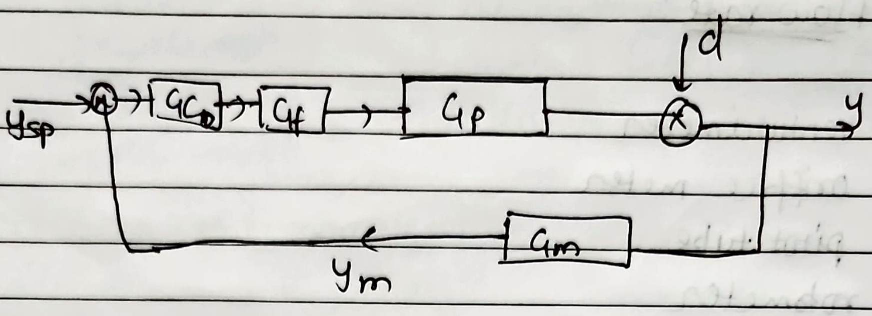
Instrumentation:



1) Generalized description of measuring instruments
2) Measuring instruments : selection and functioning
3) Hardware of pneumatic control system.
4) control valve : Final control Element
5) Symbols for P and ID

Temperature:

1) Thermocouple
2) Liq filled thermometers.
3) Radiation Pyrometer
4) Resistance thermometer
5) Bimetallic

Pressure:

① manometer
② Piezo
③ Diaphram
④ Bellows
⑤ Bourdon Tube

Measeirment system Application and Design

Ernest O. Doebelin

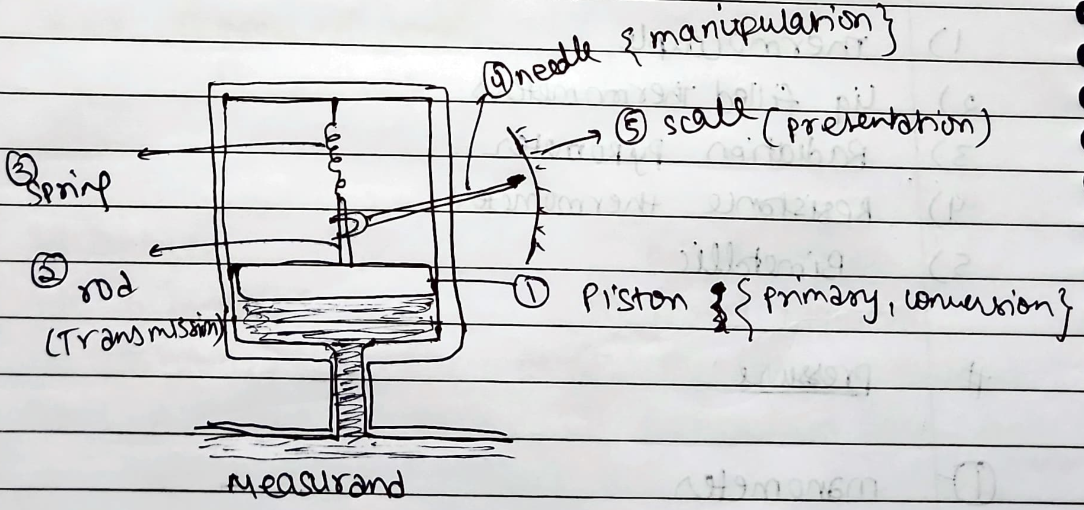
_/_/_

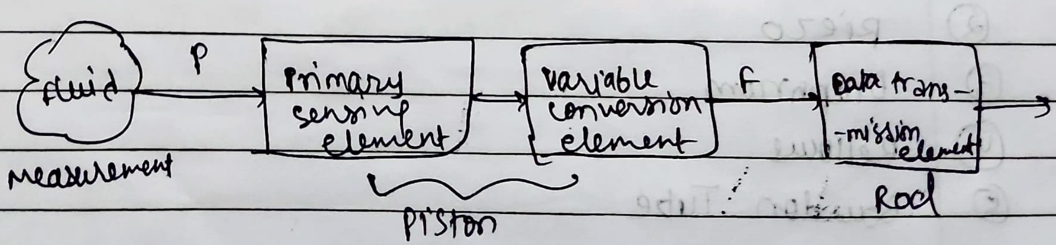
Flow rate:

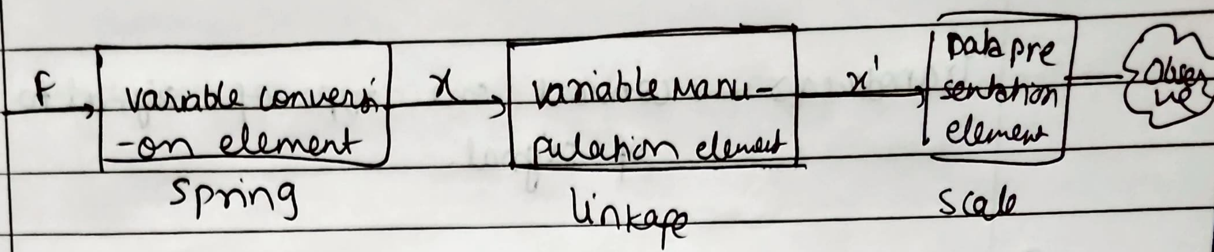
1) venturimeter
2) oriffice meter
3) pitot tube
4) rotameter
5) coriollis meter
6) ultra-sonic flowmeter

Functional elements:

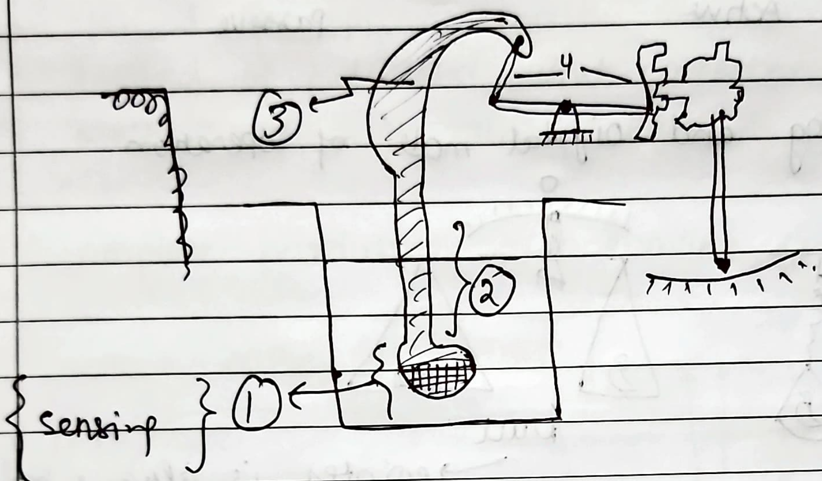
1. Primary sensing Elements: {Extracts energy from the system}
2. Variable conversion Element
3. variable manipulation Element
4. Data transmission Element
5. Data presentation Element

