22/10/19

INSTRUMENTATION

Components of a process : (Control system)

1. Sensor
2. Comparator & controller.
3. Final Control element.

SENSOR :

a. Temperature
b. Pressure
c. Flow rate
d. Concentration — (most difficult to measure)
e. Liquid level

Temperature :

i) ~~Thermostat~~
ii) Thermometer - liq filled
ii) Thermocouple
iii) Resistance Temp. Detector } low temp
iv) Semiconductor
v) Bi - metalic
vi) Radiation Pyrometer } high
vii)

Pressure

i) Manometer
ii) Diaphragm cell
iii) Bourdon Tube
iv) Bellows
v) Strain gauge
vi) Piezo (crystals respond electrically to pressure).

Flow

i) Orifice —"—
ii) Venturi meter
iii) Variable area meter (Rotameter) } works for clean liquid → digital display
iv) Pitot tube
v) Hot wire anemometer — high precision
vi) Ultrasonic flow meter (large pipelines)
vii) Coriollis meter — (measures mass flow rate directly)

crystals of hydrocarbons along with (Gas) hydrocarbons

d) Level

i) Float ii) Optical / Conductivity & sonic measurements

e) Composition

i) Chromatography – long time for analysis

ii) Turbidimetry

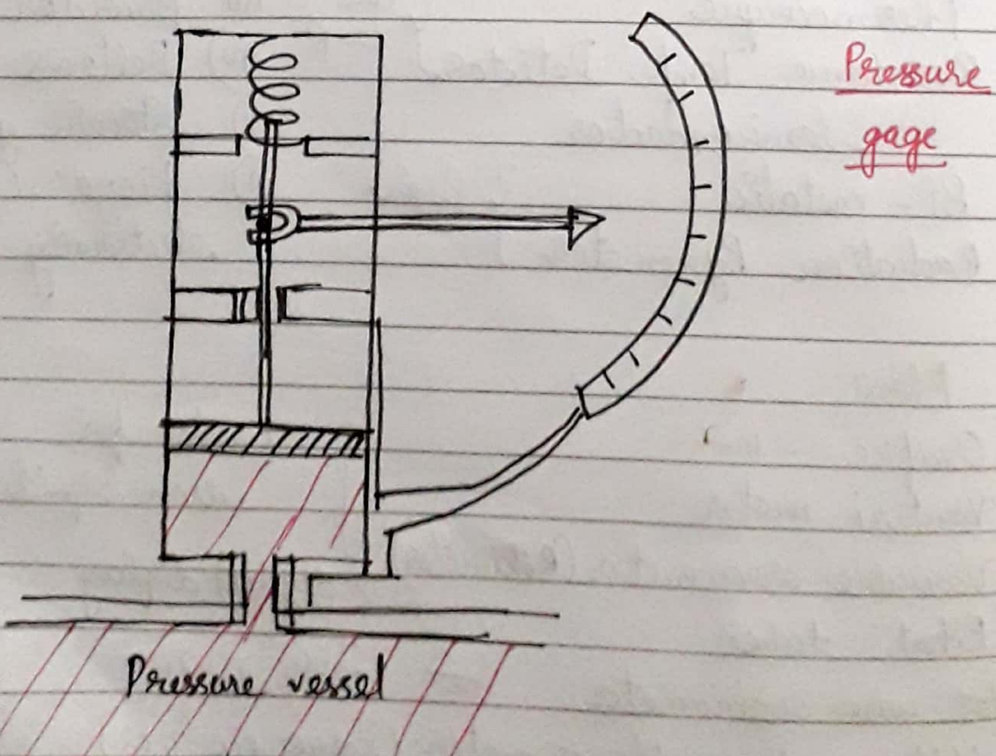
iii) pH measurement / electrical conductivity

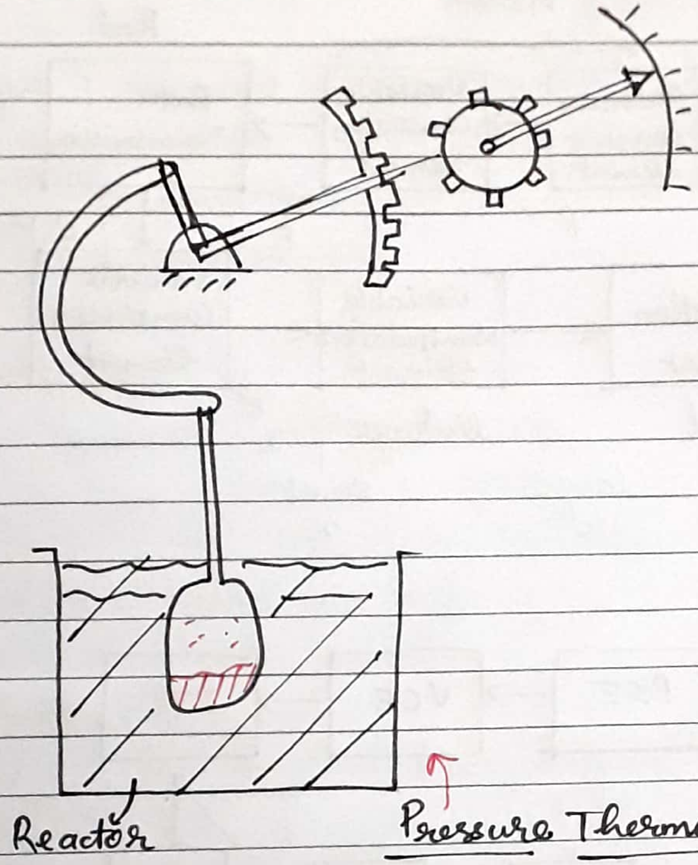
iv) optical measurement / polarization of light

