Mechanical Measurement & Control

B. Tech, 3rd Year

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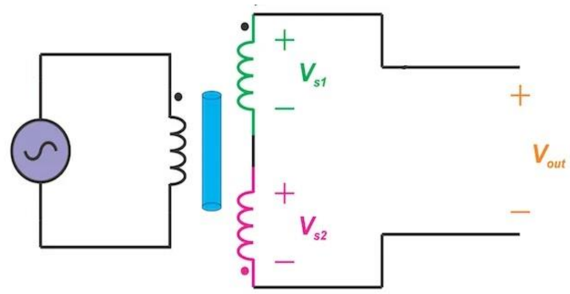
(Assistant Professor)



Indira Gandhi Institute of Technology

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(An autonomous Institute of Govt. of Odisha)

Date 03/02/2022

* Principle of Measurement :→
We compare a parameter (unknown variable) with known standard.

* Fundamental Unit:

	MKS	CGS	FPI/IPS	
Length -	m	cm	ft	in
Mass -	kg	gm	lbs	lbs
Time -	s	s	s	s

* Derive Units → m/s , m/s^2

SI system ⟶ MKS
[India/Europe]

USA ⟶ IPS

⇒ 1m - Pt-Ra [International
IB- Paris

$1m = \frac{1}{29979248}$ s [Distance travelled by light in vacuum]

Time : T = 9,192,631,770 vibrations of Cs atom
= 1s.

⇒ Boiler → Pressure gauge } Monitor process
Control process
Data for engg. analysis

⇒ Speedometer
⇒ Thermometer / Thermocouple
⇒ Triple point - 273.16 K

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* Industrial Units :→

→ Mass : 1 lbs = 0.4534 kg [lbs : pound]

2.2 kg = 1 lbs

1 lbs = 16 ounce = 7000 grains

25 lbs = 1 quarter

Ton = 1016 kg / 2000 lbs

Tonne = mT = 1000 kg

→ Distance : For ships & aircrafts – Nautical miles.

1 mile = 1.61 km

= 1760 yards

= 8 furlong

1 furlong = 220 yards

= 10 chains

1 chain = 22 yards [cricket pitch]

Nautical mile = 1.852 km

→ Area : Acre = 4840 yards

Hectare = $100 \times 100\ m^2$

Are = $100\ m^2$

→ Volume :

	European (UK)	American
Gallon =	4.5461 l	3.7854 l
Barrel =	163.66 l	119.24 l

Oil Barrel = 0.75 Barrel [US]

→ Pressure : 1 atm = 1.01325 bar

= 101.325 kPa [1 bar = 10^5 Pa]

= 1.0332 kgf/cm^2 [Industrial purpose]

1 bar = 14.5 PSI (Pound per $inch^2$)

→ Heat: BTU = 1055 J
[British thermal Unit]

Temperature: °C/K

* Measurement System:→

Mechanical – Temperature
Pressure
Acceleration
Torque
Force

Electrical – Impedance
Resistance

→ Measurement system consist of sensor, measurand, PSE

22-02-2022

* Measurement → Unit
→ Conversion

* Need: i) Process control
ii) Monitoring of process
iii) Data for engg. analysis

⇒ Temp., pressure, acceleration, force, torque

* Functional / Characteristics Elements of Measurement System:

1. Primary Sensing Elements [PSE]:

→ It is the element or the component that comes in contact with the measurand for the first time.

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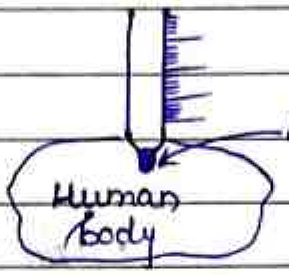
Measurand : It is the body or device on which the exercise of measurement is performed.



Here human body is measurand & bulb is the PSE

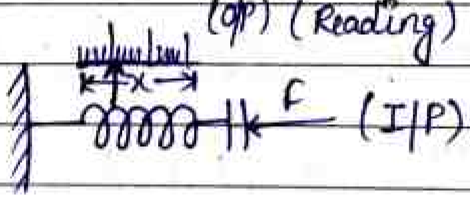
→ PSE is also defined as the one that picks the signal for the first time for non-contact measuring device.

* Important Consideration :
→ PSE should draw minimum amount of energy

2. Variable Conversion Element [VSE] :→
→ It is for any kind of measurement.

~~→ This element is used to amplify the output signal without disturbing the main signal or nature of main signal.~~

→ This element is used to convert one form of signal to another without disturbing the main signal.



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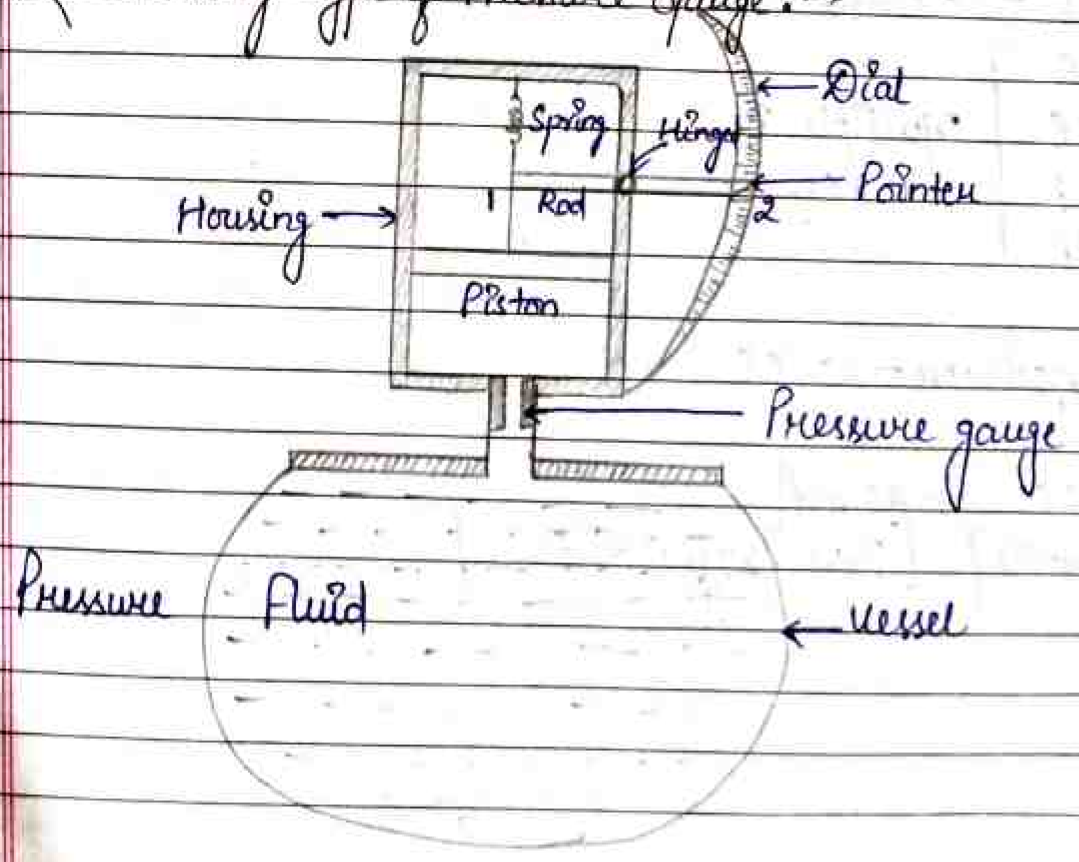
3. Variable Manipulation Element [VME]:→
This element is used to amplify the output signal without disturbing the main signal or nature of the main signal.

4. Data Transmission Element [DTE]:→
This element is used to transfer/transmit the signal from one location to another.
e.g. shafts, rod, belts etc.

5. Data Presentation Element [DPE]:→
This element is the last component of any measurement system which is used to display the data in the form of numerics.
e.g. dial of the dial gauge, scale, computer screen etc.

Rudimentary Type of Pressure Gauge:→



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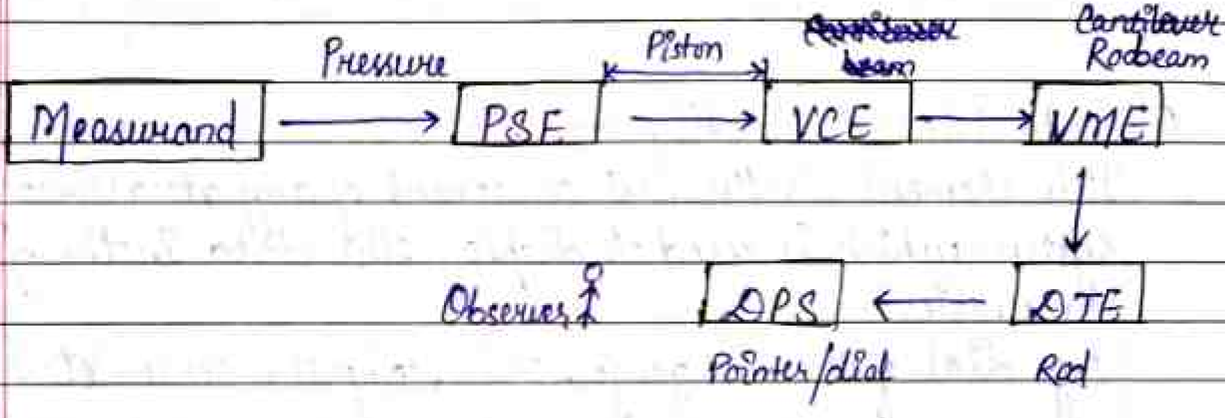
⇒ Measurand → Fluid
→ Signal required → Pressure
⇒ PSE → Piston
⇒ VCE → Piston
⇒ The arrangement 1-2 is acting as cantilever beam which is VME.
⇒ DTE → Rod
⇒ DPE → Dial / Pointer.



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* PSE ⟶ single element
VCE, VME, DTE, DPE] Multiple in nos.

⟹ Transducer ⟶ VCE

0-10VDC   4-20 mA.
[More accurate]   [Over larger distance]

Transducer element senses the desired input in one physical form and convert it to an output signal in some other form.

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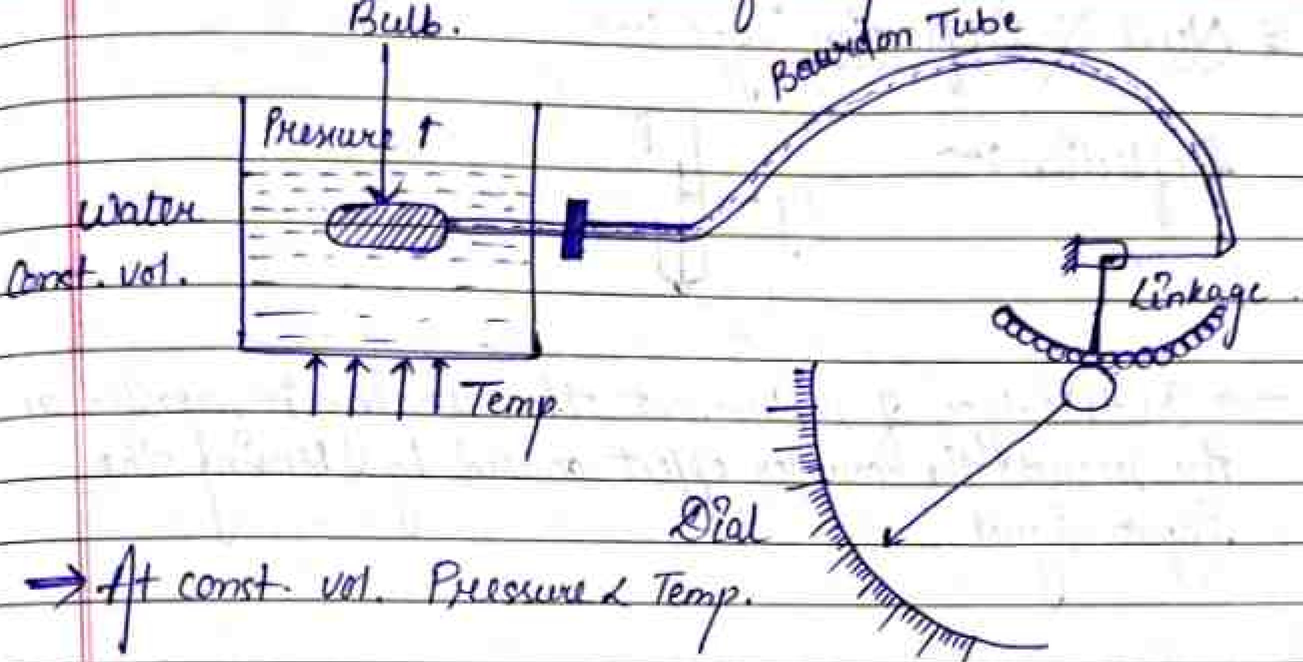
Measurement of Temperature



→ At const. vol. Pressure ∝ Temp.