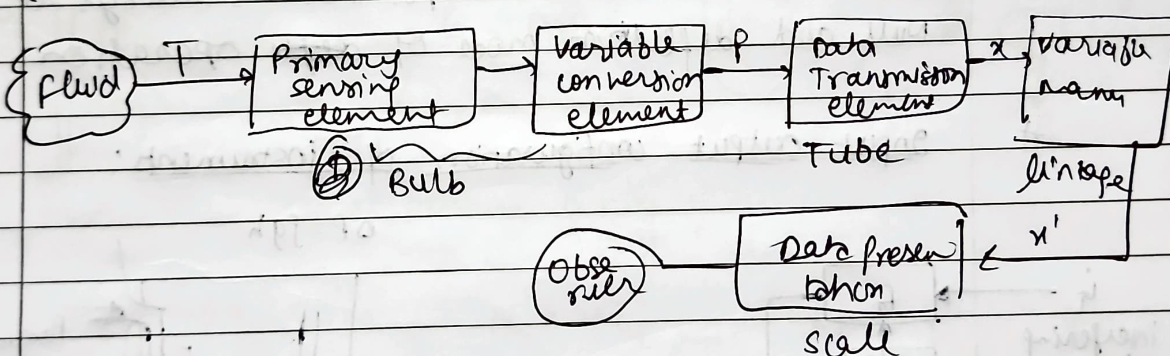




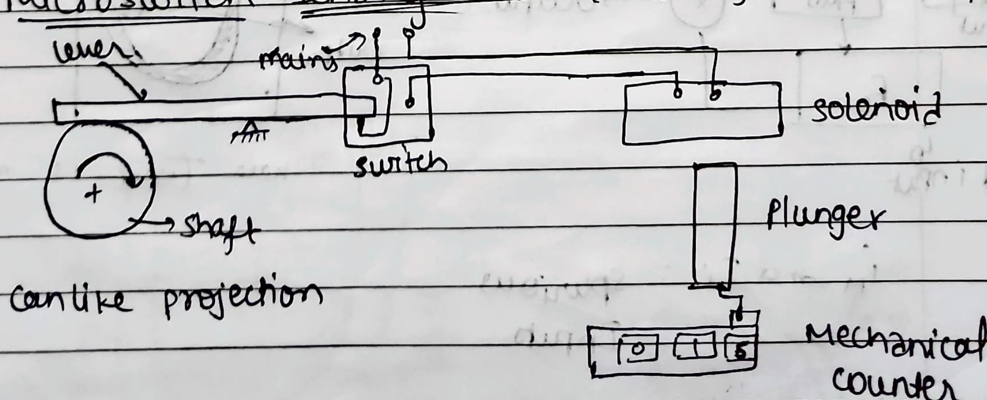


Pressure thermometer:





Microswitch sensing Arm: {counting the no. of revolution}



Different function of elements:

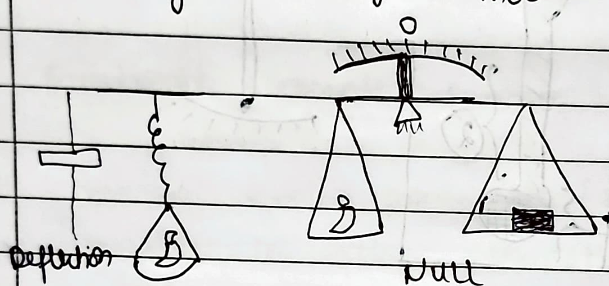
Transducers → convert one type of signal to other type of signal.

① Transducers

Active   Passive

② Analog and Digital mode of operation

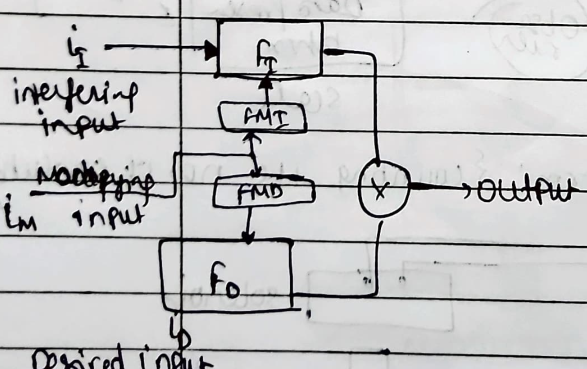
③



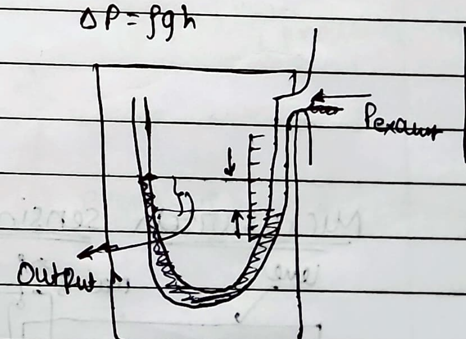
→ pointer is always at null point

Null and deflection mode of ~~depth~~ operation.