1. Measurement System Application & Design by E.O. Doeblin } Ch-2 (Pg 13-38) Ch-3 (Part)

2. Coulson & Richardson (vol-?)

Functional Elements of a measuring Instrument





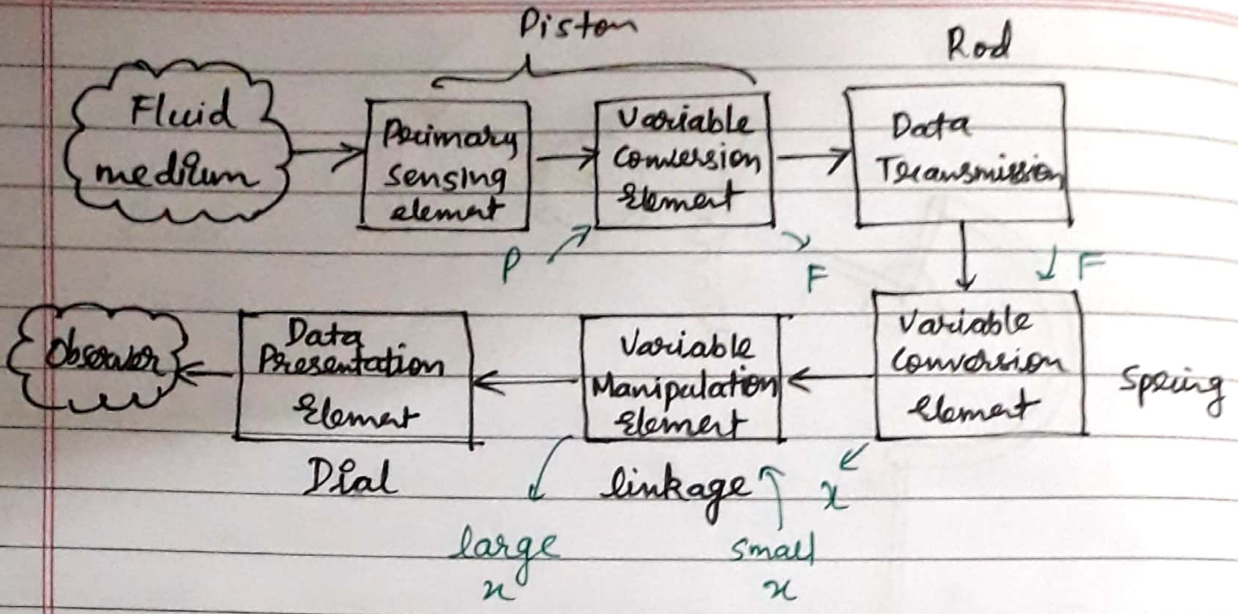
Pressure Thermometer

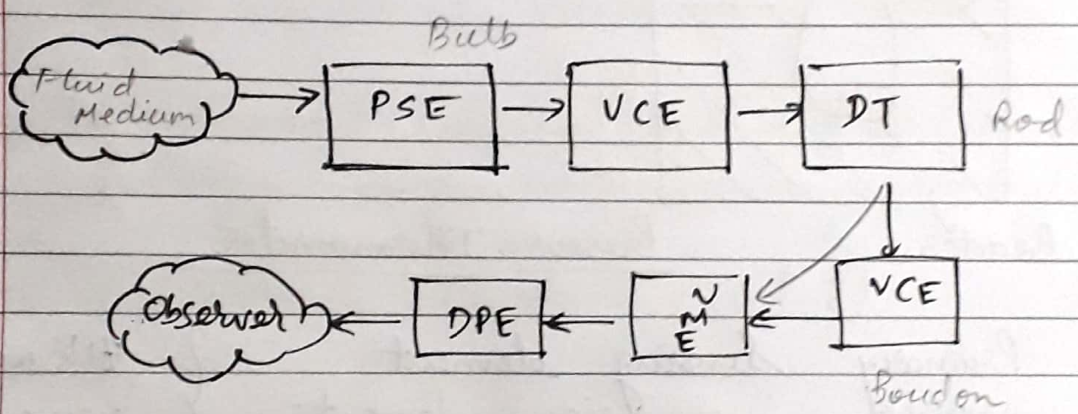
ⓐ Primary Sensing element
ⓑ Variable conversion element
ⓒ Variable Manipulation element.
ⓓ Data transmission element
ⓔ Data presentation element.

It's not necessary they have to be in this sequence always.

★ all measurement devices - disturb the system

ⓐ PSE — piston for pressure gauge.
— bulb Pre. The
ⓑ VCE — pressure to force
ⓒ VME — Boudon tube - manipulates (magnify displacement) of ~~pito~~ needle
ⓓ DTE - transmitting data — without conversion and manipulation
ⓔ DPE - human readable version.





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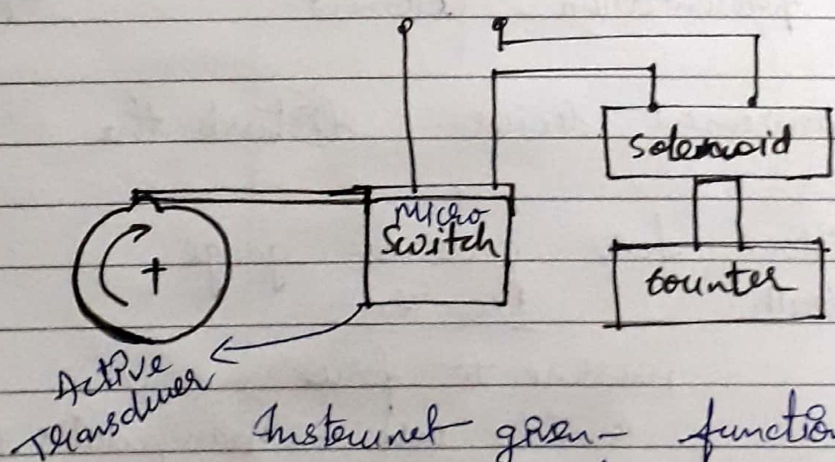
Mechanical Counter



Identify
Instrument given - functional elements ?
PSE → Rod → DT In exam
↓
Variable Conversion

Switch :

Majority of PSU are of analog type.

For this – Revolution counter – digital instrument

Wires	Solenoid :-	Counter	Switch (Mech to Elec)
Data transmission	Variable Conversion	Data Presentation	Variable Conversion
	~~Counter :-~~		

counts the

Basic diffⁿ -> Press thermo.   Mechai. Counts

extract energy from the system – Transducer/Transmitter

① Analog
② Digital
Modes of operation

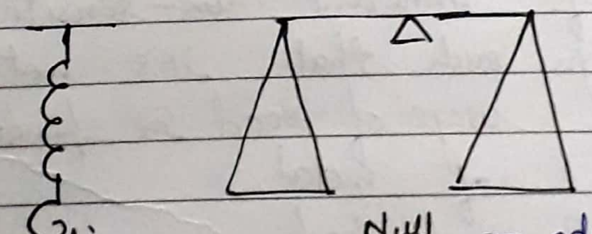
Transducer – take one type give out another

[Here transducer is not an energy conversion element.]

Transducer
- Active (Power source is needed)
- Passive → [output energy supplied entirely or almost entirely by its input signal.] (Power is drawn from the system)

Input signal supplies only an insignificant portion.

{binary (on/off) nature} ← Discrete – Digital
Continuous – Analog.



Deflection   Null – adv :- can measure slight amount of departure

D

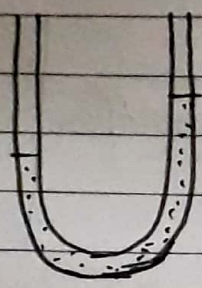
Input-Output Configuration

I → $\boxed{\Delta P = \Delta h \rho g}$ → O

Deflection-type device : The measured quantity produces some physical effect that engenders a similar but opposing -11- in some part of the instrument.

I = ΔP

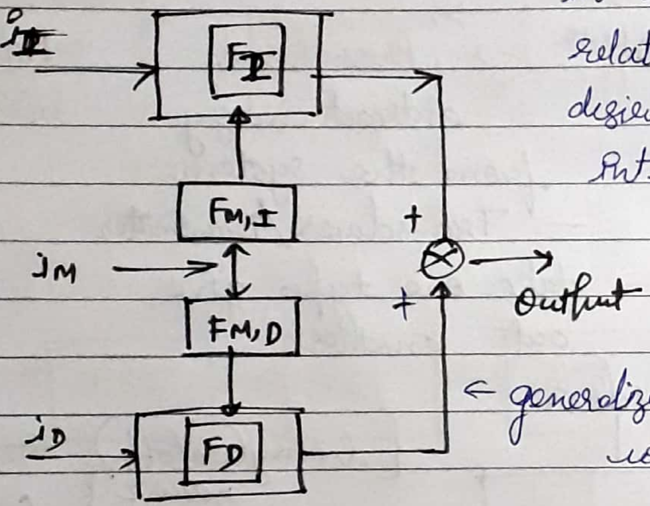
O = Δh



specifically intended to measure

① Desired input
② Interfearing input
③ Modifying input
↳ cause a change in the input-output relations for the desired and interfering inputs.

spurious



← generalized input-output configuration.

Instrument be inherently sensitive only for desired inputs.

Methods for correction of interfering & modifying (spurious) inputs

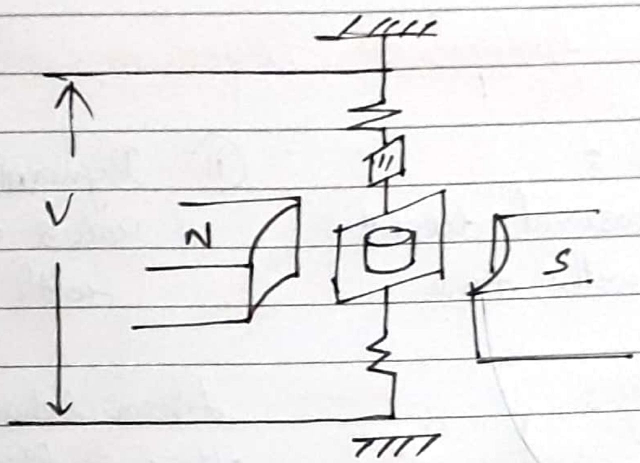
ⓐ Method of inherent non-sensitivity
- design such that it's not much sensitive
  e.g. usage of wood in pendulum instead of metal.