⇒ Signal - Temp.
Measurand - Water
PSE - Bulb
VCE - Bulb

→ Bourdon tube is a tube, in which there is only enlongation & no lateral transformation.

VME - Linkage
DTE - Bourdon Tube.
DPE - Dial

* Classification of measuring elements:→

1. Null & Deflection type.
2. Manually op & Automated type
3. Analog and Digital type
4. Self generating & power operated.
5. Contact & Non-Contact Type

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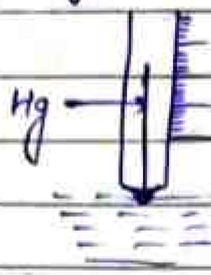
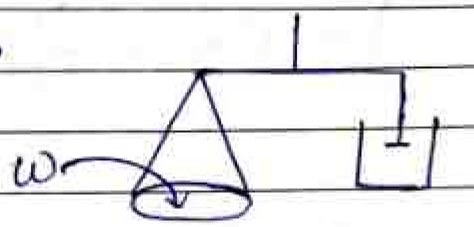
* Null & Deflection Type :→

Deflection :→



→ In this type of Instrument the reading is reported as the result the counter effect caused by sensing the Input signal.

Null :→



→ In this type of Instrument, the reading is reported by neutralising the effect caused by ~~the~~ sensing the Input signal.

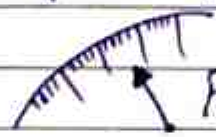
* Manual & Automated Type :→

→ In manual type of Instrument, the reading can be obtained by the use of human operator
e.g thermometer, pyrometer, oximeter

→ In automated type of Instrument, the reading can be obtained by the use of computers / PLCs along with the need of human operator

* Analog & Digital Type :→

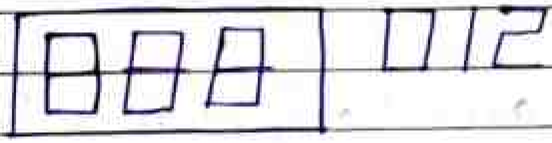
Analog :



→ In analog type of instrument, the reading is observed by deflection of the pointer.

→ The output signal carries the information of the input signal.
→ It is more accurate compared to the digital instruments and it is not recommended when sampling rate is high.

Digital :



→ The reading is in the form of binary digits [ON/OFF]

→ It is used to store a huge data in the computer format.
e.g. 7.5.2312 V
This reading of voltage by the voltmeter is not an indication of accuracy it only displays the output at any instant.

→ There are analog to digital (A–D) & D–A converters in the market.

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* Self Generating & Power Operated Type:→

Self Generating:

→ In this type of instruments, the reading of output signal can be obtained without any extra power input.
e.g. Thermometer (bulb type)

Power Operated:

→ The reading of the o/p signal can be obtained with an additional auxiliary power input (battery/ electricity/cell)
e.g. oximeter.

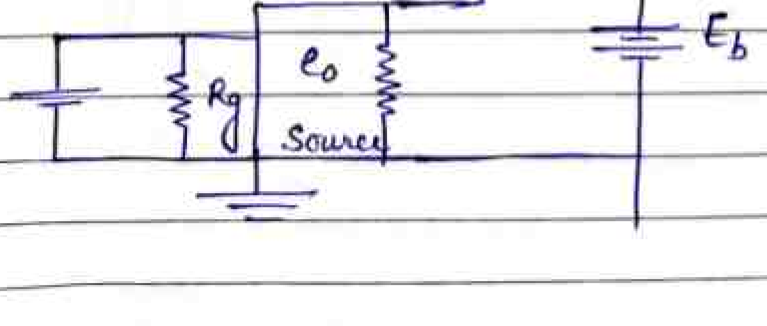
→ Transducers are classified as active & passive transducer

Active :→ No power input

Passive :→ Power required

⇒ Power operated/generated instruments are more accurate as it strengthens the signal.

* Field Effect Transistor:



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Contact & Non-Contact Typ

Contact Type:

→ In this type of instrument, PSE comes in contact with the measurand.

e.g. bulb type thermometer.

Non-Contact types:

→ In this type of instrument, PSE doesn't not contact with the measurand.

e.g. pyrometer, infrared thermometer.

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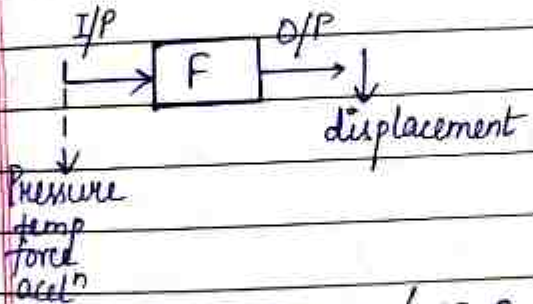
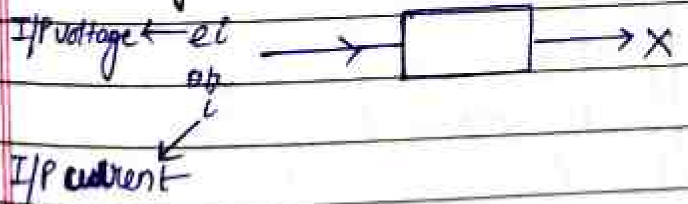
* Input / Output Signal Configuration: →



F → Transfer function
[Transfer one signal to another]

→ Mechanical Input (difficult to amplify)

→ Normally I/P – electrical signal – easy to amplify



⇒ 3 types of signal
i) Desired
ii) Interfering signal] eliminate
iii) Modifying

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* Desired Signal:

It is the signal to the instrument for which it is designed
The Instrument is designed.

* Interfering Signal:

It is the signal to the instrument for which it is unintentionally insensitive.

eg - the presence of magnetic field acts as a interfering signal for a voltmeter which is designed to record a voltage.

* Modifying Signal:

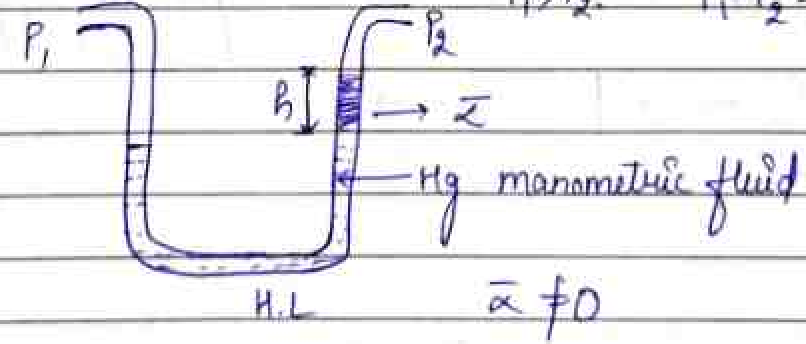
The signal to the instrument which changes input-output relation.

$ei/i \longrightarrow$ [F] $\longrightarrow x$

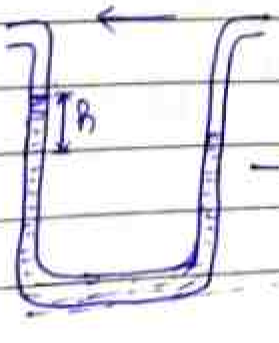
$x = f(e \text{ or } i)$
- → linear (desired)
- → non-linear (non-desired)

modifying → linearity change to non-linearity.

$P_1 > P_2$. $P_1 - P_2 = v$



$\bar{\alpha} \neq 0$



- Interfering signal

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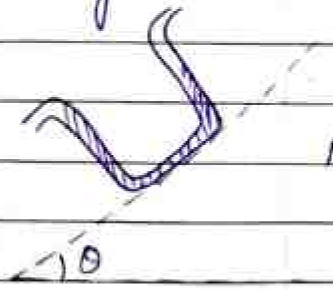
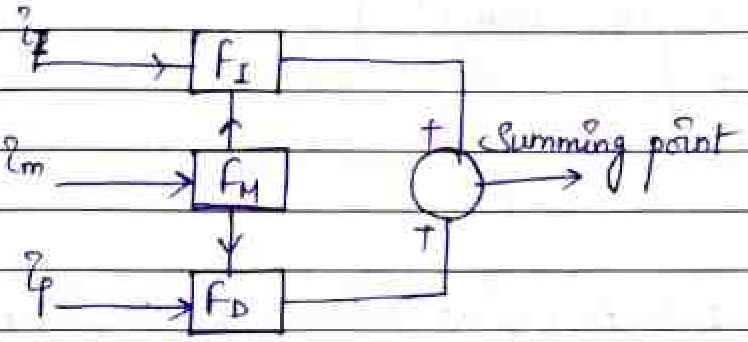
* There is always a time lag b/w I/P & O/P for any measurement system (not time load)

time lag ↓ — not desired





I → Interfering

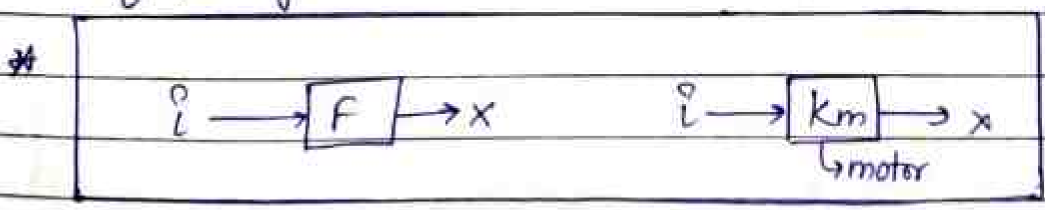
F → transfer function – function which convert I/P signal to O/P signal

F_D → desired signal

F_m → manupulate both Interfering & desired signal

* Methods of Correcting Interfering & Modifying Signal :→

i) High feed back gain system
ii) Signal filtering
iii) Method of opposing I/P.



km – sensitivity

→ Sensitivity of any measuring instrument is defined as the ability or capability of the instrument to accomplish responce (O/P) with smallest possible I/P.

Static] Characteristic]
Dynamic]
Electrical circuit
Temperature]
Flow
Pressure | Measurement]
Acceleration
Torque]

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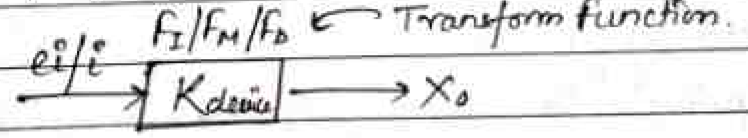
* Method of Correcting Interfering & Modifying Signal :→

1. Method of high gain feedback.



$T.F = K_A \cdot K_B$

→ This type of system is not recommended.