Input output configuration of instruments:



$\Delta P = \rho g h$



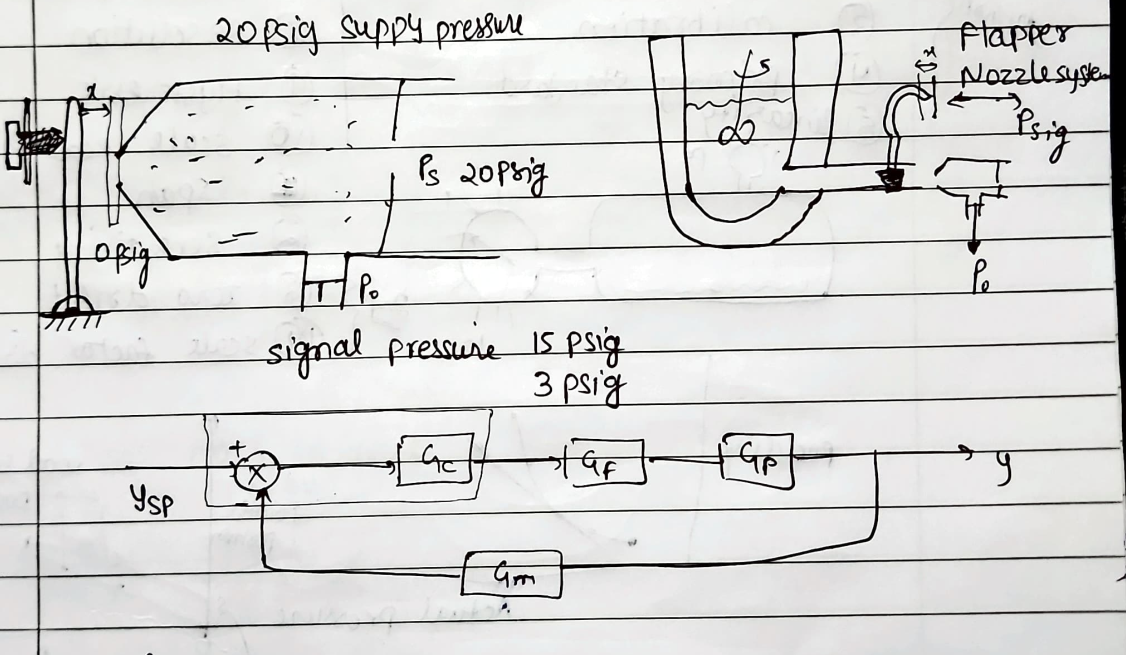
here Temp is modifying input

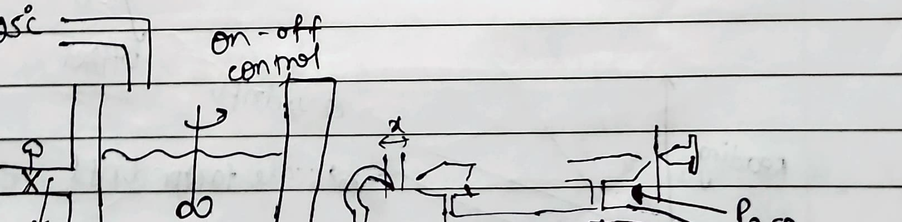
i_M and I_i = spurious Inputs

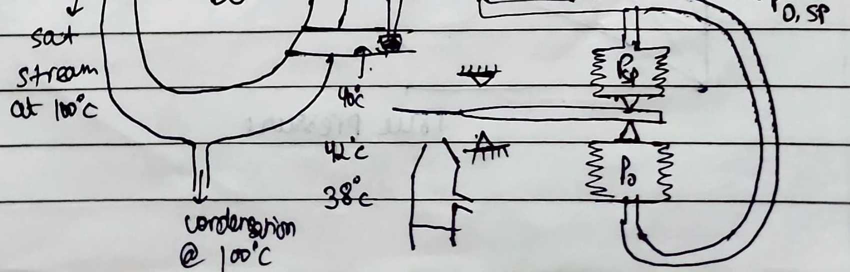
Methods for correction of interfering and modifying inputs:

1. Method of inherent sensitivity.
2. Method of signal filtering
3. Method of opposing inputs
4. Method of calculated output correction
5. Method of high gain feedback.

complete hardware of pneumatic control system.



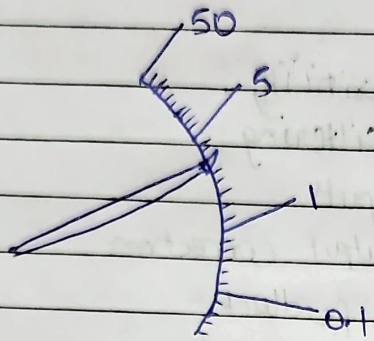




_/_/__

when $P_o > P_{o,sp}$; $P_{o,\text{controller}} = 15$ psig

when $P_o < P_{o,sp}$; $P_{o,\text{controller}} = 3$ psig

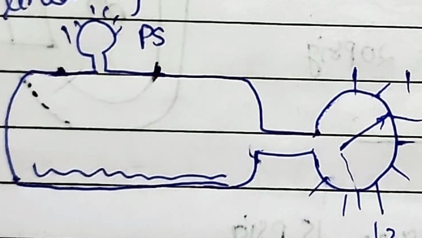


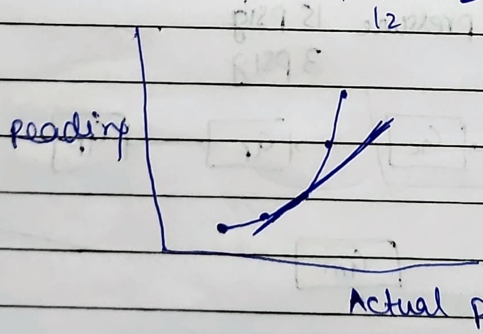
Generalized performance characteristics of instruments

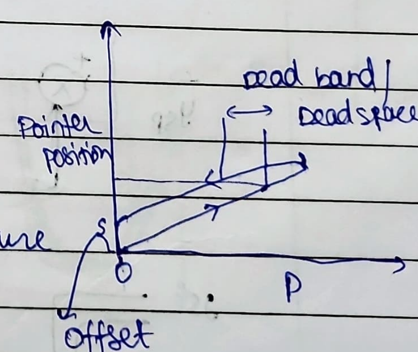
definitions

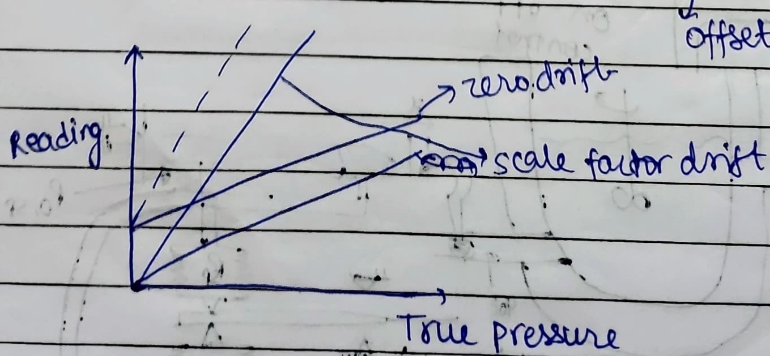
1. Static characterization
2. Dynamic "
3. calibration
4. primary standard
5. linearity
6. Threshold
7. Noise floor
8. Resolution
9. Hysteresis
10. scale Readibility
11. span
12. sensitivity
13. zero drift
14. scale factor drift