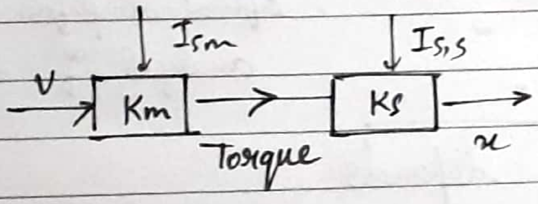
ⓑ High gain feedback
ⓒ Calculated output correction.
ⓓ Signal filtering — thermocouple → thermal insulation
ⓔ Opposing input. — if we can measure disturbance

vibration — spurious input

ⓒ → measure or estimate the magnitudes of interfering / modifying inputs and to know quantitavely how they affect the output.

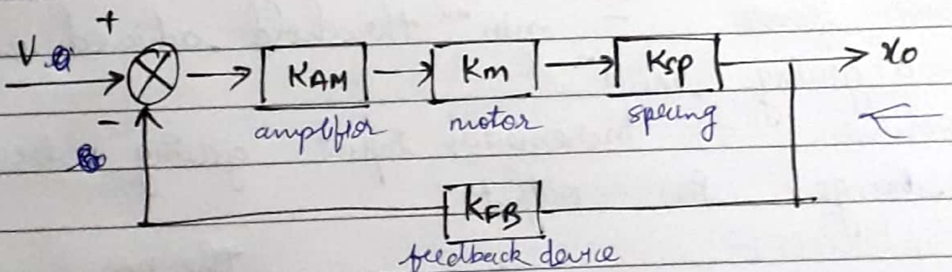
Null → Maintain deflection at zero by suitable application of an effect opposing that generated by the measured quantity.





— open loop

$$V(K_m)(K_{sp}) = x$$



High gain feedback

$$\cancel{V+} \quad \frac{x_o}{V} = \frac{1}{1 + K_{AM} K_m K_{sp} K_{FB}}$$

$$(V - K_{FB} x_o) \times K_{AM} K_m K_{sp} = x_o$$

$$V K_{AM} K_m K_{sp} = x_o + x_o K_{FB} K_{AM} K_m K_{sp}$$

$$\frac{x_o}{V} = \frac{K_{AM} K_m K_{sp}}{1 + \underbrace{K_{FB} K_{AM} K_m K_{sp}}_{\gg 1}}.$$

Improvements ⋆ feedback loop works for many cases.

then $\frac{x_o}{V} = \frac{1}{K_{FB}}$

Now we require only K_{FB} to stay constant

Adv. ① Amplifier supplies most of the power, ∴ feedback device can be designed with low power handling capacity → greater accuracy

Also input signal carry negligible power, ∴ feedback extracts less energy from measured medium

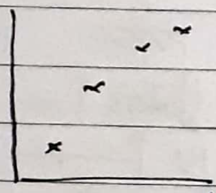
Signal filtering – Introducing certain elements into system which in some fashion block the spurious signals so that their effects are removed.

Generalised Performance Criteria

(i) Static :
value measured doesn't change with time

(ii) Dynamic :
values are changing with time.

(a) linearity :



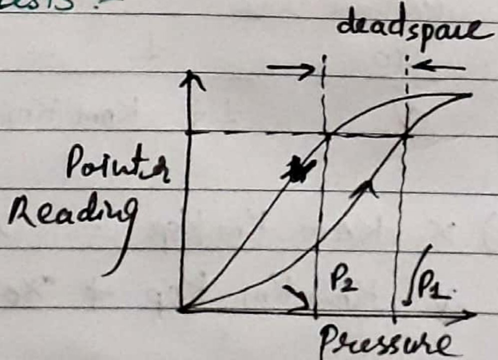
Linear behaviour of the parts often simplifies design and analysis of the whole.

(b) threshold : depends

(c) Noise floor – min^m threshold achieved under for a giving cond^n

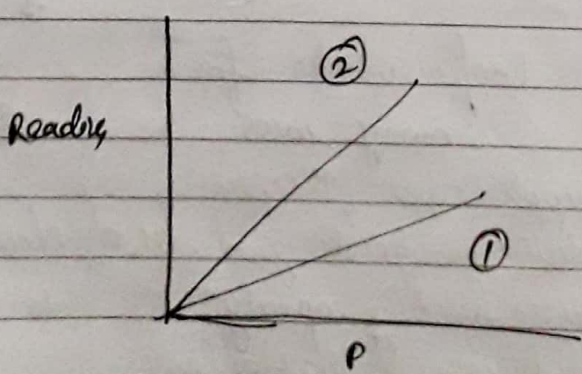
(d) Resolution :– Incremental input giving desired change in output.

(e) Hysteresis :–



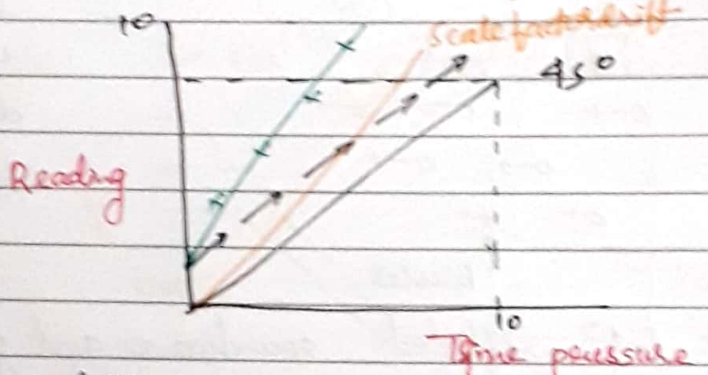
The non-coincidence of loading and unloading curves is due to internal friction or hysteretic damping of the stressed parts

(f) Static sensitivity



Opposing effects — Intentionally introducing into the instrument interfering and/or modifying inputs that tend to cancel bad effects of spurious inputs.

Zero drift & Scale factor drift



→ Scale factor as well as zero

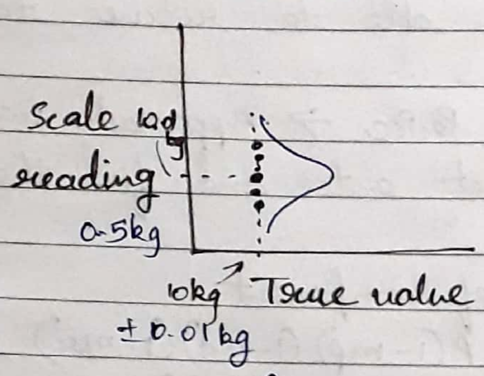
Zero drift

IPC

Date 24/10/19

Page

Calibration



Random variables →

All possible conditions (that may act as interfering or modifying inputs).

Ambient Temp = 20 ± 2°C

Level of Vibration :

Atmospheric P :

10 ± 0.01kg → Primary Std.