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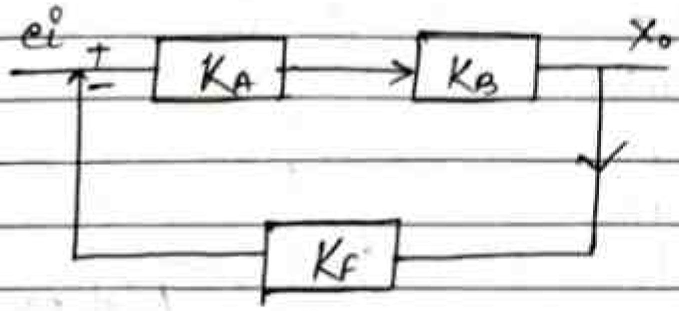
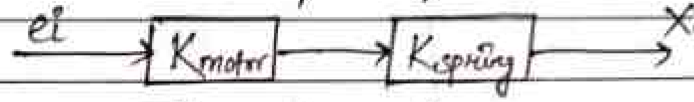


[Closed loop]
Recommended.

$$T.F = \frac{K_A K_B}{1 \pm K_A K_B K_F}$$

→ If the feedback is coming in negative then we will take the +ve sign in denominator & vice-versa.

Open loop



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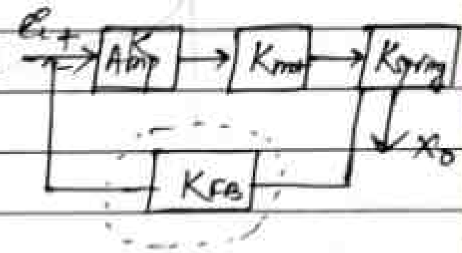

$TF = K_{motor} K_{spring}$

$K_{FB} >>> K_{amp}, K_{motor}, K_{spring}$

$$TF = \frac{K_{amp} K_{motor} K_{spring}}{1 + K_{amp} K_{motor} K_{spring} K_{FB}} = \frac{X_0}{e_i}$$

$K_{FB} >>> K_i$

$$\frac{X_0}{e_i} = \frac{1}{K_{FB}} \Rightarrow \boxed{X_0 = \frac{1}{K_{FB}} \cdot e_i}$$

This means we are control

→ By this method, of providing high gain feedback entire control is concentrated on the feedback device to alter the output signal.

→ This causes reduction of undesired signals (Interfering & modifying)

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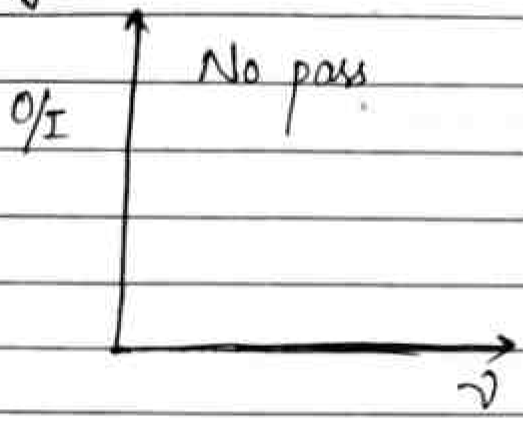
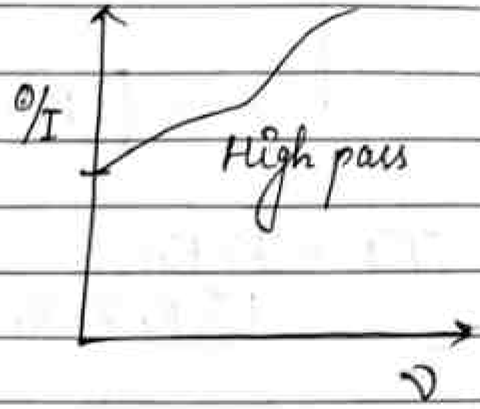
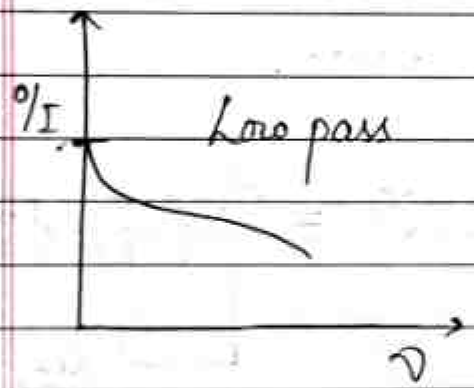
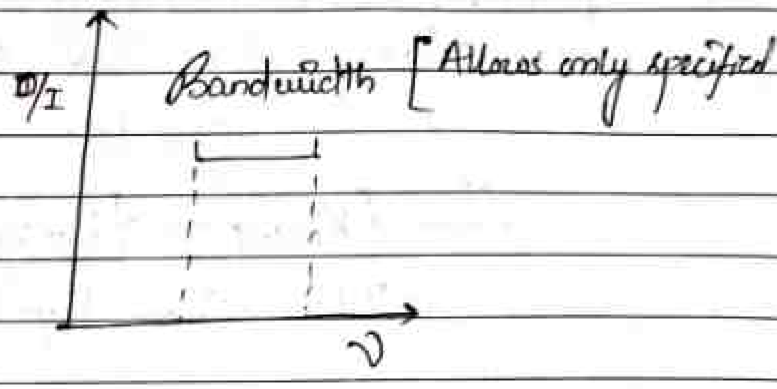
2. Signal Filtering:→

→ Using in electronics.









→ Signal filtering refers to the process in which the signal with specified frequecy is allow or disallowed.

→ They are of three types – i) No pass
ii) High pass
iii) Low pass

→ This process helps in reducing the undesired frequency by constricting their frequencies.

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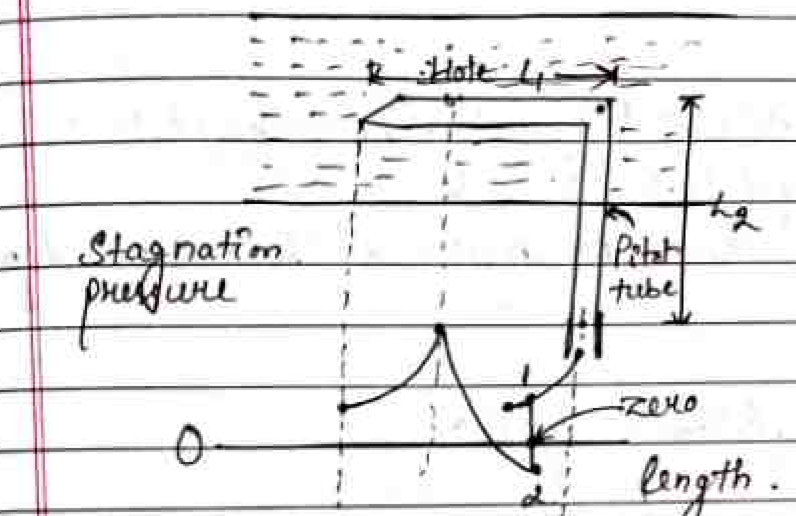
3. Method of opposing Input :→

Pitot tube : used to measured velocity.

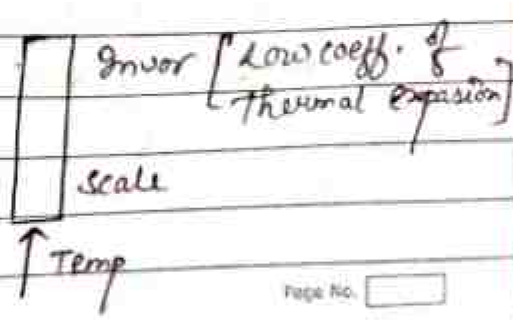


Hole : acts as constriction.

→ It refers to the superposition of two signals which are equal in magnitude but in opposite direction. This results in the reduction of undesired signals.
e.g. pitot tube, orifice meter.

→ In a pitot tube, the length L_1 & L_2 are designed in such a way that the final pressure from both the sections (L_1 & L_2) they cancel each other.

4. Inherent Insensitivity :→
→ It denotes that the measuring instrument is made insensitive to the undesired signals.
e.g. scale made up of Invar.



5. Correction of Signal In the O/P:→

→ In this method the amount of interfering & modifying signal in the i/p is computed by various programmable devices to get the desired o/p.

* Static Characteristics of Measuring Instruments:→

$y \neq f(time)$

→ These are those features/parameters which does not depend upon time.

→ They are of the following types:

1. Scale range
2. Scale span
3. Error
4. Calibration
5. Accuracy
6. Precision
7. Resolutions
8. Threshold
9. Linearity
10. Drift
11. Repeatibility
12. Reproducibility
13. Hysteris

→ The motive behind obtaining the static characteristics of measuring instruments is to quantify their performance capability and limitations.

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1. Scale Range :→ (working range)

→ e.g. 0-100 V (voltmeter) , 80-150°F (thermometer)

2. Scale Span :→

Scale span = Upper limit - Lower limit

Voltmeter → Scale span = 100 - 0 = 100 V
Thermometer → 150 - 80 = 70°F

→ It is defined as the difference between max and minimum values that can be detected by the measuring instrument.

3. Error :→

→ It is defined as the difference b/w the measured value & the true value.

$$\text{Error} = X_m - X_t = \pm$$

eg. Voltmeter

$X_m = 215\,V$, $X_t = 220\,V$

$\text{Error} = 215 - 220 = -5\,V$.

→ + ?

→ The true value

$$X_t = X_m - (\pm E)$$

Que: A voltmeter shows a reading of 150 V with an error of 10V. Calculate the actual reading to be recorded.

Sol:

$$X_t = X_m - (\pm E)$$
$$= 150 - 10$$
$$= 140V.$$

* **Correction = − Error**

* Types of Error :→
  i) Systematic / Cumulative
  ii) Accidental / Random
  iii) Miscellaneous / Gross } (+/−)

i) Systematic Error :→
→ It is always positive, unideration.

Systematic Error
- Environmental
- Instrument
- Loading effect

Accidental Error
- System defect
- Inconsistancy
- Random Varying parametr

Miscellaneous Error
- Human
- Defects
- Improper application

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i) Systematic Error :→

→ They are unidirectional in nature and the error keeps on added.

→ They are of three types – i) Environmental

ii) Instrument

iii) Loading effect.

Environmental Error :–

→ Change in temperature

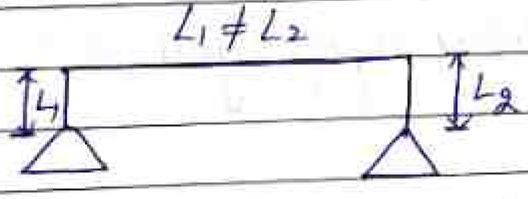
→ Change in humidity

→ Expansion.

Instrument Error :→

→ Uneven scale reading / divisions.

→



Loading Effect :–

→ Extraction of energy may take place.

e.g. Rotameter (Obstruction in the flow)

ii) Accidental Error :→

→ They incur while taking the readings from the measurand. in either positive or negative direction.

→ They are of three types – i) System defect

ii) Inconsistancy

iii) Random Varying Parameter

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System Defect :-

→ Misalignment

→ Backlash [unable to restore the capacity to zero]

It is the inability

Inconsistancy :-

$L = 750\,mm$

748 mm, 752 mm, 751 mm
(-) (+) (+)

→ They incur as error due to the repeated deviations from the true value of the readings.

Random Varying Parameter :-

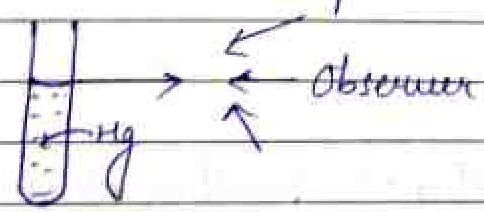
→ Vibrations

→ Fluctuations in electrical inputs signal.