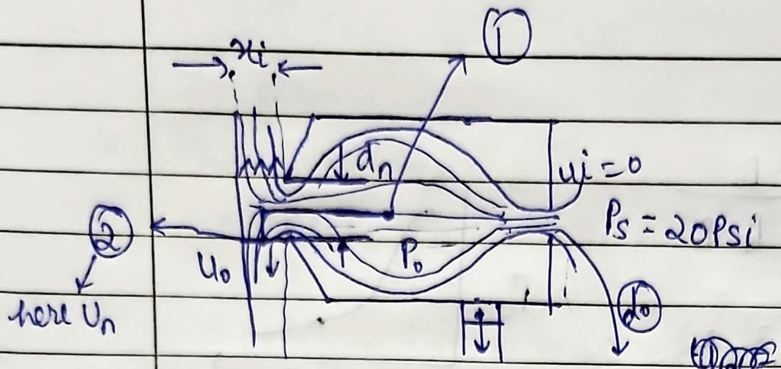
grp (13, 14)

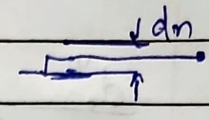












$$P_s + \cancel{\rho g h} + \frac{1}{2}\rho \cancel{v_i^2} = P_o + \cancel{\rho g h} + \frac{1}{2}\rho u_o^2$$

$$\boxed{C_o\sqrt{\frac{2(P_s-P_o)}{\rho}} = u_o}$$

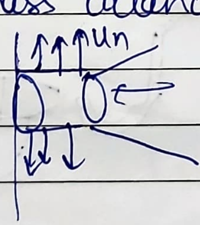
Bernoulli b/w (I) and (II)

$$P_o + \frac{1}{2}\rho v_1^2 + \rho g\frac{d_n}{2} = P_a + \frac{1}{2}\rho v_n^2$$

$$P_o - P_a + \frac{1}{2}$$

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

Now mass balance

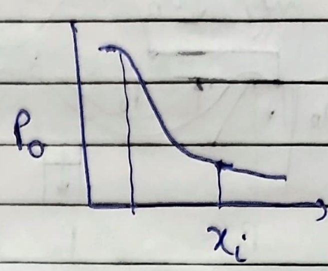


$$u_n \times \rho \times 2\pi x_i\left(\frac{d_n}{2}\right) = \frac{\pi d_o^2}{4}u_o\rho$$

$$\sqrt{\frac{\cancel{2}P_o}{\rho}}\,\cancel{\rho}\times\cancel{2}\cancel{\pi}\,x_i\frac{d_n}{\cancel{2}} = \frac{\cancel{\pi}d_o^2}{4}C_o\sqrt{\frac{\cancel{2}(P_s-P_a)}{\cancel{\rho}}}\times\rho$$

$$\frac{d_o^2}{4d_n x_i} = \sqrt{\frac{P_o}{P_s-P_o}}$$

$$\frac{d_o^4}{16 d_n^2 x_i^2} = \frac{P_o}{P_s - P_o}$$

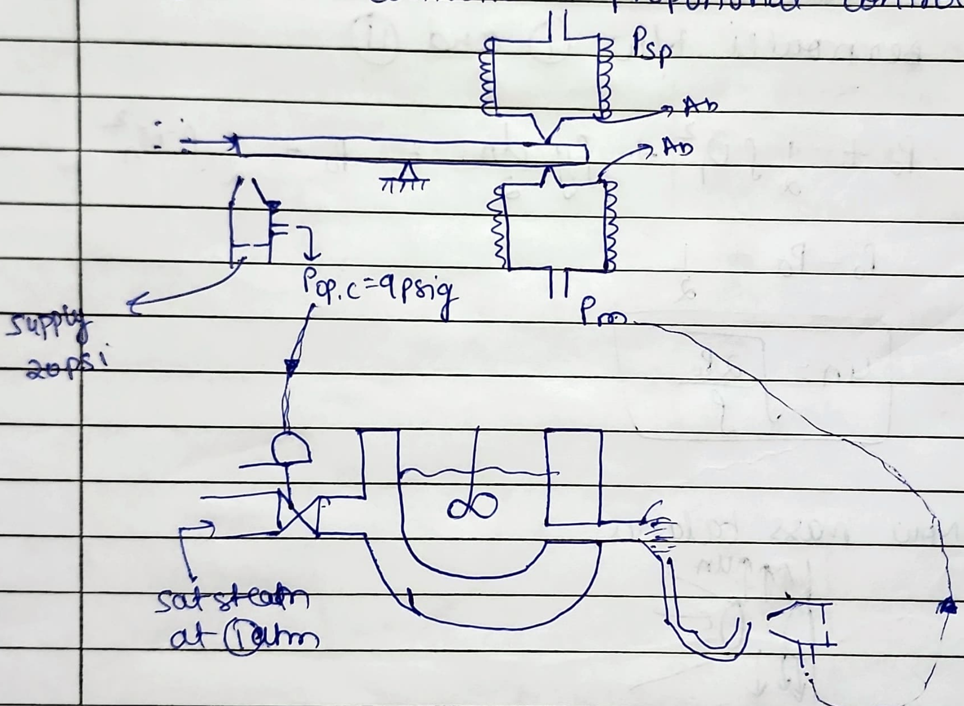


$$\frac{P_s - P_o}{P_o} = \frac{16 d_n^2 x_i^2}{d_o^4}$$

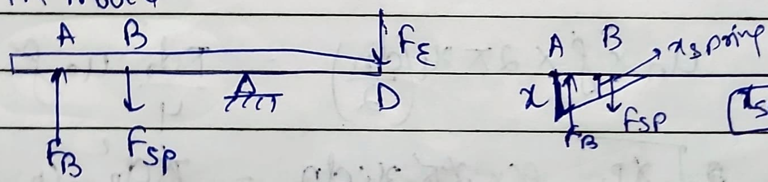
$$\frac{P_s}{P_o} = \frac{16 d_n^2 x_i^2}{d_o^4} + 1$$

$$\boxed{\frac{dP_o}{dx_i} = -k_{fn}}$$

Pneumetic controller : proporional control



⇒ photo in mobile



$\boxed{x_{sp} = k_g x}$

$$-AC\, F_{B,0} + BC \cdot F_{sp,0} - CD\, F_{E,0} = 0$$ { taboutc when no error in pcontroller

