photodetector



Laser Doppler anemometry



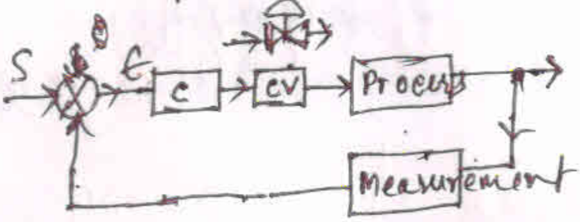
Droplet velocity measurement using laser Doppler anemometry

Reference

- Hughes T.A., Measurement and control basis, 3rd eds., ISA, 2002.
- Dunn, W.C., Introduction to Instrumentation, Sensors, and Process Control, ARTECH HOUSE, INC, 2006.
- Coughanowr, Process Systen Analysis, MGH.

Control valve

Process control consists of three elements: measurement, evaluation and final control. Final control elements are control valve, motor, pump. These are most important because their direct connectivity to process.

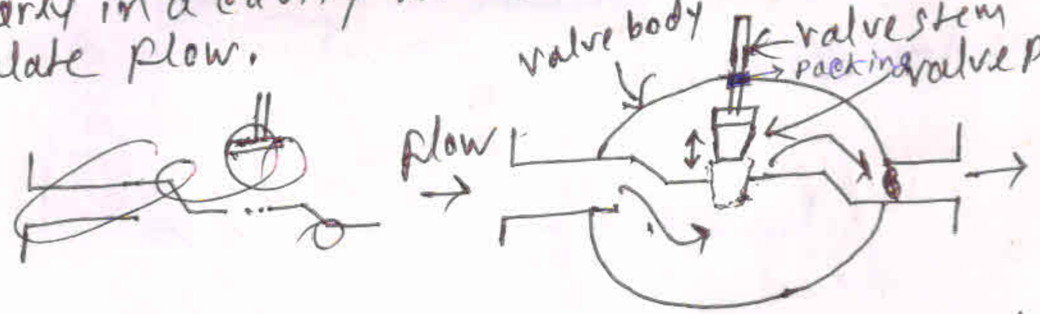


C is controller/evaluation
CV is control valve or final control element.

control valve is a variable orrifice that is used to regulate the flow of a process according to the requirement of the process. An actuator is connected to the valve's plug stem and moves the valve between the open and closed positions to regulate flow in the process. The valve body is mounted in the process fluid line to control the flow of fluid in the process.

Most common types are globe, gate, diaphragm, butterfly, and ball valve.

In globe valve, the plug is attached to stem, which is moved linearly in a cavity with a somewhat globular shape to regulate flow.



Globe valve.