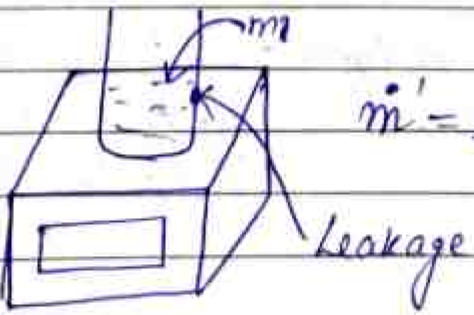
Miscellaneous Error :→

Human Error :-

→ It is also termed as personal error.



Defective :-



$$\dot{m}' = \frac{m_1 - m_2}{t}$$

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→ There is defect in the measurand itself.

** Improper Application :-
Voltage = 2V.
0 - 100V ✗
0 - 3V ✓

→ The least count plays a great role in determining the type of the measuring instrument to be selected.

4. Calibration →
5. Accuracy :→

→ It is defined as how close the reading to the true value.
→ It is manifestation of error in the reading.
→ There is linear/proportional relationship b/w error and accuracy.

eg. $X_t = 250V$, $X_m = 249.95V$.

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6 Precision :→
→ It is the agreement between the subsequent readings.

Voltmeter : $X_t = 220V$.
250, 249, 250.2, 251, 250.3 ....

[Close argreement]

→ A measuring instrument should have good accuracy and good precision

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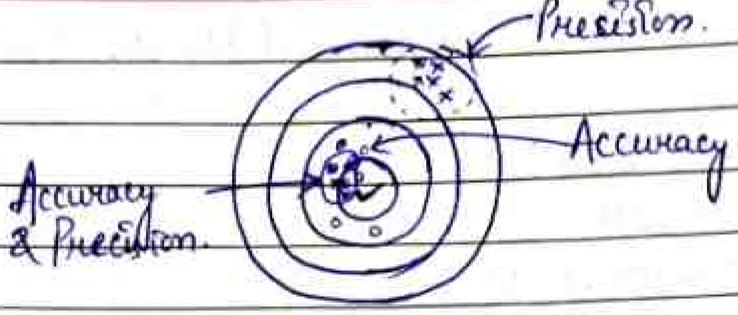
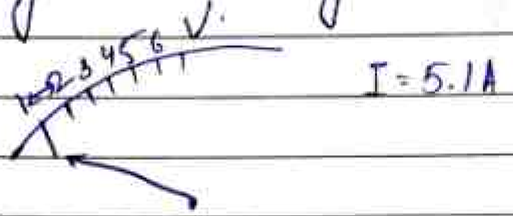


7 Resolution :→

→ It is defined as the smallest input change that can be detected by the measuring Instrument.

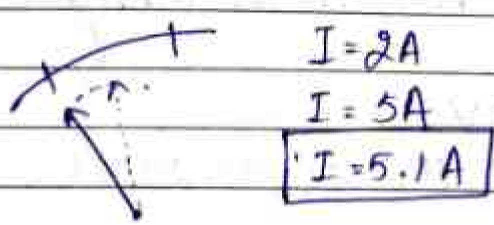


e.g. least count of any device.

→ It is also defined as the smallest input to the instrument for which it is sensitive.

8. Threshold :→

→ It is defined as the smallest input to the instrument that can be detected with certainity by the instrument.



⟹ A good measuring instrument should have zero threshold and zero resolution which is not possible. The reason behind this is due to the presence of friction & inertia.

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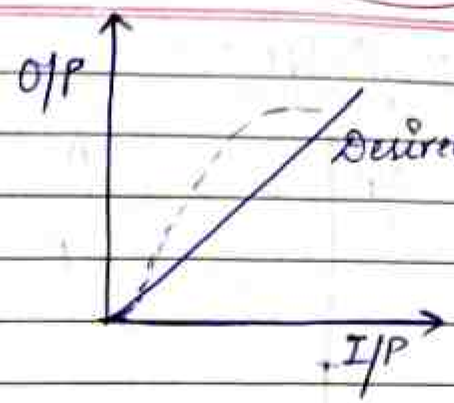
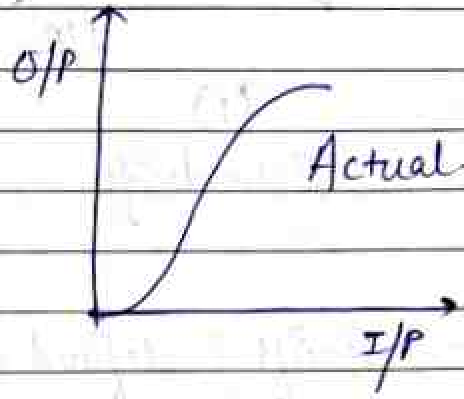
9. Linearity :→

→ Linearity of a measuring instrument indicates the output signal/response is proportional to the input signal.

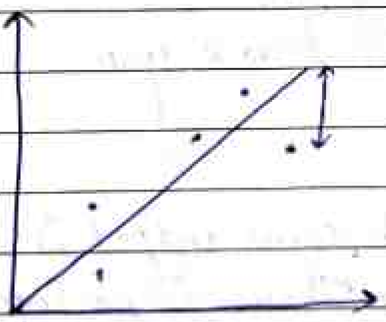


→ A good measuring instrument should have high degree of linearity.



Non-Linearity :→

→ It is the max deviation from the true line.



Sensitivity :

It is defined the ratio of output signal to input signal.

$$S = \frac{|O/P \text{ signal or response}|}{|I/P \text{ signal}|}$$

$$\boxed{\frac{1}{S} = \text{Deflection factor}}$$

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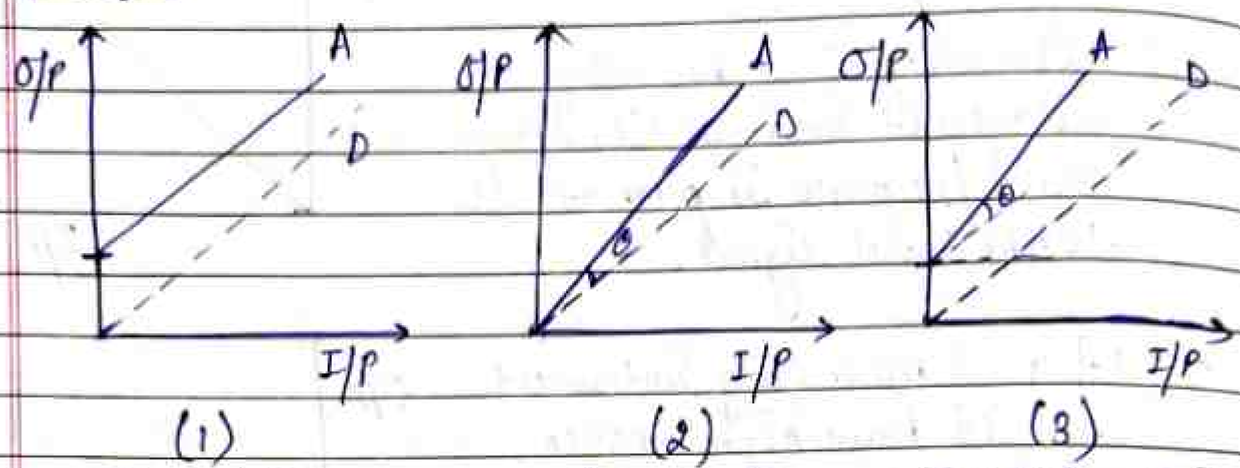
10. Drift :→



Zero drift | Span Drift | Zero & Span Drift

→ Drift is defined as the undesired gradual shift of the output signal w.r.t input signal.

→ They are of three types : i) zero
ii) span
iii) zero & span.

Zero drift :
It is the condition in which some output is already stored in the instrument even when there is no input.

Span Drift
It is the condition in which there is a angular deviation of the output signal w.r.t input signal.

Zero & Span drift
It is combination of zero and span dri

Causes of Drift :→

i) Wear & tear of mating parts.
ii) Sudden change temp. and ambient conditions.
iii) Development of stresses.
iv) Contamination of PSE.
v) Due to friction & inertia.

11. Repeatability :→

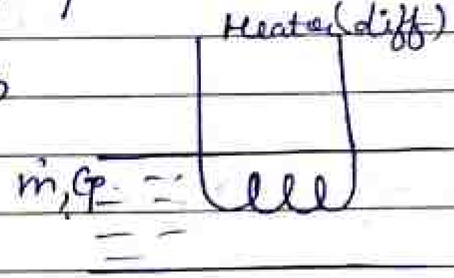
$Q = \dot{m} c_p \Delta T$

n expts.

ΔT = same

→ It is defined as the ability of the measuring instrument to produce same readings/output each time.

→ It is closely related with precision.



Diff. location, time

ΔT = same.

12. Reproducibility :→

→ It is the ability of measuring instrun to reproduce the same readings/outcomes each time at differ locations & time slots

13. Hysteresis :→

→ O/P = f (direction of loading)

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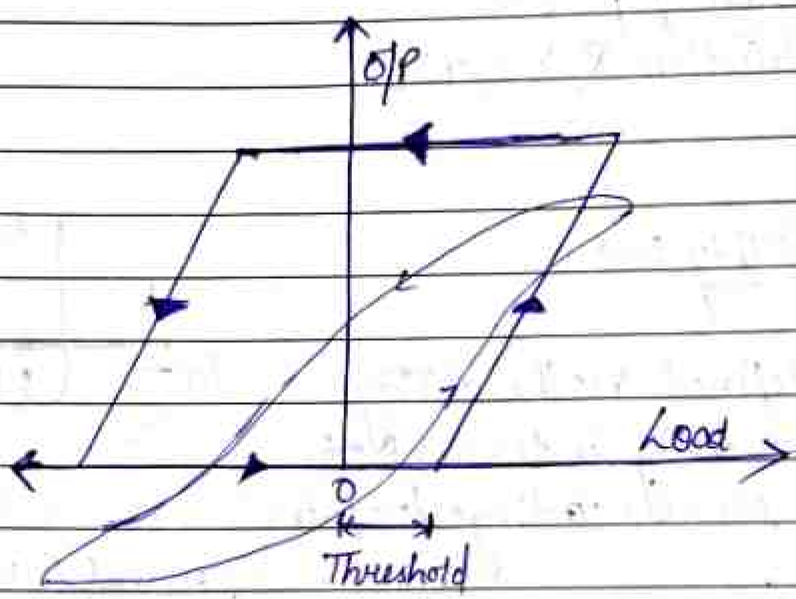
→ It is defined as the condition in which the o/p is a function of the direction of loading of measurand or the measuring instrument.



4. Callibration :→

→ It is defined as the process of maintaining zero stability of the measuring instrument.

→ Zero stability is defined as the ability of measuring instrument to restored to zero reading after the removal of the measurand along with all other variations such as temp, pressure, humidity etc.

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* Loading Effect and Impedance Matching :→

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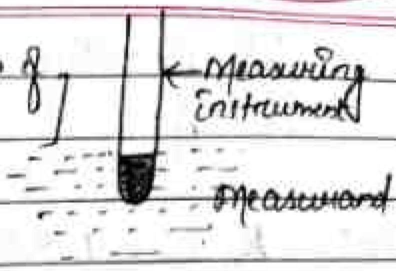
* **Loading Effect:** →

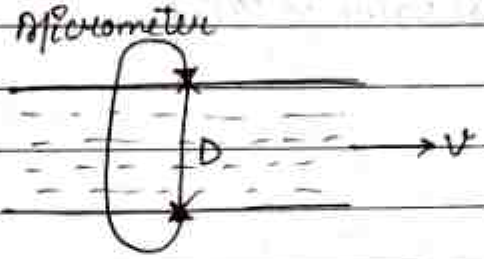
1. [Extraction of energy]



2.