Trials	Reading	
1	10.02	
2	10.20	(std dev)
3	9.97	
4	10.20	
5	9.81	

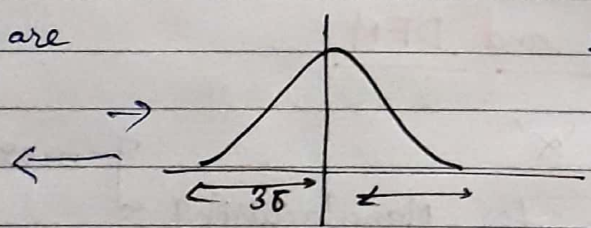
$\bar{x} = 10.04 \pm 0.39$ ← imprecision

$s = \cancel{0.147}$ (std dev)

0.165

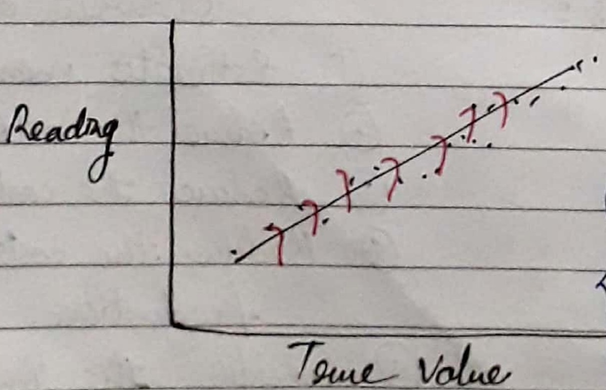
0.997 is probability the reading will be bet^n 10.04 − 0.39 & 10.04 + 0.39

We are

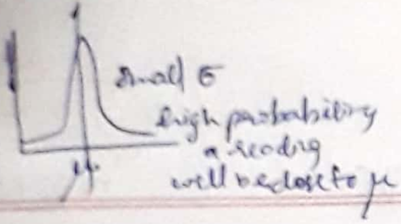


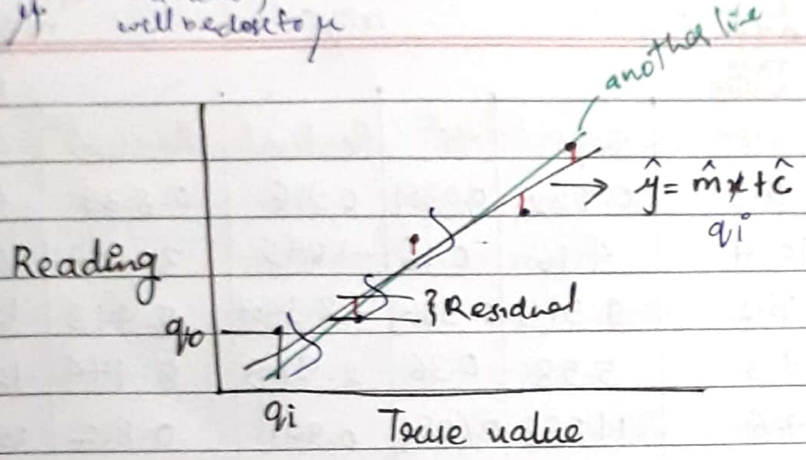
Bias = 10.04 − 10.0 = 0.04

Measure Scatter :



The straight line or the perfect Gaussian line "would be perfectly followed by data from an infinitely large sample of Gaussian data which had the same μ and σ values as our actual data sample





eq^n for straight line

$q_o = m q_i + c$

$$L = \sum (y_i - \hat{y})^2 = \sum_i (y_i - \hat{m}x - \hat{c})$$

$$\frac{dL}{d\hat{m}} = 0 \qquad \frac{dL}{d\hat{c}} = 0$$

$$m = \frac{N \sum q_i q_o - \sum q_i \sum q_o}{N \sum q_i^2 - (\sum q_i)^2}$$

$$c = \frac{\sum q_o \sum q_i^2 - (\sum q_i q_o)(\sum q_i)}{N \sum q_i^2 - (\sum q_i)^2}$$

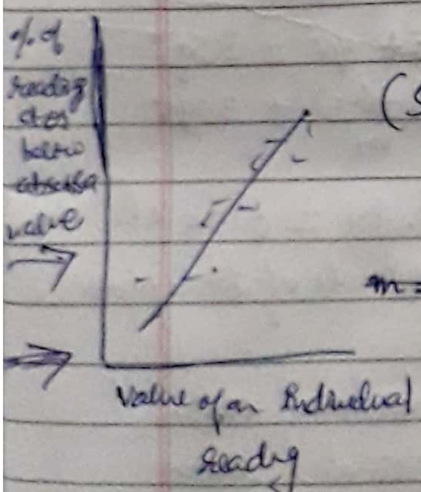
Slope and intercept has certain randomness, because those points fall within some distribution.

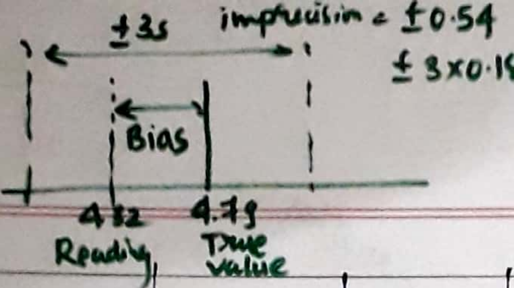
$$S_m^2 = \frac{N (S q_o)^2}{N \sum q_i^2 - (\sum q_i)^2} \qquad S_c^2 = \frac{(S q_o)^2 \sum q_i}{N \sum q_i^2 - (\sum q_i)^2}$$

$$(S q_o)^2 = \frac{1}{N-2} \sum [\underbrace{(m q_i + b) - q_o}_{\text{Residual}}]^2$$

$$\cancel{m = 6} \quad (S q_i)^2 = \frac{1}{N-2} \sum \left(\frac{q_o - b}{m} - q_i \right)^2$$

$$= \frac{\sum \text{Residual}^2}{m^2}$$





mq_i $\quad$ mq_i+c $=$ $\hat{a}$

	q_i	q_o	q_iq_o	q_i^2	Residual	Residual^2	$\hat{a}$
1	0.19	3.8	0.722	0.0361	0.916	0.839	4.716
2	0.40	10.4	4.16	0.16	-1.895	3.404	8.5549
3	0.63	15.1	9.513	0.3969	-2.3407	5.478	12.7593
4	0.6	9.3	5.58	0.36	2.9109	8.474	12.2109
5	0.78	14.6	11.388	0.6084	0.901	0.812	15.5013
6	1.05	20.9	21.945	1.1025	-0.463	0.214	20.4369
7	1.74	31.3	54.462	3.0276	1.75	3.062	33.0501
8	1.62	32.7	52.974	2.6244	-1.843	3.396	30.8565
	Σ 7.01	Σ 138.1	Σ 160.744	Σ 8.3159		Σ 25.679	Σ 138.08

$c = 1.2428$

$s_m = 1.4034$

$s_c = 1.3137$

$$m = \frac{8 \times 160.744 - 7.01 \times 138.1}{8 \times 8.3159 - (7.01)^2}$$

$m = 18.28$

$\boxed{s_{q_i}^2 = 0.0768}$

$$c = \frac{138.1 \times 8.3159 - 160.744 \times 7.01}{8 \times 8.3159 - (7.01)^2}$$

$c = 1.2429$

frequency range from 0 to 1

$$\frac{c.f - 0.5}{8}$$

$$Z = \frac{x-\mu}{\sigma}$$

C.f – cummulative frequency

Uncertainty ?? Bias

Probability plot

-	C.f	
-0.91	1	0.0625
1.85	2	0.1875
2.34	3	0.3125
-2.91	4	0.4375
-0.90	5	0.5625
+0.46	6	0.6875
-1.75	7	0.8125
+1.84	8	0.9375

→ eg if $q_o = 4.32$ kPa

To determine ~~q_i~~ True value

$= q_i \pm 3s_{q_i}$

$= \dfrac{q_o + (-c)}{m} \pm 3s_{q_i}$

$= 4.79 \pm 0.54$ kPa

estimate of true pressure

☆ error due to ~~bias~~ imprecision – random error

☆ bias is also called systematic error

31/10/19

Measurement Equipment (Selection & Functioning)