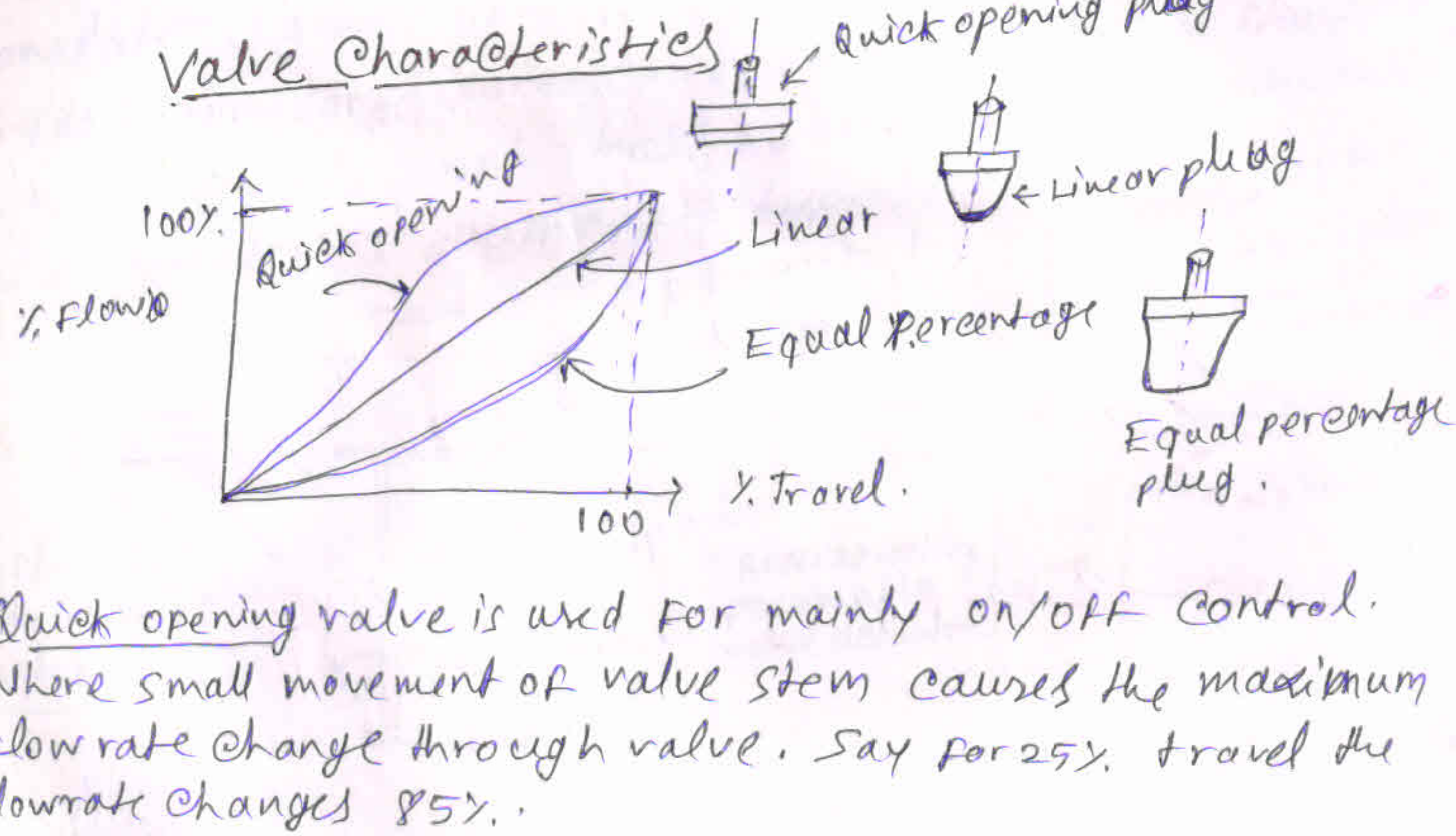
In gate valve, a flat or wedge-sphaped plate is moved into or out of the flow path to control flow. Used for manual on/off service, few designs are used in throttling service.

Diaphragm valve are linear motion valves with flexible diaphragms that serve as flow closure chambers. Used for corrosive liquid and slurries. Valve body is lined with glass, plastic or teflon. Diaphragm is made of rubber, teflon etc.

Butterfly valve are rotary motion valve which is available in wider size ranges (1½" – 200"). In vary large pipe sizes, the butterfly valve is only cost-effective valve.

Ball valve is also rotary motion valve. A sphere closes the internal passageway of fluid. It gives tight shut-off. It is now used in on/off service for batch process.

Valve Characteristics



Quick opening valve is used for mainly on/off control. Where small movement of valve stem causes the maximum flow rate change through valve. Say for 25% travel the flowrate changes 85%.

Linear valve: Flowrate varies linearly with the position of the stem.