Energy will be drawn. from the shaft

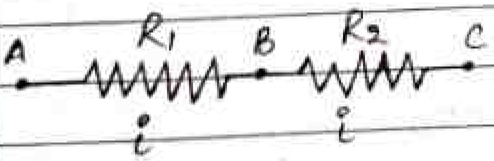
3.



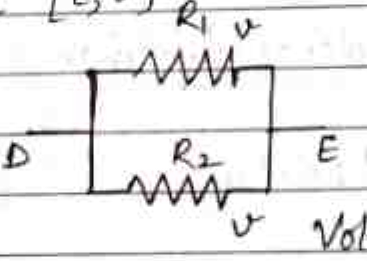
⇒ In all of the cases, o/p will be reduced.

⇒ When PSE or measuring instruments comes in contact with the measurand, some amount of energy is drawn, this effect is called loading effect.

Electrical Circuits: R, L, C [i, v]



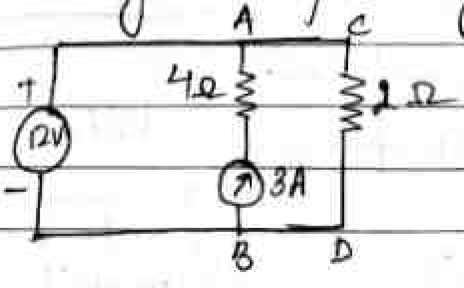
Current will be same



Voltage is same

Que: Calculate the loading error for the given circuits:

1.



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The reading shown by the voltmeter is changed to ammeter is 3A.

Ans: $R_q = \frac{8}{6} = 1.33\,\Omega$, $I = \frac{V}{R} = \frac{12}{1.33} = 9A$.

$i_1 = \frac{2}{4+2} \times 9 = 3A$ = Apparant , $i_2 = \frac{4}{4+2} \times 9 = 6A$.

$$\text{Error} = \frac{\text{Apparant} - \text{Actual value}}{\text{Actual}} \times 100$$

$$= \frac{3-3}{3} \times 100 = 0$$

2. The ammeter shows 2.5A, find loading error.

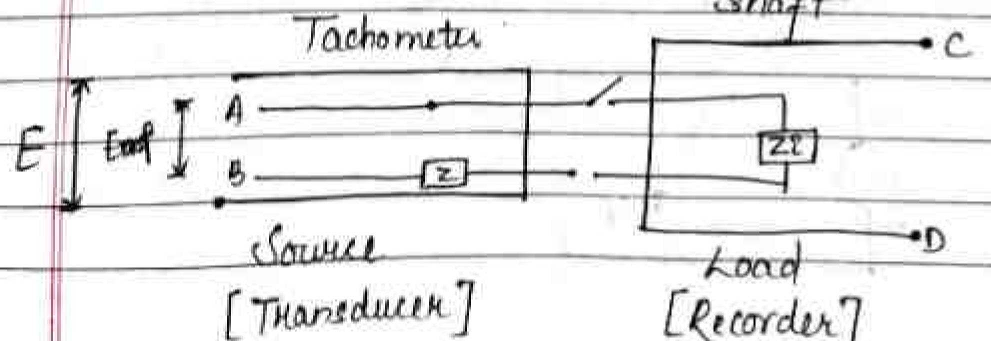
$$\text{Error} = \frac{3-2.5}{2.5} \times 100$$

$$= 20\%$$

* Impedence Matching :→

Resistance → Z. [Impedence]

→ Impedence is defined as resistance to the flow of current.



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Principle of Operation:

$$E_{AB} = \frac{EZ_i}{Z+Z_i}$$

→ Z & Zi are in series.

$Z >> Z_i$

$$E_{AB} = E$$

$$\text{Power amplified} = \frac{V^2}{R} = \frac{E_{AB}^2}{Z}$$

$$= \frac{E^2 Z^2}{(Z+Z_i)^2 \times Z}$$

$$P = \frac{E^2 Z}{(Z+Z_i)^2}$$

$$P = Z(Z+Z_i)^{-2} \cdot E^2$$

$$\frac{dP}{dZ} = 0$$

$$\Rightarrow E^2\left[Z \cdot -2(Z+Z_i)^{-3} + (Z+Z_i)^{-2}\right] = 0$$

$$\Rightarrow -2Z(Z+Z_i)^{-3} = -(Z+Z_i)^{-2}$$

$$\Rightarrow \frac{2Z}{Z+Z_i} = 1$$

$\Rightarrow 2Z = Z+Z_i \Rightarrow Z = Z_i$

Energy transmission is max when $Z = Z_i$

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⟹ Impedence matching is carried out b/w the source & the load by making a higher Impedence of source so that the Impedence of load is negligible wrt the Impedence of the source.

Que.1 Prove that the max energy transmission takes place when the Impedence of source matches with the Impedence of load.

Que.2. Classify the different types of measuring Instruments.

Que.3. Explain the various components of a mechanical measuring system.

Que.4. Write short notes on the following -
a) Accuracy & Precision.
b) Resolution & threshold
c) Repeatibility & reproducibility
d) Drift
e) Types of error.

Que.5. Explain the different comppents of a mechanical measurement system with help of an example.

* Dynamic Characteristics of a Measuring Instruments:-→

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* Dynamic Characteristics of a Measuring Instruments :→

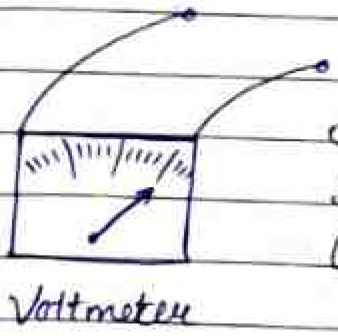
$$Y = f(\text{time})$$

→ Error is going to remain same with time.

→ Signal - Input $= f(\text{time})$

Output / Responce $= f(\text{time})$

$= f(\text{input})$



Responces of Pointer

Sluggish → very slow response

Sudden

Oscillatory

⇒ The dynamic characteristics of the measuring instruments :→

→ This comes into the focus of study as the I/P signal varies with time as a result of which the responce also becomes time dependented.

→ They are categories into following :

i) PERIODIC

→ The signal varies with time and repeats after a constant interval.

ii) Harmonic :

→ Harmonic motion is that kind of motion in which restoring force acts and is proportional to displacement (linear or

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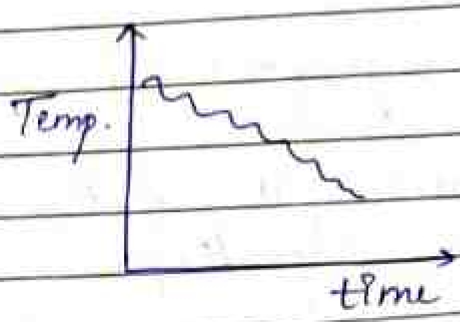
3. Transient:

→ This signal it varies non-cyclically with time and it dies out after certain interval of time. There is no oscillation after certain interval of time.

e.g. quenching of steel
(sudden cooling)



4. Random:

→ The random signal varies randomly with time with no definate amplitude and phase.

→ This may be continous but non-periodic.

* Generalised Mathematical Model of a Measurement System:→

$$a_n \frac{d^n q_o}{dt^n} + a_{n-1} \frac{d^{n-1} q_o}{dt^{n-1}} + a_{n-2} \frac{d^{n-2} q_o}{dt^{n-2}} + \dots + a_1 \frac{dq_o}{dt} + a_0$$

$$= b_m \frac{d^m q_i}{dt^m} + b_{m-1} \frac{d^{m-1} q_i}{dt^{m-1}} + \dots + b_1 \frac{dq_i}{dt} + b_0$$

$\frac{d}{dt} = D$ → Laplace Transform 'Operator'

$$\Rightarrow (a_n D^n + a_{n-1} D^{n-1} + a_{n-2} D^{n-2} + \dots + aD + a_0) q_o$$

$$= (b_m D^m + b_{m-1} D^{m-1} + b_{m-2} D^{m-2} + \dots + bD + b_0) q_i$$

q_o = output
q_i = input

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$q_0 = q_0/CF + q_0/PI$

CF = Complementary function (fixed)
PI = Particular Integral (No universal)

$D^2 + 4D + 4 = \sin x$

$D = \frac{-b^2 \pm \sqrt{4ac}}{2a} = \frac{-16 \pm \sqrt{4(4-\sin x)}}{2}$

$= \frac{-16 \pm 4}{2}$

Complementary function
Roots

Real

Repeated — S_1, S_1

Non Repeated — S_1, S_2

Complex

Repeated — $\frac{2}{a} \pm \frac{3i}{b}, 2 \pm 3i$

Non repeated — $a \pm ib$

Solⁿ:-

Real, Repeated: $(C_1 + C_1 t)e^{+S_1 t}$

Real, Non Repeated: $C_1 e^{S_1 t} + C_2 e^{S_2 t}$

Complex, Repeated: $(C_0 + C_1 t)e^{at}\sin(b_0 t + \phi_0) + (C_1 + C_2 t)e^{at}\sin(b_1 t + \phi_0)$

Complex, Non repeated: $C_1 e^{at}\sin(bt + \phi)$

22/03/2022

* Zero Order System/Control:

→ All the derivative terms will be zero.

$a_0 q_0 = b_0 q_i$

$$\boxed{q_0 = \frac{b_0}{a_0} q_i}$$

$\boxed{q_0 = K_s q_i}$, where K_s = static sensitivity.

e.g. potentiometer, lever

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* **1st order :→** f(nature of input).

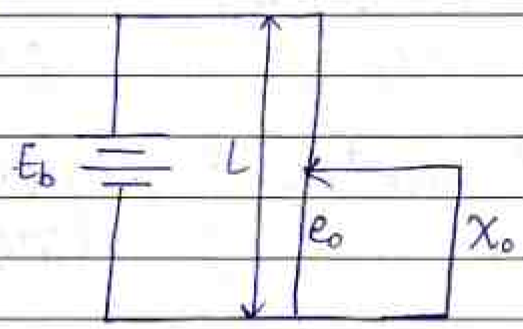
$$a_1 \frac{dq_o}{dt} + a_o q_o = b_o q_i$$

$$\Rightarrow \frac{a_1}{a_o} \frac{dq_o}{dt} + q_o = K_s q_i$$

$\frac{a_1}{a_o}$ = time constant of system = τ or λ

$$\Rightarrow \boxed{(\tau D + 1) q_o = K_s q_i}$$

* **Potentiometer :→**



→ It shows the potential difference b/w two points

$$e_o = \frac{X_o}{L} \cdot E_b = \left(\frac{E_b}{L}\right) X_o$$

$$\boxed{e_o = \left(\frac{E_b}{L}\right) X_o}$$

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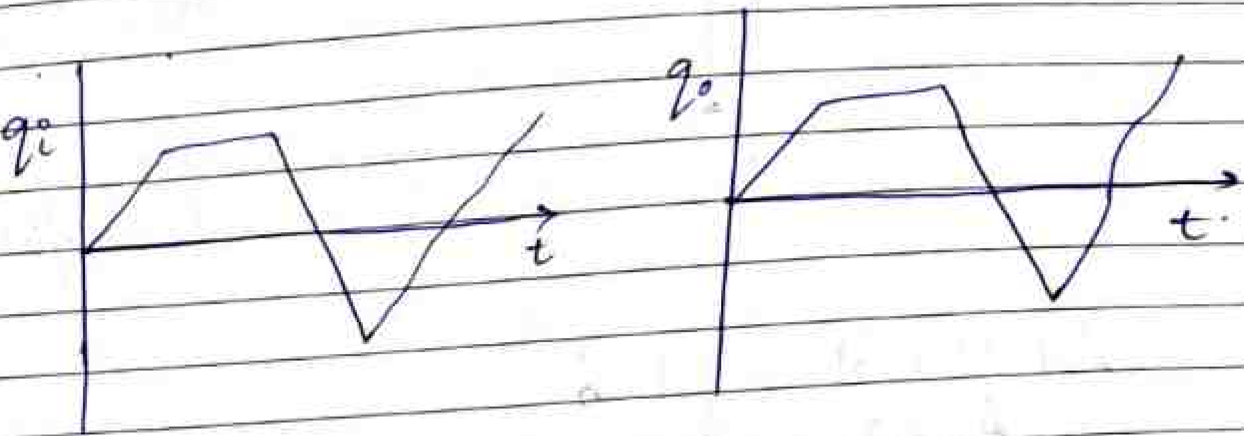
Characteristics of zero order system:

→ Time lag is zero.
→ Perfect dynamic response.