Transmitter

Electric signal → vibrating

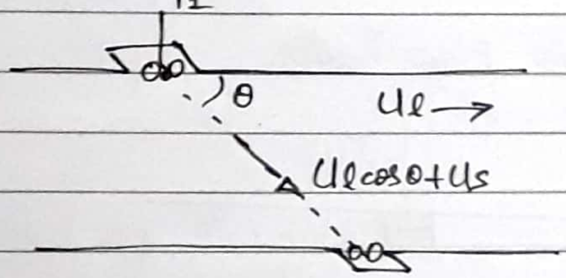
↓

carried by fluid

↓

vibrations felt → produce electric signal

receiver



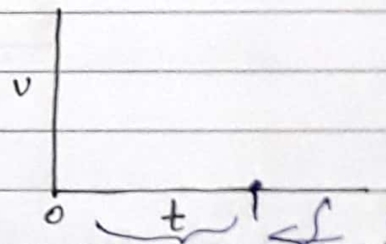
Time of Flight

Ultrasonic

This method is not dependable on the particles in the fluid

Velocity of sound $= U_s$

liq $= u_l$

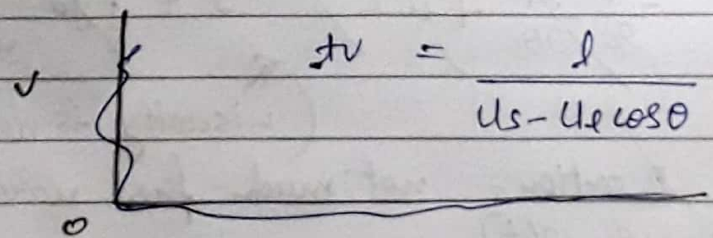


$\left[\frac{l}{u_l\cos\theta + u_s}\right]$

Pressure fluctuation (sound) → propagates to 2nd Piezo

at $t=0$ ~~no~~ pressure → to voltage P_1

P_2 receives voltage sends pressure signal

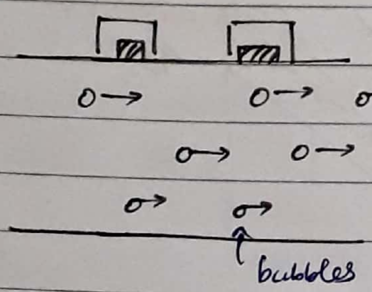


$$t_U = \frac{l}{u_s - u_l\cos\theta}$$

$$\frac{t_U}{t_d} = \frac{u_s + u_l\cos\theta}{u_s - u_l\cos\theta}$$

★ By measuring frequency shift between the ultrasonic frequency source, the receiver and fluid carries, the relative motion are measured.

Doppler

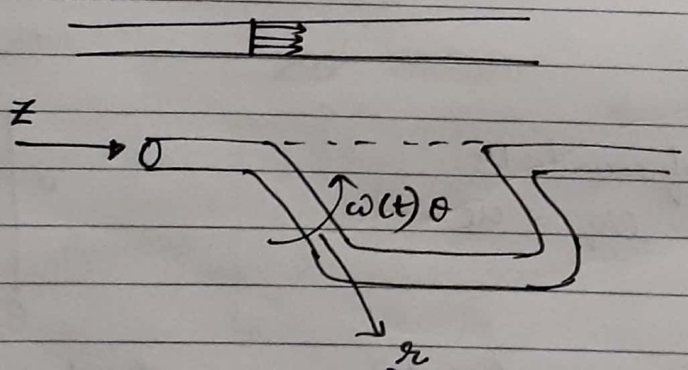


– will not work for clean liquid.
works for dirty liquid.

Diff^r bet^n reflected soundwave and generated soundwave.

2 phase flow – mass flow meter

Coriolis Flow meter



$\rho V_r \Leftarrow$ mass flow rate

$$\rho\left(\cancel{\frac{\partial V_\theta}{\partial t}} + \overbrace{V_r \frac{\partial V_\theta}{\partial r}}^{V_r\,\omega(t)} + \frac{V_\theta}{r}\cancel{\frac{\partial V_\theta}{\partial \theta}} + \overbrace{\frac{V_r V_\theta}{r}}^{V_r\,\omega(t)} + \cancel{V_z \frac{\partial V_\theta}{\partial z}}\right)$$

$$= -\frac{1}{r}\cancel{\frac{\partial P}{\partial \theta}} + \mu\,[\cancel{\quad}] + \cancel{\rho g_\theta}$$

~~The swinging is generated by vibrating the tube in which~~

(viscosity is neglible) no gravity

θ section – not much press. variation

$V_\theta = r\,\omega(t)$

Twist $\propto$ mass flow rate

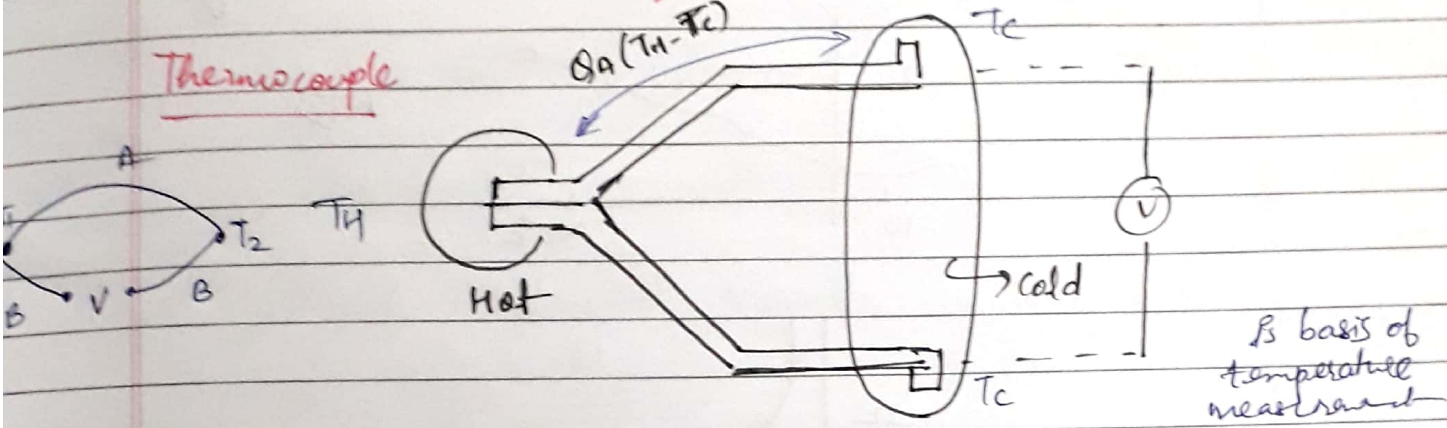
* Selection of instrument for given

* Coulson Richardson

Date 4/11/19

Measurement of temp

Thermocouple



Seebek effect – Relation betn voltage and Temperature T_H, T_C ↑

One end at hot junn and one at cold junn – there is voltage diffn

$$V = \int_{T_1}^{T_2} (Q_A - Q_B)\, dT = \alpha_{AB}(T_2 - T_1)$$

5μ V/m

* Voltage created by thermocouple is very small.
* It will measure temp diffn and not the absolute temp.

what is reference junction → need not be

Thermocouple requires reference temp.

Batting measuring

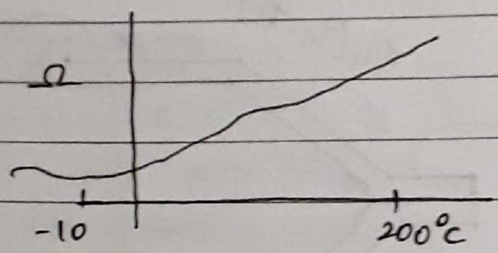
① Resistor Temp Detector (RTD) – high accuracy

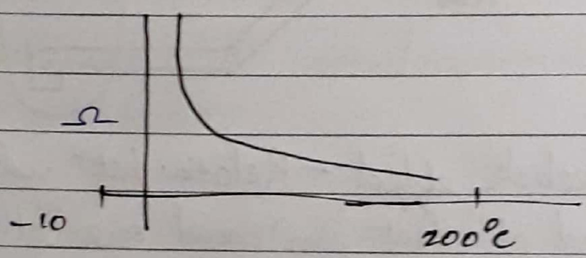
② Thermistor – a resistor whose resistance depends on temp – Linearity Sensitivity & Material/ Inertness

Types of thermocouple

①	J	Cu	Constantan	-100°C	1200°C
②	K				

Slope of Input - Output curve - sensitivity



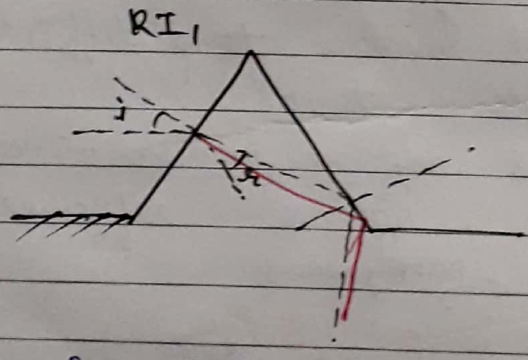


perimeter on a wall.