When there is an Error :

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

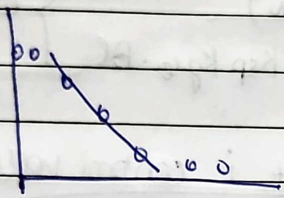
⑪ - ①

~~$-AC(AB - AB_o)$~~

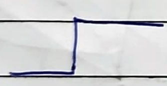
$$-AC(F_B - F_{B,o}) + BC(F_{sp} - F_{sp,o}) - CD(F_E - F_{E,o}) = 0$$

$$-AC(A_{fb,1}P_o - A_{fb,b}P_{o,o}) + BC \cdot K_{sp}\Delta x_{sp} - CD\, A_b(P_{sp} - P_m) = 0$$

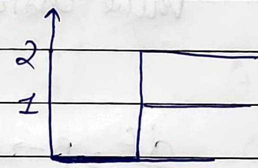
$P_o = -K_{fn} \cdot x$ $\quad \longrightarrow \quad -AC \cdot A_{fb,b}(-K_{fn}x + K_{fn}x)$



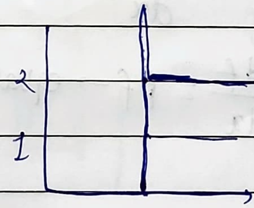
So, $-AC \cdot A_{fb}(-K_{fn})(\Delta x) + BC \cdot K_{sp}\Delta x_{sp} - CD \cdot A_b \cdot \epsilon = 0$



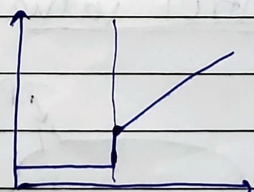
P only
$K_C = 2$



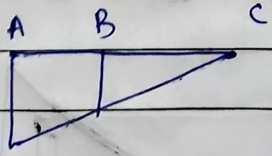
P and D



P and I



$\epsilon = P_{sp} - P_m$

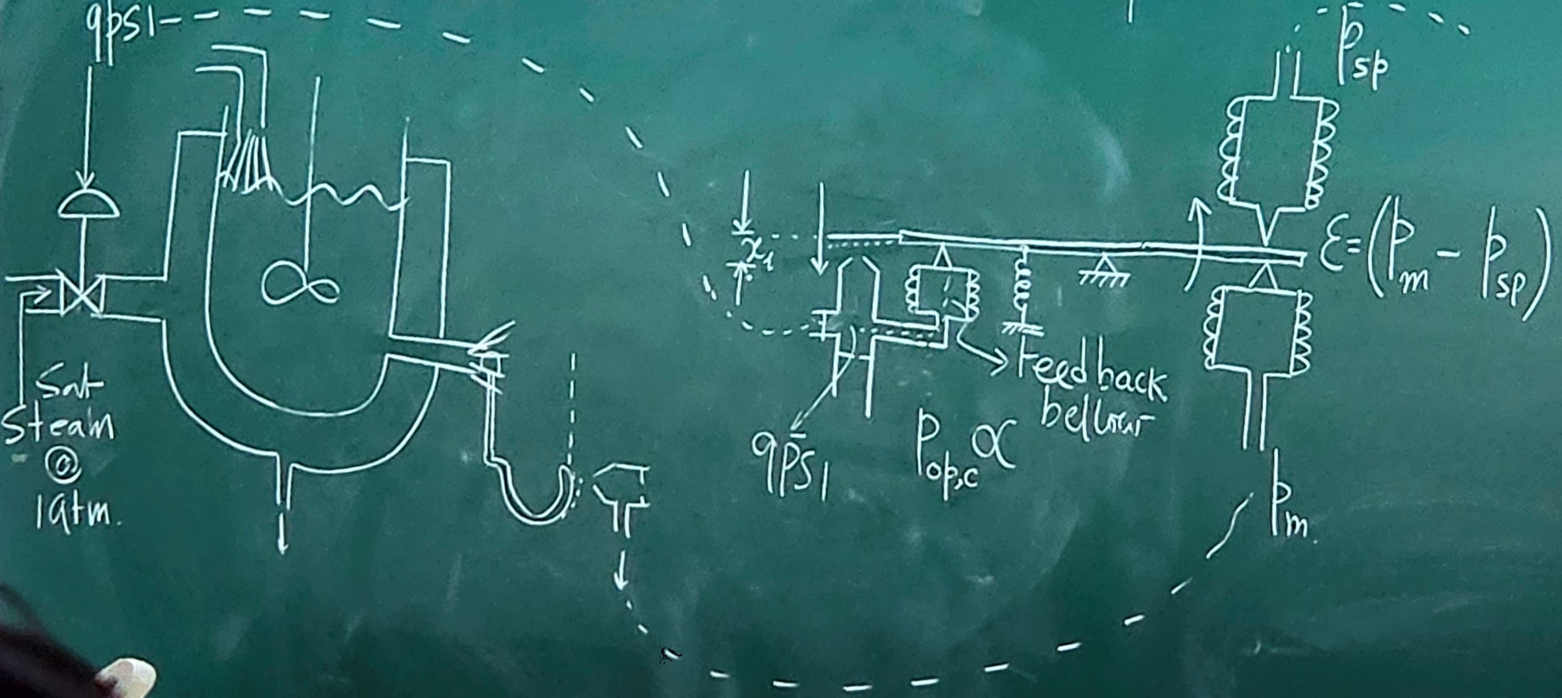


$x_{sp} = k_g x$

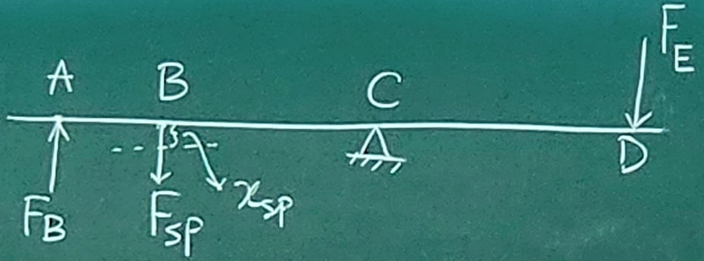
$$\begin{aligned} F_B &= F_{b,o} - F_{b,1} \\ &= P_{o,o}A_b - P_{o,1}A_b \\ &= (P_{o,o} - P_{o,1})A_b \\ &= -K_{fn}\, x\, A_b \end{aligned}$$