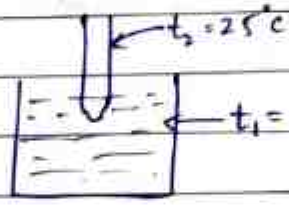
Limitations:
→ There is ~~slight~~ slight loading error/effect.



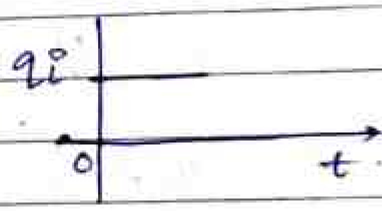
* 1st order system :→

Nature of Input : i) Step   e.g. putting thermometer in boiling water.
ii) Ramp
iii) Impulse.

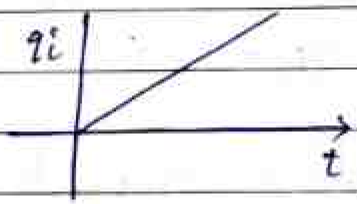
i) Step :



Step I/P = Δt



ii) Ramp :



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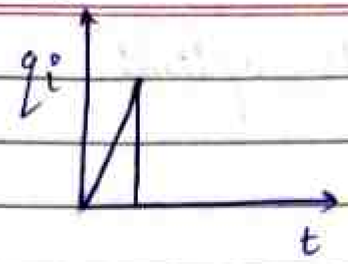
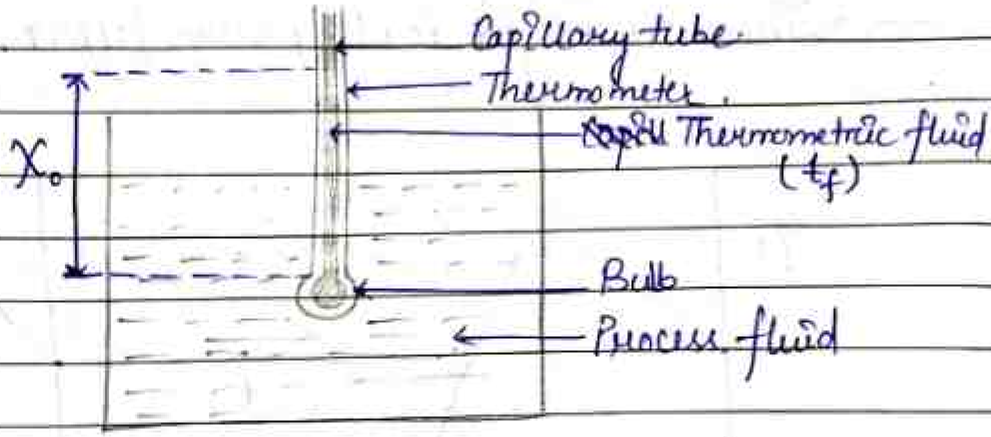
iii) Impulse:



* **Modelling of 1st order system:→**

Thermometer



Let V_b = volume of bulb
A_c = area of cross section of capillary tube
α = coeffient of differential expansion of the thermometer bulb & fluid.
H = coeffient of heat transfer across the bulb.
A_b = cross sectional area of bulb
ρ = density of thermometric fluid
C_p = specific heat capacity of thermometric fluid
θ_i = temp. of process fluid

Balancing of heat energy

Heat stored = Heat I/P − Heat O/P (→ 0)

→ The heat sense by the thermometer should be equal to heat released/showed by the thermometer.

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$$\rho V_b C_p d\theta = HA_b(\theta_i - \theta_f)\,dt$$

$$\Rightarrow \rho V_b C_p\, d\theta = HA_b\theta_i dt - HA_b\theta_f dt$$

$Q = mC_p dt \rightarrow$ solid.
$Q = hA\,d\theta \rightarrow$ fluid → solid

$$\Rightarrow \boxed{V_b \rho C_p \frac{d\theta}{dt} + HA_b\theta_f = HA_b\theta_i} \quad \text{— (1)}$$

There is an expansion of the thermometric fluid, therefore the volumetric expansion of the thermometric fluid can be expressed as

$$\text{Volumetric expansion} = A_c \times dX_0$$

$$\alpha V_b \cdot d\theta_f = A_c\, dX_0$$

$$\Rightarrow V_b \cdot d\theta_f = \frac{A_c}{\alpha} dX_0 \Rightarrow V_b \frac{d\theta_f}{dt} = \frac{A_c}{\alpha}\frac{dX_0}{dt}$$

$$\Rightarrow \boxed{V_b\theta_f = \frac{A_c}{\alpha} X_0}$$

Put in eq. (1), we get.

$$V_b \rho C_p \left(\frac{A_c}{\alpha V_b}\frac{dX_0}{dt}\right) + HA_b \frac{A_c}{\alpha V_b} \frac{dX_0}{dt} = HA_b\theta_i$$

$$\Rightarrow \frac{V_b \rho C_p A_c}{\alpha V_b HA_b A_c} \times \alpha V_b \frac{dX_0}{dt} + X_0 = \frac{HA_b \alpha V_b}{HA_b A_c}\theta_i$$

$$\Rightarrow \boxed{\frac{V_b \rho C_p}{HA_b}\frac{dX_0}{dt} + X_0 = \frac{\alpha V_b}{A_c}\theta_i}$$

$$Z = \frac{V_b \rho C_p}{HA_b}, \quad K_s = \frac{\alpha V_b}{A_c}$$

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The value of the time constant should be as min as possible in order have quick response system (good dynamic response)

$$\tau = \frac{V_b \rho C_p}{H A_b}$$

Thus the product of H, A_b as large as possible & ρC_p should be as minimum as possible.

24/08/22

* 1st order system:

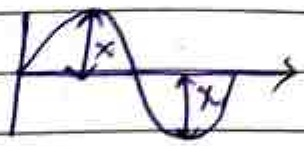
The governing equation is

$$(\tau D + 1) q_o = K_s q_i$$

For static case, $D = \frac{d}{dt} = 0$

$$\boxed{q_o = K q_i}$$

→ Amplitude is the magnitude of the signal.



Assuming, $q_i = X_i \sin \omega t$

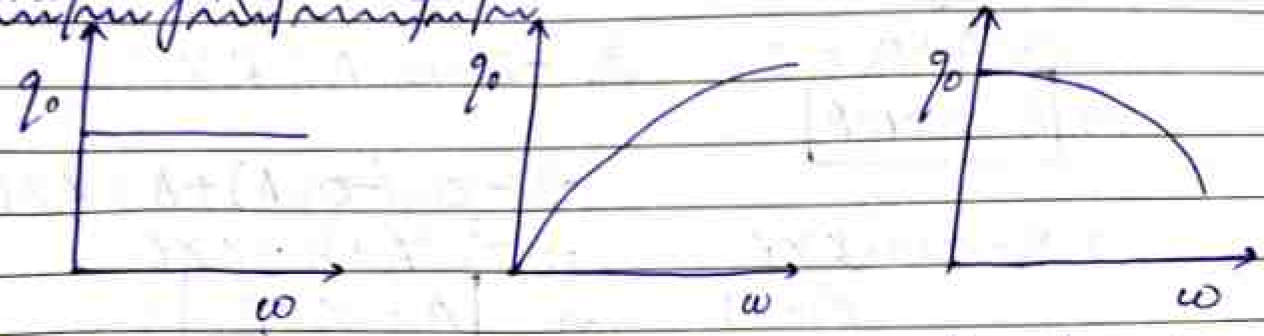
where, X_i = amplitude of the input signal

ω = angular frequency / circular frequency (rad/s)

$$\omega = 2\pi f = \frac{2\pi}{T}$$

→ The variation of the output signal (q_0) with frequency (ω) is known as frequency response.

* Frequency Response Graph:



Flat frequency response is good for both slow as well as fast varying signals. This is the desirable requirement for any instrument.

Poor low frequency response

Poor high frequency response.

Assuming steady state solution,

$$q_0 = A \sin\omega t + B \cos\omega t$$

and substituting it in the governing differential equation

$$(\tau D + 1)(A \sin\omega t + B \cos\omega t) = K(X_i \sin\omega t)$$

$$\Rightarrow \tau D A \sin\omega t + \tau D B \cos\omega t + A \sin\omega t + B \cos\omega t = K X_i \sin\omega t$$

$$\Rightarrow \tau A D \sin\omega t + \tau B D \cos\omega t + A \sin\omega t + B \cos\omega t = K X_i \sin\omega t$$

$$\Rightarrow \tau A \omega \cos\omega t + \tau B(-\omega \sin\omega t) + A \sin\omega t + B \cos\omega t = K X_i \sin\omega t$$

$$\Rightarrow (A - \tau B\omega) \sin\omega t + (\tau A\omega + B) \cos\omega t = K X_i \sin\omega t$$

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$\Rightarrow (\tau\omega A + B)\cos\omega t + (-\tau\omega B + A)\sin\omega t = KX_i \sin\omega t$

So, we get

$\tau\omega A + B = 0$ & $-\tau\omega B + A = KX_i$

$\Rightarrow \boxed{B = -\tau\omega A}$

$\Rightarrow -\tau\omega(-\tau\omega A) + A = KX_i$

$\Rightarrow B = -\tau\omega \cdot \frac{KX_i}{\tau^2\omega^2+1}$ $\Rightarrow \tau^2\omega^2 A + A = KX_i$

$\Rightarrow \boxed{A = \frac{KX_i}{\tau^2\omega^2+1}}$

$\boxed{B = -\frac{KX_i\tau\omega}{1+\tau^2\omega^2}}$

Substituting the value of A & B in solution, we get

$q_0 = \frac{KX_i}{1+\tau^2\omega^2}\sin\omega t + \frac{-K\tau\omega X_i}{1+\tau^2\omega^2}\cos\omega t$

$\Rightarrow \boxed{q_0 = \frac{KX_i}{1+\tau^2\omega^2}\left[\sin\omega t - \tau\omega\cos\omega t\right]}$

It can be written as,

$q_0 = X_0 \sin(\omega t + \phi)$ where ϕ = phase angle / phase difference

By substituting,

$\frac{KX_i}{1+\tau^2\omega^2} = X_0\cos\phi$, $\frac{-\tau\omega KX_i}{1+\tau^2\omega^2} = X_0\sin\phi$

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$$\frac{X_0 \sin\phi}{X_0 \cos\phi} = \frac{-\tau\omega K X_i}{1+\tau^2\omega^2} \times \frac{1+\tau^2\omega^2}{K X_i}$$

$$\tan\phi = -\tau\omega$$

$$\boxed{\phi = \tan^{-1}(-\tau\omega)}$$

$$\boxed{X_0 = \frac{K X_i}{\sqrt{1+\tau^2\omega^2}}}$$

$$\boxed{\frac{X_0}{X_i} = \frac{K}{\sqrt{1+\tau^2\omega^2}}}$$, $\frac{X_0}{X_i}$ = amplitude ratio.