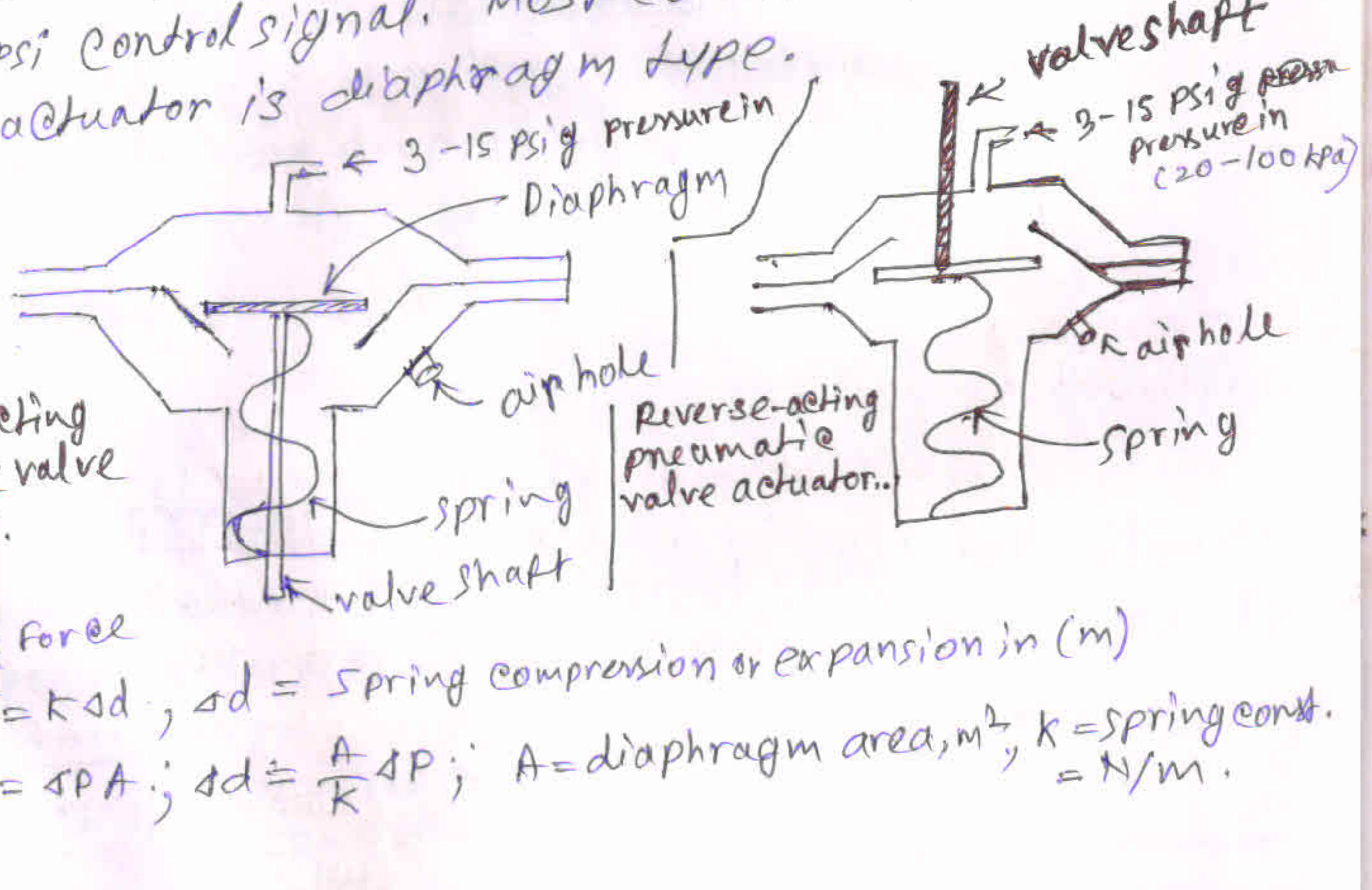
$$\frac{Q}{Q_{max}} = \frac{X}{X_{max}}$$ Q and X are flowrate and stem position respectively.

Equal percentage valve: For a given percentage change in stem position, the equal percentage change of flow rate occurs. This type of valve does not shut off the flow completely in its

Rimit of travel. There rangability term is defined by
$R = Q_{max}/Q_{min}$.