$P_o = -K_{fn}x$

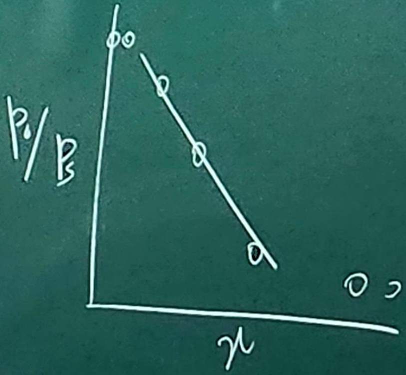
Pneumatic Controller : Proportional Control



ontrol.



$p_0 = -k_{fn} \cdot x$



$- p_{sp})$

$$-AC.\, F_{B_0} + BC.\, F_{sp,0} - CD\, F_{E,0} = 0$$

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

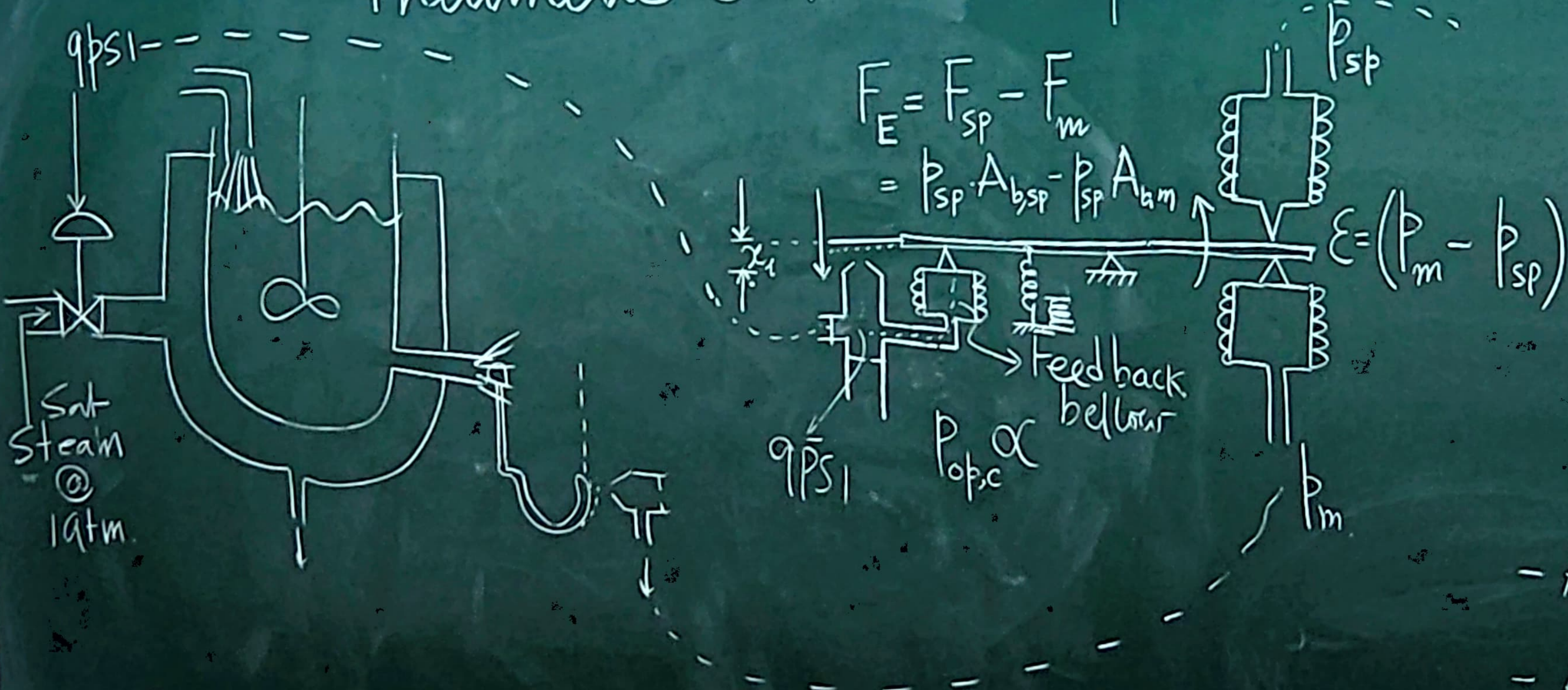
$$-AC\left(F_B - F_{B_0}\right) + BC\left(F_{sp} - F_{sp,0}\right) - CD\left(F_E - F_{E,0}\right) = 0$$

$$-AC\left(A_{fb,b} \cdot p_0 - A_{fb,b} \cdot p_{0,0}\right) + BC.\, k_{sp} \cdot x_{sp} \quad - CD \cdot A_b\left(p_{sp} - p_m\right) = 0$$

$$-AC \cdot A_{fb,b}\left(-k_{fn} \cdot x + k_{fn} x_0\right)$$

ε

Pneumetic Controller : Proportional Control



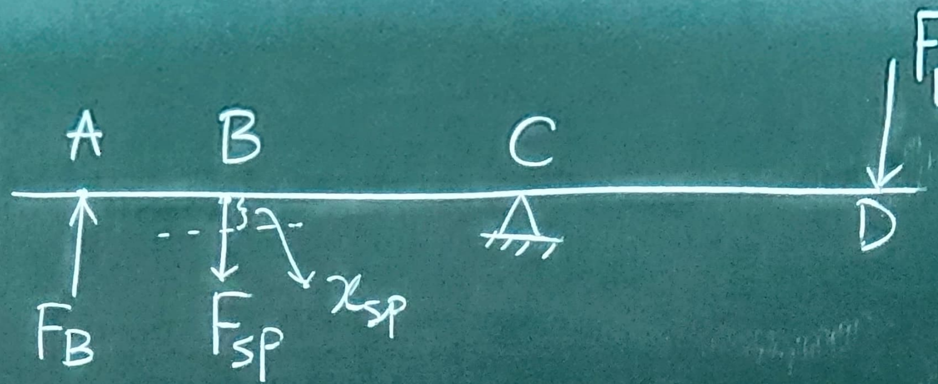
$$F_E = F_{sp} - F_m$$
$$= P_{sp} \cdot A_{b,sp} - P_{sp} A_{b,m}$$

$$\varepsilon = (P_m - P_{sp})$$

- Ac

- Ac

hol.