→ As the value of ω increases, the amplitude ratio decreases.
So, at $\omega = \frac{1}{\tau}$,

$$\frac{X_0}{X_i} = \frac{K}{\sqrt{2}}.$$

$$\Rightarrow \frac{X_0}{K X_i} = 0.707$$

This value of frequency is known as break point frequency.

26/03/22 **Frequency Response**

* Amplitude ratio

$$(M) = \frac{q_o(i\omega)}{q_i(i\omega)} = \frac{X_o(t)}{X_i(t)} = \frac{K}{\sqrt{1+(\tau\omega)^2}}$$

Phase shift,

$$\phi = \tan^{-1}(-\tau\omega)$$

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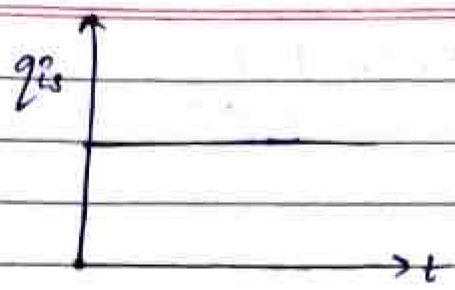
Step I/P



At $t=0$ $\quad q_i = q_o$

$\dot{q}_i = q_o = 0$

$(\tau D+1)q_o = Kq_i$

$q_o = q_o|_{cf} + q_o|_{pi}$

$(\tau D+1)q_o = 0$

$\tau D+1 = 0$

$D = -\frac{1}{\tau}$

$q_o|_{cf} = C_o e^{-t/\tau}$

$q_o = C_o e^{-t/\tau} + K\dot{q}_{is}$

At $t=0$, $q_o=0$, $q_i=0$

$0 = C_o + K\dot{q}_{is}$

$C_o = -K\dot{q}_{is}$

$$\boxed{q_o = K\dot{q}_{is}\left(1-e^{-t/\tau}\right)}$$

Error in measurement $= \dot{q}_{is} - \frac{q_o}{K}$

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$$Error = q_{is} - \frac{K q_{is}(1-e^{-t/\tau})}{K}$$

$$Error = q_{is} e^{-t/\tau}.$$ * Never overshoot.

Que: A thermometer has time constant of 3 sec. It is quickly taken from a temp. 0°C to a water bath having 80°C. What temp. will be indicated after 1.6 sec.

Ans: Given, $\tau = 3$ sec, $t = 1.6$ sec.

$$\theta_0 = \theta_i(1-e^{-t/\tau})$$

$$= (80-0)(1-e^{-1.6/3})$$

$$= 33.06°C$$

$$\approx 33.1°C$$

Que: A 1st order instrument is to measure signals with freq upto 100 Hz with an amplitude in accuracy of 5%. What is the max allowable time constant & phase shift at 50 Hz.

Ans: $M = 5\% = 0.95$ $\omega = 2\pi \times 100 = 314.16$

$$0.95 = \frac{1}{\sqrt{1+(\tau^2 50^2}}$$ $$50 = \tan^{-1}(-\tau \times 314.16)$$

$$0.95^2 = \frac{1}{1+\tau^2 50^2}$$ $$0.95 = \frac{1}{\sqrt{1+\tau^2 \times 314.16^2)}}$$

$$0.95^2 + 50^2 \times 0.95^2 \tau^2 = 1$$

$$\tau = 5.23 \times 10^{-4}$$

$$\phi = -9.33°$$

* 2^{nd} order System:

$$a_2 \frac{d^2 q_o}{dt^2} + a_1 \frac{dq_o}{dt} + a_0 q_o = b_0 q_i \quad \text{—— (1)}$$

$$\frac{b_0}{a_0} = K, \quad \sqrt{\frac{a_0}{a_2}} = \omega_n, \quad \frac{a_1}{2\sqrt{a_0 a_2}} = \xi \text{ (damping ratio)}$$

$K, \omega_n, \xi \rightarrow$ known

$a_0, a_1, a_2, b_0 \rightarrow$ unknown.

$$\frac{2\xi}{\omega_n} = \frac{a_1}{\sqrt{a_0 a_2}} \Big/ \omega_n$$

$$= \frac{a_1}{\sqrt{a_0 a_2}\sqrt{\frac{a_0}{a_2}}}.$$

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$$\frac{2\xi}{\omega_n} = \sqrt{\frac{a_1^2 a_2}{a_0 a_2 a_0}}$$

$$= \frac{a_1}{a_0}$$

$$\frac{a_2}{a_0}\frac{d^2 q_0}{dt^2} + \frac{a_1}{a_0}\frac{dq_0}{dt} + \frac{a_0}{a_0} q_0 = \frac{b_0}{a} q_i$$

$$\left(\frac{1}{\omega_n^2} D^2 + \frac{2\xi}{\omega_n} D + 1\right) q_0 = K q_i$$

Amplitude ratio, $M = \frac{q_0}{q_i} = \frac{1}{\sqrt{(1-r^2)^2 + (2\xi r)^2}}$

Phase shift $\Rightarrow \tan\phi = \frac{2\xi r}{(1-r^2)}$

$$\phi = \tan^{-1}\left(\frac{2\xi r}{(1-r^2)}\right)$$

where,

$r = \frac{\omega}{\omega_n}$

Que: A second order system is characterised by the following parameters

$a_0 = 2.05$, $a_1 = 3.75$, $a_2 = 5.25$, $r = 0.65$,

find i) ω_n (natural circular freq.) iv) phase shift

ii) damping ratio ξ

iii) amplitude ratio

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$$\omega_n = \sqrt{\frac{a_0}{a_2}} = \sqrt{\frac{2.05}{5.25}} = 0.624 \text{ rad/sec.}$$

$$\zeta = \frac{a_1}{2\sqrt{a_0 a_2}} = \frac{3.75}{2\sqrt{2.05 \times 5.25}} = 0.57 \text{ (underdamped)}$$

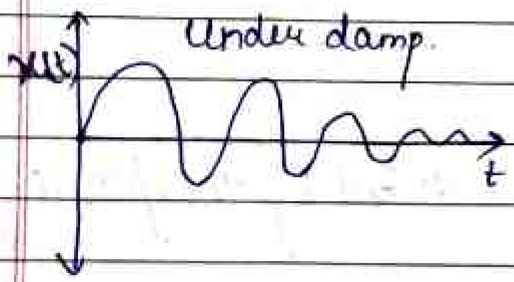
* $\left\{ \begin{array}{l} \zeta > 1 \text{ overdamped} \\ \zeta = 1 \text{ critically damped} \\ \zeta < 1 \text{ under damped} \end{array} \right\}$

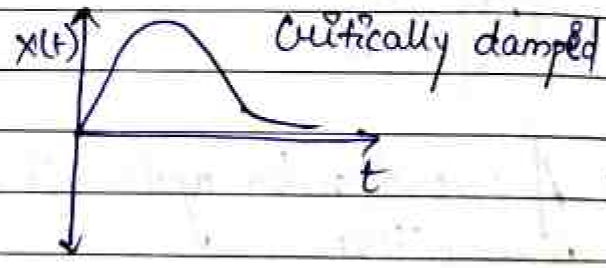
$$M = \frac{1}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}} = \frac{1}{\sqrt{(1-0.65^2)^2 + (2 \times 0.57 \times 0.65)^2}}$$

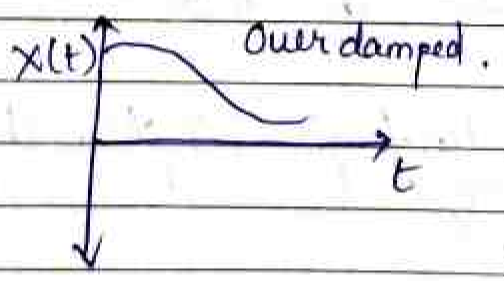
$M = 1.064$ (overshoot)

$$\phi = \tan^{-1}\left(\frac{2\zeta r}{1-r^2}\right)$$

$\phi = 52.07^\circ \approx 52.1^\circ$







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Que: The temperature of air during a particular process is cycling at the rate of 1 cycle every 5 mins. The temp sensor has a time constant 30 seconds. Calculate i) M -
ii) ϕ
iii) Time of lag

Ans. i) $M = \frac{1}{\sqrt{1 + (\tau\omega)^2}}$ $\quad$ $\omega = 2\pi f = 2\pi \frac{1}{5 \times 60} = 0.0209$

$M = \frac{1}{\sqrt{1 + (30 \times 0.02)^2}}$

$M = 0.857$
$M < 1$ [lagging in o/p]

ii) $\phi = \tan^{-1}(-\tau\omega) = \tan^{-1}(-30 \times 0.020) = +32.087^\circ$ (lag)
$= 32.1^\circ$

iii) Time lag $= \frac{\frac{32.1 \times \pi}{180} \text{ rad}}{\omega}$

$= \frac{32.1 \times \frac{\pi}{180}}{0.0209} = 26.8$ sec.

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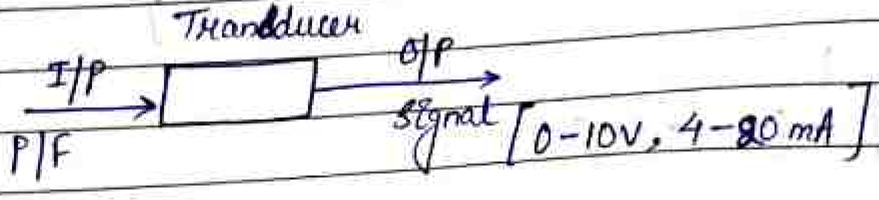
* TRANSDUCER :→

→ It is a device/component which converts one physical form into another.

ex. Thermometer : temp → displacement
Bourdon tube pressure gauge : pressure → disp.
Spring : Force → Displacement.
Manometer : Pressure → Disp.



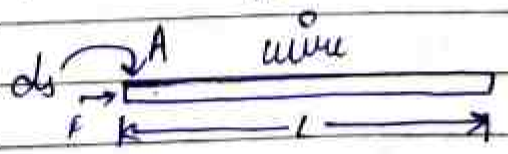
⟹ Advantages of converting mechanical input into electrical signal:

i) Effect of friction is minimised.
ii) Electrical signals are easy to amplified.
iii) Mass inertia effects are minimised
Recording & control is easy

* Classifications of Transducers :→

They are of three types : i) Resistance type transducer
ii) Inductance type
iii) Capacitance type.

1. Resistance Type Transducer :→



$R = \rho \frac{l}{A}$.

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$F \propto f(R)$

→ The resistance of a transducer it varies with temperature

$$R = R_0(1+\alpha \Delta T)$$

R_0 = reference resistance at reference temp. (room) of the material

α = coefficient of thermal expansion

ΔT = change in temp.

* Advantages:

1. They are inexpensive & easy to operate.
2. Electrical efficiency is high
3. Useful to measure large amplitude measurement

Disadvantages:

1. Significant loading effect
2. Generation of noise, misalignment may take place.

→ Commonly used resistance type transducers in mechanical applications:

a) Resistance strain gauge:
The change in value of resistance of metal, semi-conductor due to elongation or compression is known by the measuring torque, displacement & force.

b. Resistance Thermometer:
The change in resistance of metal wire due to change in temp. known by the measurement of the temperature.