Control valve actuator.

It transmits signal from controller (normally 4 to 20 mA or 3 to 15 psi) into large force or torque that is needed to manupulate a valve. Actuators are Electronic type and pneumatic type. Electric motor actuators are used to control the opening & closing of smaller rotary-type valves such as, butterfly valves. The pneumatic actuators are used more widely because it can effectively translate a small control signal into a large force or torque. vary large force can be developed by the standard 3-15 psi control signal. Most common type of pneumatic valve actuator is diaphragm type.



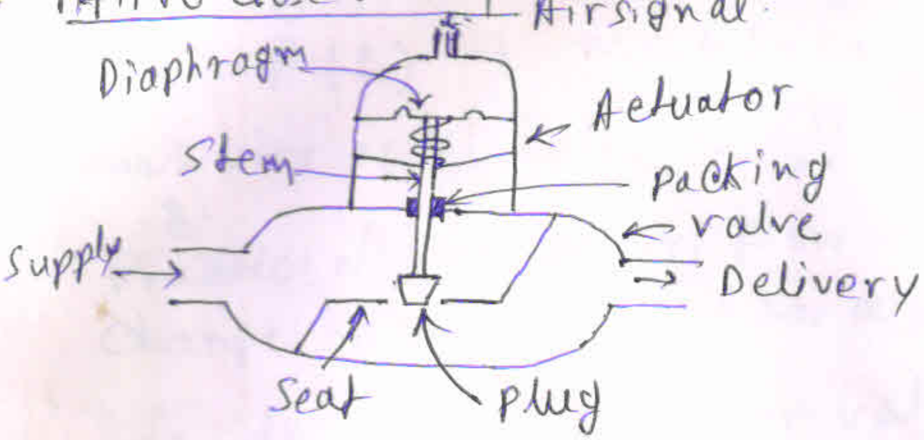
Direct-acting pneumatic valve actuator.

Reverse-acting pneumatic valve actuator..

$F = k\Delta d$ (F → force), Δd = spring compression or expansion in (m)

$\Rightarrow F = \Delta P A$; $\Delta d \doteq \frac{A}{K}\Delta P$; A = diaphragm area, m^2, k = spring const. = N/m.

* **Air to close valve**



Valve sizing

To specify the size of a valve in terms of capacity to provide flow when fully open

$$q = C_v\sqrt{\frac{\Delta P_v}{G}} \longleftrightarrow \text{For fully open valve}$$

$$\Rightarrow \quad q = C_v\, f(x)\sqrt{\frac{\Delta P_v}{G}} \Rightarrow \text{For partially open valve}$$

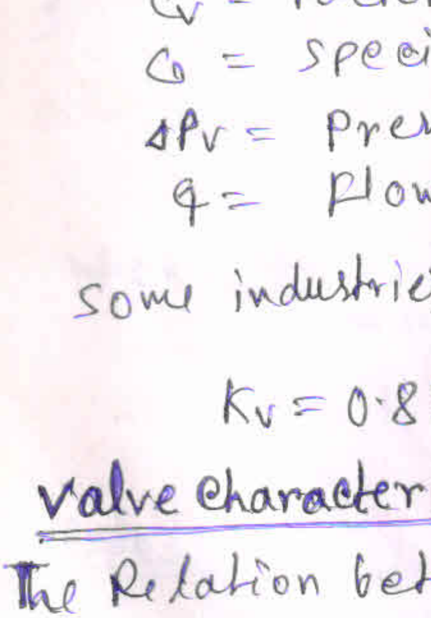
C_v = Factor associated capacity of a valve.
G = specific gravity, water $G = 1$.
ΔP_v = Pressure drop across wide open valve, psi
q = flow rate, gpm.