$p_{sp})$

$$-AC \cdot F_{B_0} + BC \cdot F_{sp,0} - CD\, F_{E,0} = 0$$

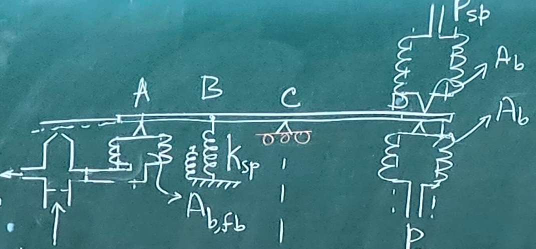
$$-AC\, F_B + BC\, F_{sp} - CD\, F_E = 0$$

$$-AC\left(F_B - F_{B_0}\right) + BC\left(F_{sp} - F_{sp,0}\right) - CD\left(F_E - F_{E,0}\right) = 0$$

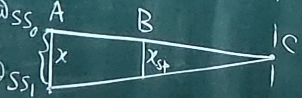
$$-AC\left(A_{fb,b} \cdot p_0 - A_{fb,b} \cdot p_{a,0}\right) + BC \cdot k_{sp} \cdot x_{sp} \quad - CD \cdot A_b\left(p_{sp} - p_m\right) = 0$$

$$-AC \cdot A_{fb,b}\left(-k_{fh} \cdot x + k_{fh} x_0\right)$$

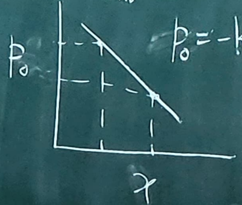
ε



$p_s = 20$ psig



$x_{sp} = k_g x$



$p_o = -k_{fn} \cdot x$

$$\varepsilon = p_{sp} - p_m$$

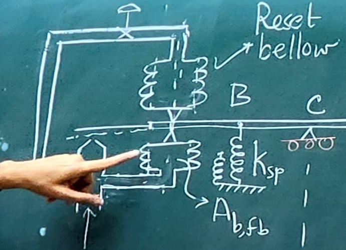
$$\bar{F}_B = F_{b,0} - F_{b,1}$$
$$= p_{o,0} A_b - p_{o,1} A_b$$
$$= (p_{o,0} - p_{o,1}) A_b$$
$$= -k_{fn} \cdot x \cdot A_b$$

$$-\bar{F}_B \cdot AC + \bar{F}_{sp} \cdot BC - \varepsilon \cdot A_b \cdot CD = 0$$

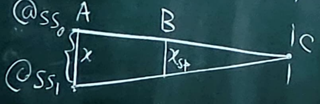
$$-p_o \cdot A_{fb} \cdot AC + k_{sp} \cdot x_{sp} \cdot BC - \varepsilon \cdot A_b \cdot CD = 0$$

$$k_{fn} \cdot x \cdot A_b \cdot AC + k_{sp} \cdot k_{geo} \cdot x \cdot BC = A_b \cdot CD \cdot \varepsilon$$

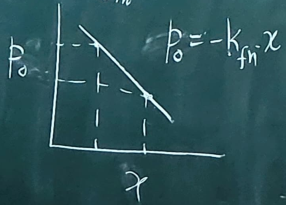
$$p_o = \underbrace{\left\{ \frac{A_b \cdot CD(-k_{fn})}{k_{fn} \cdot A_b \cdot AC + k_{sp} \cdot k_{geo} \cdot BC} \right\}}_{k_c} \varepsilon$$



$p_s = 20$ psig



$$x_{sp} = k_g x$$



$$p_0 = -k_{fn} x$$

$$\varepsilon = p_{sp} - p_m$$

$$\bar{F}_B = F_{b,0} - F_{b,1}$$
$$= p_{0,0} A_b - p_{0,1} A_b$$
$$= (p_{0,0} - p_{0,1}) A_b$$
$$= -k_{fn} \cdot x \cdot A_b$$

$$-\bar{F}_B \cdot AC + \bar{F}_{sp} \cdot BC - \varepsilon \cdot A_b \cdot CD = 0$$

$$-p_0 \cdot A_{fb} \cdot AC + k_{sp} \cdot x_{sp} \cdot BC - \varepsilon \cdot A_b \cdot CD = 0$$

$$k_{fn} \cdot x \cdot A_b \cdot AC + k_{sp} \cdot k_{geo} \cdot x \cdot BC = A_b \cdot CD \cdot \varepsilon$$

$$p_0 = \underbrace{\left\{ \frac{A_b \cdot CD(-k_{fn})}{k_{fn} \cdot A_b \cdot AC + k_{sp}\, k_{geo} \cdot BC} \right\}}_{K_c} \varepsilon$$

$$-F_B AC + F_{sp} BC - \epsilon A_b . CD = 0$$

$$-P_o A_{fb} AC + K_{sp} X_{sp} BC - \epsilon A_b CD = 0$$

$$K_{fn} x A_b AC + K_{sp} . K_{geo} x . BC = A_b CD\epsilon$$

$$P_o = \left\{ \frac{A_b CD (-k_{fN})}{K_{fn} A_b . AC + K_{sp} K_{geo} . BC} \right\} \epsilon$$

Final control Element i control value:

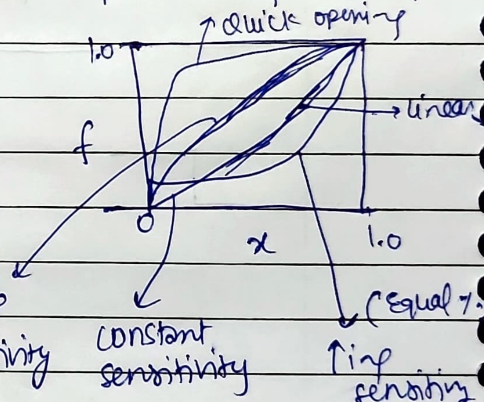
$$F = k . f(x) . \sqrt{\frac{\Delta P}{\rho}}$$

gal/min

$f(x)$ → value characterstics

x = fractional opening

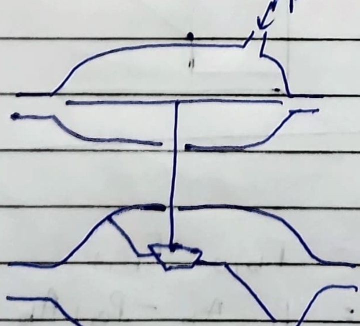
f = fraction of max flow



$\frac{df}{dx} = \beta$ → linear

$\frac{df}{dx} = \beta f$ → equal %

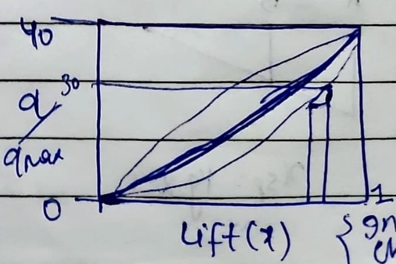
control value characteristes :



$$q = C_v . f(x) . \sqrt{\frac{\Delta P_v}{(s.g)}}$$

$f(x)$ = value characterstics

$$q_{max} = C_v \sqrt{\frac{\Delta P_v}{(s.g)}} \times \underbrace{f(x)}_{1}$$



linear

$\frac{df}{dx} = \alpha$

{inherent characterstics}

Control valve ~~too~~ characteristics

inherent (constant ΔP across the valve)

installed (under actual operation:, ΔP across valve changes as flow changes)

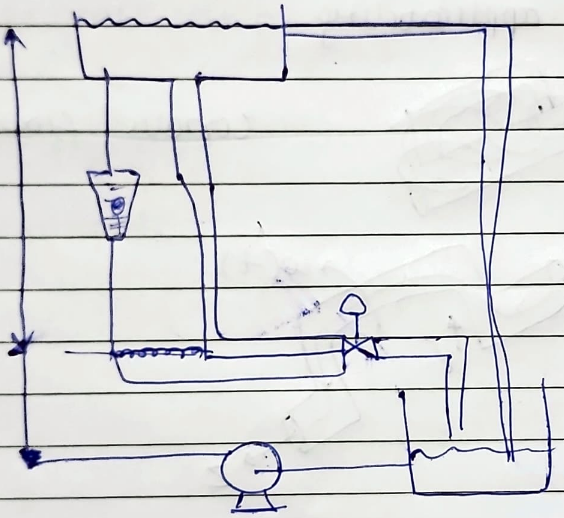
For equal % valve:

$$\frac{df}{dx} = \beta f \qquad \frac{df/f}{dx} = \beta$$

$$\int_{f_0}^{f} \ln f = \int_{x_0}^{x} dx$$

$$\ln \frac{f}{f_0} = x - x_0$$

#



q = gal/min

Δp in PSI = 100

$C_v = 4.0$

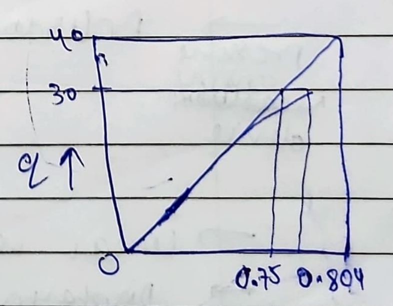
$q_{max} = 40$

$q = 30$ gal/min

Case a) line loss negligible

$x = 1$ $\quad q = 40$ gal/min

$x = 0.75$ $\quad q = 30$ gal/min



Case b) significant line loss

$q = 30$ gal/min

$\Delta P = 24$ psi

$q_{max} = 37.3$ gal/min

$$x = \frac{30}{37.3} = 0.804$$

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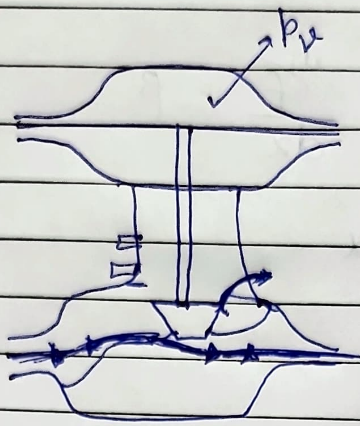
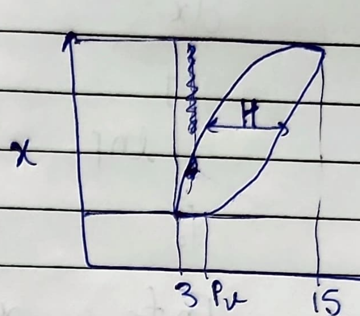
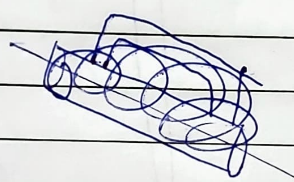
control valve positioner:



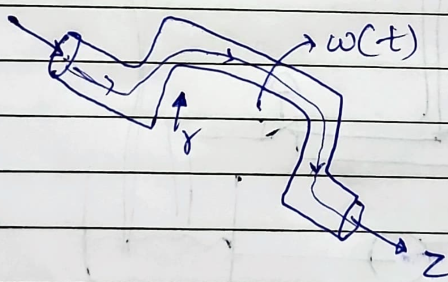


Dead band

limit of applicability.



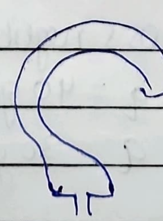
Coriolis flow meter



Time of flight meter
Doppler

→ Pressure sensing ~~measuring~~ device

Bourdon tube



→ Linear variable differential transformer
→ Diaphragm and Bellos

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→ level monitoring pressure
Assorted instruments, Piezoelectric

→ composition, monitoring
Chromatography
Refractometry

** → Temperature sensor:

a) Thermo electric effect
→ Reference junction ~~...~~ correction
→ J-type, K-type thermocouples { Range, voltage response
→ Resistance temp. (RTD)
→ Thermistors
→ ~~...~~ Radiation detectors

→ Thermopile