① Radiation Temp Detector - Infrared radiation at the T
② Thermopile. - thermocouple in series

Reaction Vessel

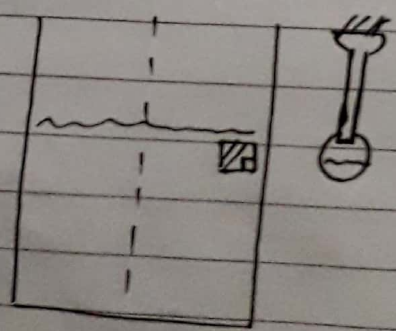
Online method



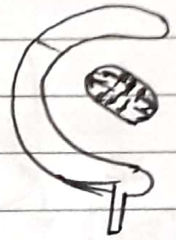
$RI_1 \sin i = RI_2 \sin r$

Location of laser spot is captured.

Level sensor



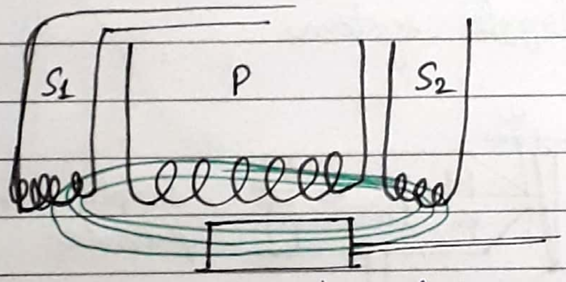
Which sensor



Voltage ⇄ Displacement

Displacement to voltage

Linear Differential Variable Transformer
L D V T



Coils in opposite dir^n emf in opp.

CoulsonRicha Vol 3 Chapter 6 — 15/11/19

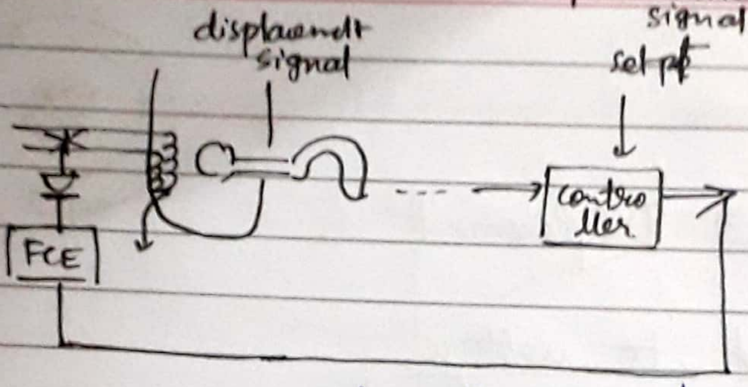
Types of thermocouple

J	iron	constantan (Cu + Ni + Mn)	−190 to 760
K	Chromel (Cr + Ni)	Alumel (Al + Ni + Mn)	−190 to 1260
E	Chromel	Constantan	−100 to 1260
T	Copper	Constantan	−200 to 371

Pneumatic :— air

Complete hardware of a pneumatic control system

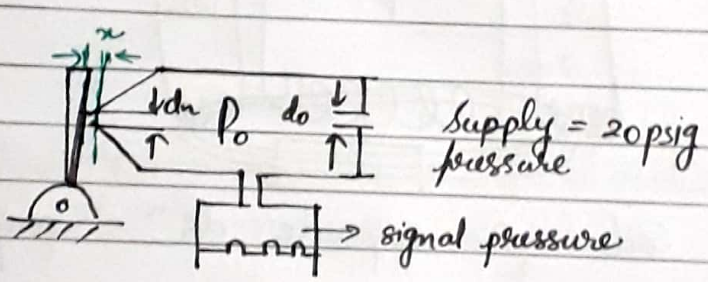
Pneumatic controls → use compressed air as the power source, are very simple and inherently analog making them ideal for controlling temp, humidity and pressure.



No voltage signal, everything - air pressure. 3-15 psi

① Sensor

② Flapper - Nozzle system



$\frac{1}{2}\rho v_1^2 + \rho g h_1 + P$

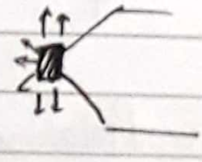
$u_n \to$ velocity at nozzle side

flow through orifice $\leftarrow u_o = \frac{C_o}{\sqrt{1-\beta^4}} \sqrt{\frac{2(P_s - P_o)}{\rho}}$

Bernoulli

$\frac{P_o}{\rho} = \frac{u_n^2}{2}$

Flow area : $\pi d_n x$



$u_n = \sqrt{\frac{2P_o}{\rho}}$

$\cancel{\rho}\frac{\pi d_o^2}{4}\sqrt{\frac{2(P_s - P_o)}{\rho}} = \pi d_n x \sqrt{\frac{2P_o}{\rho}}\ \cancel{\rho}$

$d_o^4\ 2(P_s - P_o) = (d_n x)^2\ 2P_o$

$2d_o^4 P_s - 2d_o^4 P_o = 2P_o(d_n x)^2 \times 4$

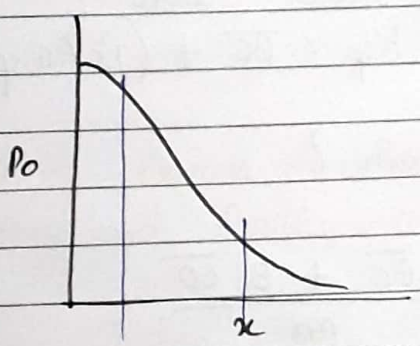
The hardware consists of pressure to electric transducers for analog inputs and motorized devices which accept digital outputs.