Some industries use $q = K_v\sqrt{\frac{\Delta P_v}{G}}$, $q = m^3/hr$.
$\Delta P_v = kgf/cm^2$
G = S.P. Gravitity.

$K_v = 0.856\, C_v$.

Valve characteristics

The Relation between the flow through valve and valve stem position (or lift is called valve characteristics)



I = Linear
II = Equal percentage
III = quick opening valve.

$q = f_1(L, P_0, P_1)$.
L = Stem position
P_0 = upstream pressure.
P_1 = Downstream Pressure.

$m = q/q_{max}$, $x = \frac{L}{L_{max}}$

when P_0, P_1 are fixed

When P_0, P_1 are fixed
$q = f(L) \Rightarrow m = f(x)$.
Sensitivity of the valve $= \frac{dm}{dx}$.
Fractional change in flow to the fractional change in stem position for fixed P_0, P_1.

$\therefore \frac{dm}{dx} = \alpha \rightarrow$ For linear valve, $\alpha = 1 \Rightarrow$ $\underline{m = x}$.
For equal percentage valve $m = m_0 e^{\beta x}$.

For equal percentage valve
$$\frac{dm}{dx} = \beta m.$$
$$\therefore \frac{m}{m_0} = e^{\beta x}. \quad x = 0;\ m = m_0.$$

Ex $C_v = 4.0$, flow of glycerine $G = 1.26$.
$\Delta P_v = 100\,psi$.
$$\therefore q = 4.0\sqrt{\frac{100}{1.26}} = \underline{35.6\ gpm} \quad \text{Maximum flow}$$
When it is 0.80% flow for linear valve.
$\therefore m = x \therefore x = 0.8$
$$\therefore q = 4.0 \times 0.8\sqrt{\frac{100}{1.26}} = 35.6 \times 0.8\ gpm$$

Problem
$$\Delta P_l = \frac{32 f L \rho q^2}{144 \pi^2 g_c D^5}.$$ pressure drop in line (~~total drop~~).

*Assume flow rate q
$$Re = \frac{DV\rho}{\mu} = \frac{4 q \rho}{\pi \mu D}.$$
$\therefore Re \rightarrow$ calculate friction factor and hence ΔP_l is calculated.
$$\therefore \Delta P_v + \Delta P_l = \Delta P_T.$$
$$\therefore \Delta P_v = \Delta P_T - \Delta P_l.$$

Calculat $q_{max} = C_v\sqrt{\frac{\Delta P_v}{G}}$

$x = \frac{q}{q_{max}}$ For linear valve.

For equal percentage valve

m_0 is given.

$\beta = \ln\left(\frac{1}{m_0}\right)$

$\therefore m =$ calculated as above steps. assuming q.

$\therefore = q/q_{max}$.