$$2 d_o^4 P_s = 2 d_o^4 P_o + 2 P_o (d_n x)^2 \times 16$$

$$d_o^4 P_s = P_o \left[d_o^4 + 16 (d_n x)^2 \right]$$

$$P_o = \frac{d_o^4 P_s}{d_o^4 + (d_n x)^2}$$

$$\frac{P_o}{P_s} = \frac{d_o^4}{d_o^4 + (x d_n)^2 \times 16}$$



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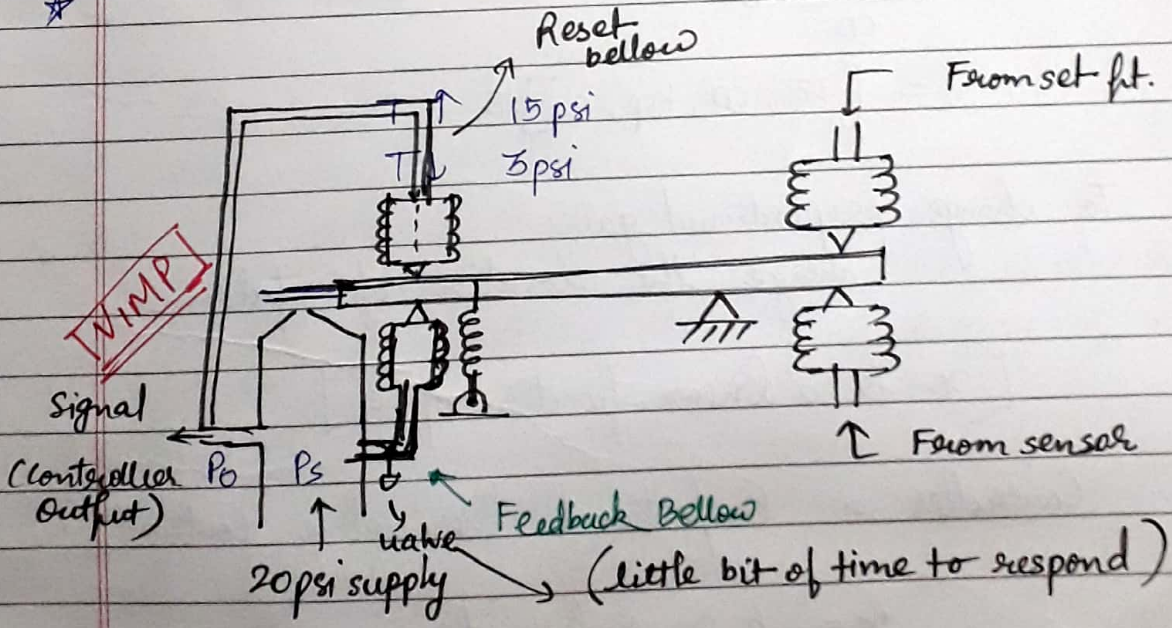
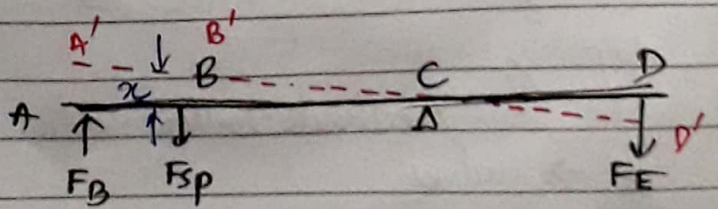




$$- F_B\, AC + F_{sp}\, BC - F_E\, CD = 0$$

$$- F_B'\, AC + F_{sp}'\, BC - F_E CD = 0$$

$$(F_B - F_{B0})AC - (F_{sp} - F_{sp0})\, BC + (F_E - F_{E0})\, CD = 0$$

$F \propto kx$ (spring)

$$A_B (P_o - P_{o,0}) . AC - K_{sp}.\, x . \overline{BC} + A_{B,E} . \epsilon = 0$$

↑ error signal

at steady state ∴ error

$$AB(P_o - P_{o,0})\, AC - K_{sp}\, x . \overline{BC} + (P_s A_{B,sp} - P_{sen} A_{B,sen}) . \overline{CD}$$

Proportional gain ?

$$\overline{P_o} = \frac{K_{sp} . x \overline{BC} + \varepsilon . \overline{CD}}{AB}$$

$$\frac{DD' BC}{CD} . \varepsilon$$

$$= [\overline{BC}, \overline{CD}, K_{sp}, AB]\, \varepsilon$$

To change proportional gain
change the location of fulcrum

[x is a linear function of ε]

Controller → Proportional Derivative Controller ?

$$P_o = k . \varepsilon + k \tau_d \frac{d\varepsilon}{dt}$$

15 psi →

Feedback bellow action delay slightly

τ_D → valve

$$P_o = k.\varepsilon + k y_{oi} \frac{d\varepsilon}{dt} + k \frac{1}{\tau_i} \int_0^t \varepsilon \, dt$$

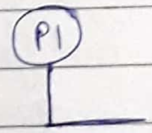
① how to relate x to ε?
② how the reset bellow acts as integral action

PNID — ?

16/11/19

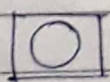
PFD — Process Flow Diagrams.
Piping and Instrumentation Diagram - PID

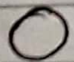
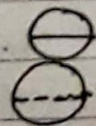
CS - Carbon ~~Stainl~~ Steel
A thick solid line → process stream.



① Cooling water
② C.W. Return
③ 265 PSIA Steam
④ Condensate
⑤ Sample port
⑥ Chemical sewer
⑦ Vent to (flare) →
⑧ Clear sewer
⑨ Vent to atmosphere

Any circle indicates display of a dial

 → computer display

① Mounted at field 
② —"— field control room 
③ —"— main control room. 

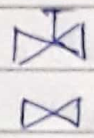
FFC — Ratio Flow controller

2nd Variable

Y → Converter
C → Controller
I → Indicator
R → Recorder
E → Sensor
T → Transmitter

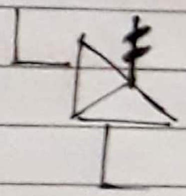
1st variable

TI → Temp Indicator
FI → Flow —"—



→ hand operated valve

V-109 → Reflux drum
Chemical sewer → chemical discharge



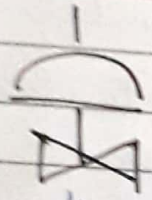
Pressure release valve

Vent and drain — Important
Fuel gas from reflux drum - some vapour generated taken as fuel gas.
MV → fuel gas flowrate
CV → Pressure of reflux drum

Sensor - senses the pressure
Transmitter - transmits.

- - - - - - - - → electrical signal
PAL → Pressure low ~~air alarm~~ alarm
PAH → —"— high press. alarm

current signal to neumatic signal.



Pneumatic

Neumatic control valve.

Pressure in reflux drum is controlled by flow rate

P-102 A & P-102B → reflux pumps

solid line process fluid

electrical

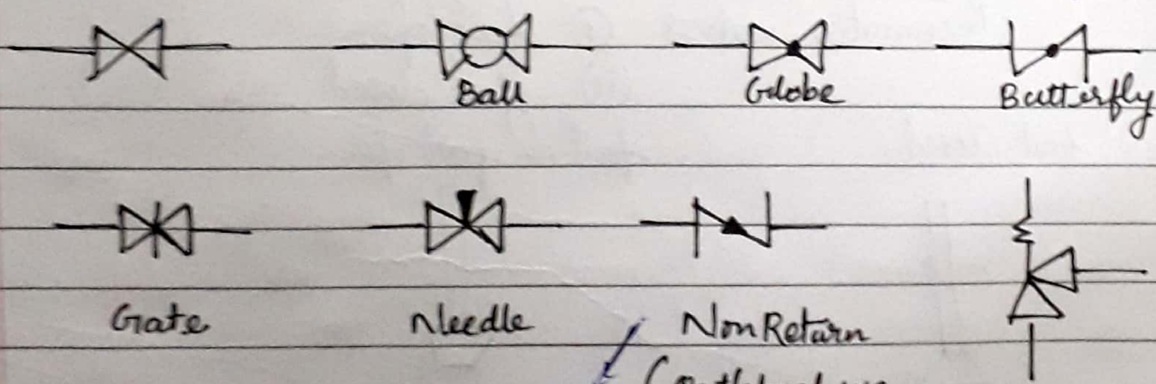
[VIMP]

1. Identify certain things in diagram
2. various lines and their symbols.
3. Location of instruments and it's accessibility
4. what do letters indicate?

Various valve symbols.

automatically control

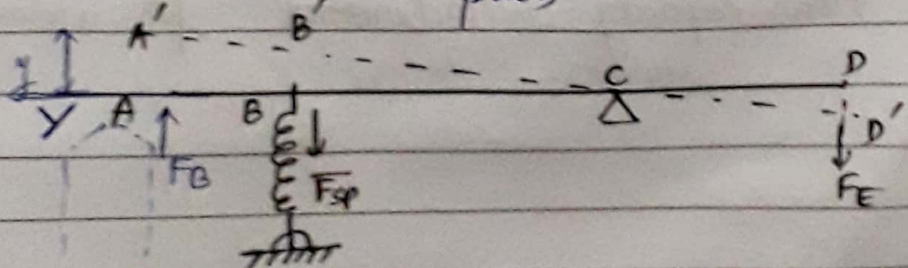
control of gas & vapour



(large pipelines)

(outlet of +ve displacement pump)

to prevent back flow of fluid in a process



50

30M — A.K Jana

20M — J.C. Sir

$K_{FN} \rightarrow$ -ve number

$$\overline{CD}\,\varepsilon = \overline{BC}\,K_{sp}\,BB' - \overline{AC}\,A_B\,(P_0 - P_{0,0})$$

Flopper Nozzle - linear

$$\overline{CD}\,\varepsilon = \overline{BC}\,K_{sp}\,BB' - \overline{AC}\,A_B\,(K_{FN}\cdot y)$$

$$\frac{y}{BB'} = \frac{CY}{CB}$$

$$\overline{CD}\,\varepsilon = \overline{BC}\,K_{sp}\,y\cdot\frac{CB}{CY} - \overline{AC}\,A_B\,K_{FN}\,y$$

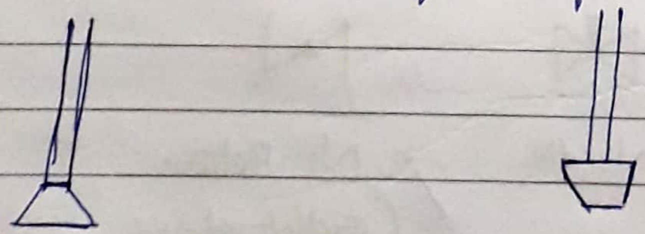
$$y = \frac{\overline{CD}}{\left(\overline{BC}\,K_{sp}\,\frac{CB}{CY} - \overline{AC}\,A_B\,K_{FN}\right)}\varepsilon$$

$$(P_0 - P_{0,0}) = \frac{K_{FN}\,\overline{CD}}{(\quad)}\varepsilon$$

Control valve

Pneumatic valves (i) fail open
(ii) fail closed

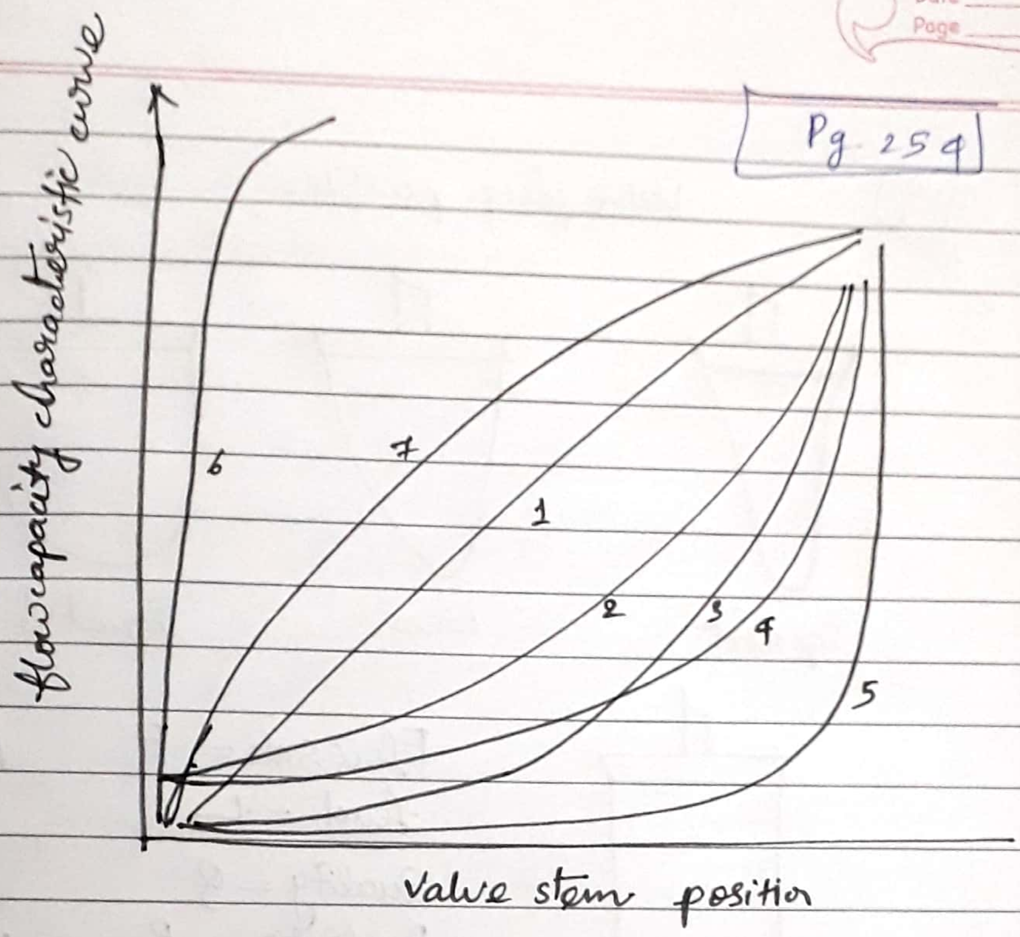
fail Closed ~~fail cl~~ fail open



Control valve curve

Flow capacity characteristics for various valves.

Pg. 254



1 Linear

2 Equal % $\alpha = 10$

3 $\alpha = 50$

4 Hyperbolic

5

6

7

For nonflashing liquids the flow through the value is given by

$$F = K f(x) \sqrt{\frac{\Delta P}{\rho}}$$

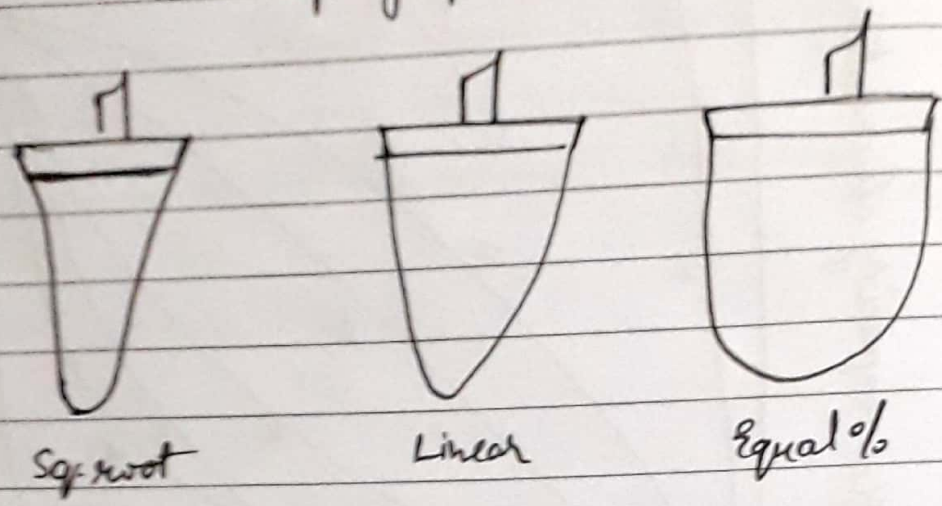
ΔP = pressure drop across the value

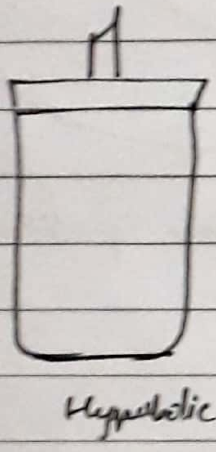
K = constant which depends on the value size

ρ = specific gravity

study this

Valve plug profile





Flow rate = F
Level = L
Quality = Q
Radiation = R
Temperature = T
Weight = W

PD → Difference or differential
pressure
H High
L Low
A Alarm

Advantages of null over deflection :

1. Accuracy attained is higher level than that of deflection method.
2. Detector can be made very sensitive because it need to cover only small range around zero while for deflection less sensitive as this covers large magnitude

Disadvantage → difficulty in kee

Unless the process changes very fast or transmission lines are very long, the dynamic behaviour of a pneumatic transmission line can be neglected