$\therefore x = \frac{1}{\beta} \ln \frac{m}{m_0}$

$dm = m_0 e^{\beta x} dx$

$= m_0 e^{\beta x} \beta dx$

$\frac{dm}{m} = \beta dx$

$m = \left(\frac{1}{m_0}\right)^{x-1}$

$\boxed{m = m_0 e^{\beta x}}$ $\ln \frac{m}{m_0} = e^{\beta x}$

$e^{\beta x} e^{-\beta} = m$

$\ln m = (x-1) \ln \frac{1}{m_0}$

$= (x-1)\beta$

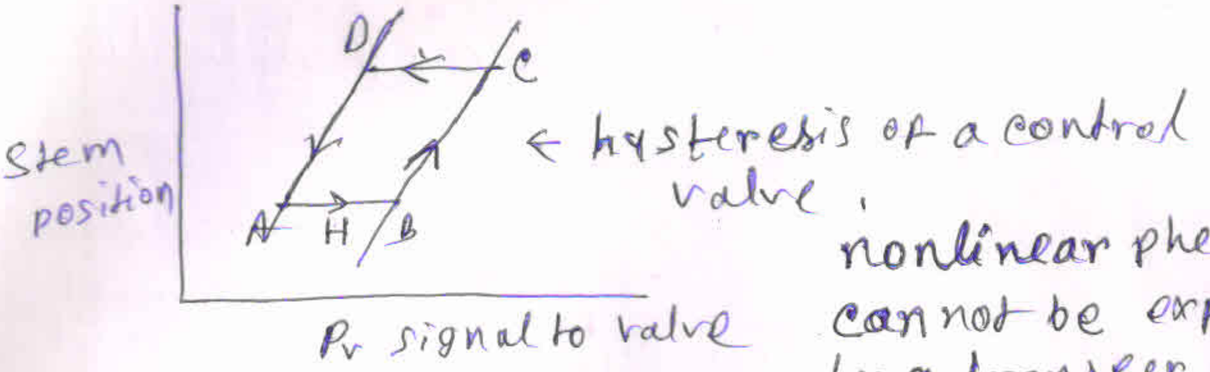
Now these steps are repeated for various q and ϕ corresponding x are obtained.

Benifit of an equal percentage valve

It has inherent non linear characteristics for the line loss to give an effective ~~characteristics~~ valve characteristic. that is nearly linear.

one can show that as the line loss increases, the linear valve will depart more from the ideal linear relation and the equal percentage valve will move more closely towards the linear relation.

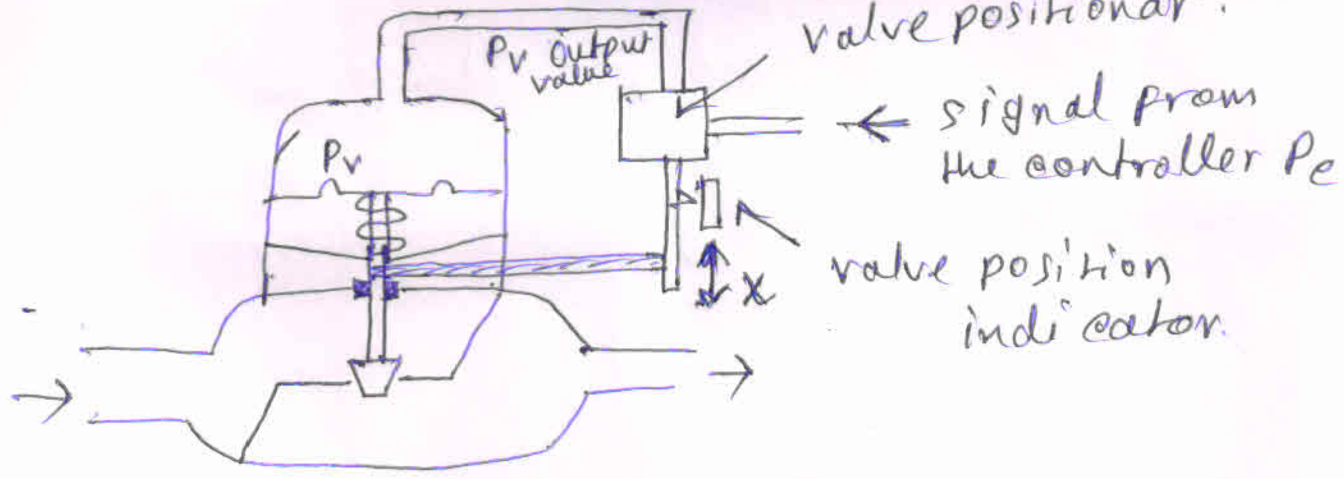
Valve positionar: The friction in the packing and guiding sufaces of a control valve to exhibit hysteresis., where valve is subjected to periodic variation of pressure.



nonlinear phenomena cannot be expressed by a transfer function.

It is not a dynamic lag ~~whi~~ that is caused by resistance to flow of air to valve top, inertia of the valve stem and plug. and is expressed by 1st order or second order ~~transfer~~ function.

To eliminate hysteresis valve positionar is used.



Valve positionar