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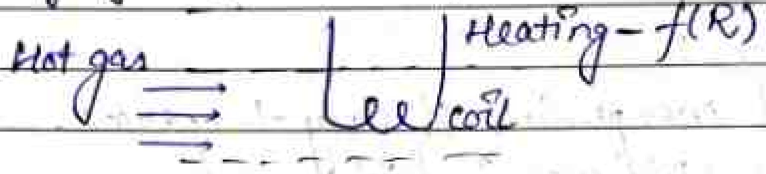
c) Resistance Hygrometer:
The change in the resistance of conducting strip due to the change of moisture content is known by the value of its corresponding humidity.

d) Hot Wire Meter:
The change in the resistance of heating elements due to convection cooling of a flow of a gas is known by its corresponding gas flow or pressure.



e) Photo Conductive Cell :→
The change in the resistance of a cell is known by the value by the corresponding change in light flux/intensity.
unit → lux

$$\text{Lux} = \text{Lumens}/m^2$$
$$\frac{W}{\text{flux}} = \frac{683}{\text{Steradian}\ (S_r)}$$

$$S_r = L_u \times Cd$$

f) Thermistor:
The change in resistance of a semiconductor that have a negative coefficient of resistance is known by its corresponding measurement of temp.

g) Potentiometer:
The change in resistance of a potentiometer reading due to the movement of the slider as a part of external force applied is known by its corresponding pressure/displ.

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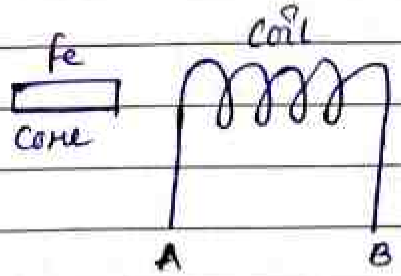
2. Inductance Type Transducer:
These transducer work on the principle of self Inductance or mutual Inductance.

a) Displacement Measurement:
i) These transducer offers considerable sensitivity for disp. or thickness measurement over a limited range.

ii) AC circuits can only be used.
iii) Proper electric & magnetic sheilding are required
iv) Iron cored coils are preferred because the magnetic flux get contain in iron path & magnetic interference is reduced.



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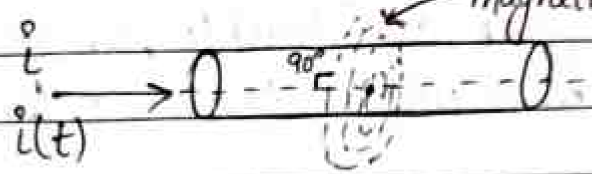
* Inductive Transducers:→

Mech $\xrightarrow{I/P}$ [Transducer] $\xrightarrow{O/P}$ Electrical.

1. displacement → [Inductive] → voltage
It is a displacement type transducer which converts displacement into voltage.

Inductive → Inductance
→ Self/ Mutual.

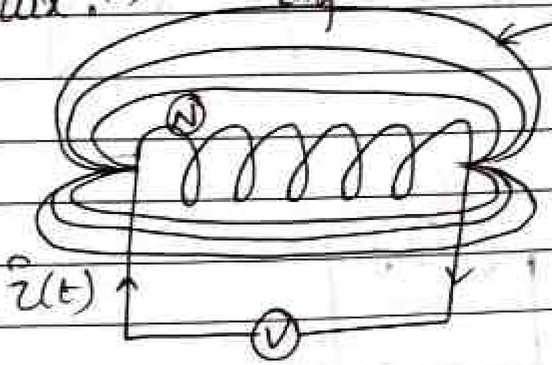
* Magnetism:



Right hand grip rule

Magnetic field lines set up around the conductor by the vicinity of the conductor.

Magnetic Flux :→ Emf.



Inductor is the electrically conductive conductor.

Faraday laws : $v =$
stated that the voltage

$$Emf \propto \frac{di}{dt}$$

$$Emf = L\frac{di}{dt}$$

↳ L inductance (Henry)

Lenz Law:

$$Emf \propto \frac{d\phi}{dt}$$

$$Emf_{(e)} = -N\frac{d\phi}{dt}$$, N = no. of turns.

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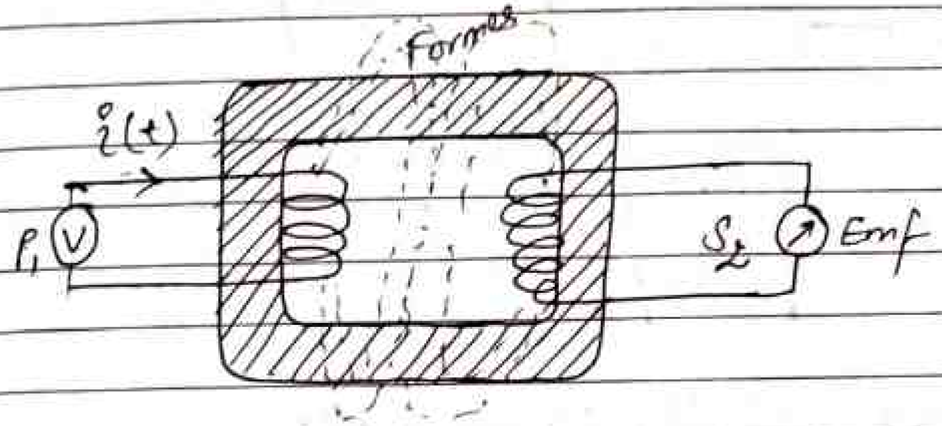
→ Emf generated opposes the applied voltage which is responsible for its generation.

* Self Inductance :→
→ The inductance is developed due to its own construction.
→ ...

* Mutual Inductance :→



→ It works on the principle of self inductance or mutual inductance & the desired electrical output is obtai by linking the magnetic flux line with the help of the armature (disp.)

* LVDT [Linear Variable Differential Transformer] :→

→ Linear means the output which is voltage is varies linearly with the input (disp.)

→ Variable : It means that the displacement is varied to get a linear output

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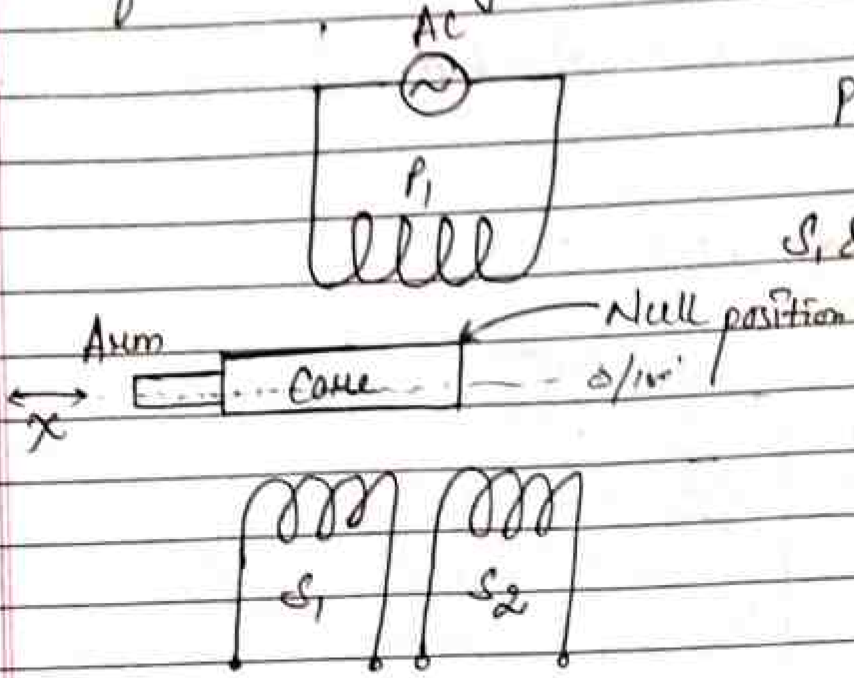
Differential: It means that the output the function of two different voltages.

Transformer: This signify its construction.

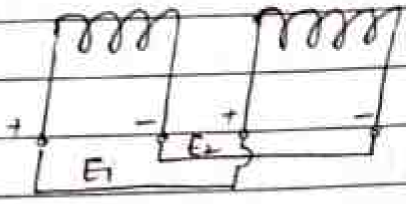


P_1 = primary winding

S_1 & S_2 = secondary windings

P_1 is energised by AC current (V).

The two secondary windings, they are maintained by series opposition.



$E_0 = E_1 - E_2$.

* Null Position :→
It is a position in which the core is prefectly aligned with the primary winding & two secondary windings.

→ When the core is moved to left hand side.

$E_1 > E_2$

$E_0 = +ve$

$\boxed{E_0 = E_1}$

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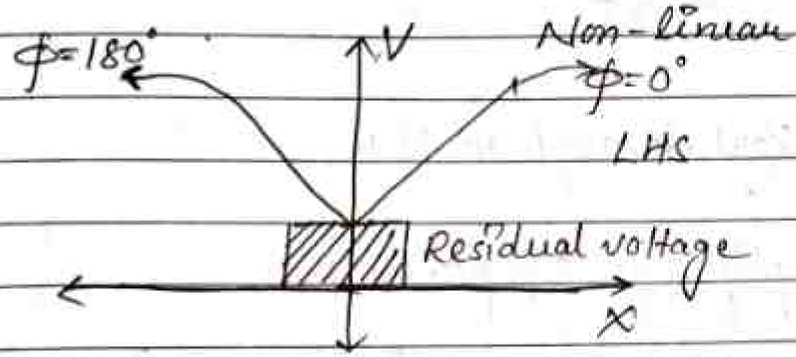
→ If we move further to LHS, this is called detached position

→ When the core is moved to RHS,

$$E_2 > E_1$$

$$E_0 = -ve$$

$$\boxed{E_0 = -E_2}$$



Advantages:

1. The effect of friction & hysteresis is reduced.
2. The output is highly linear (desired).
3. LVDT has a very high degree of resolution & sensitivity.
4. It is easy to operated & simple in construction.

Disadvantages:

1. It is influenced by the temperature effect.
2. A large displacement is required for an appreciable o/p.
3. It is influenced by the effect of vibrations.

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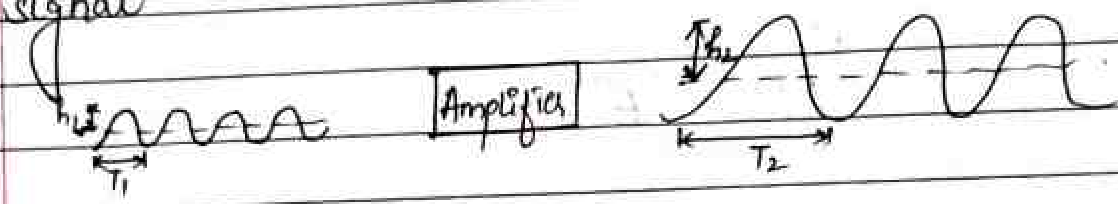
Amplifier & Operational Amplifier:

→ It is electric signal which converts weak signal to strong signal



$h_2 > h_1$

$T_2 > T_1$

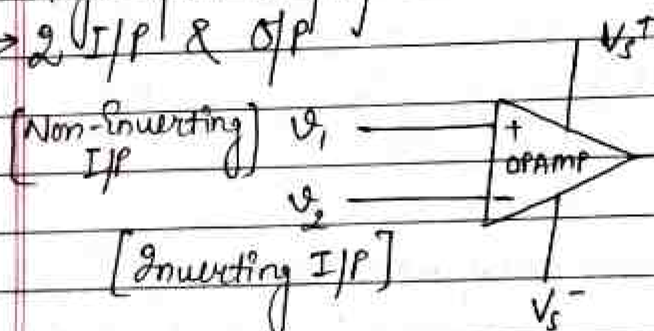
→ Invented by Karl Swetzal in 1941

* Operational Amplifier: → [Op-AMP]

→ Variety of functions. $(+ / - / \times / \div / \partial/\partial x / \int f(x)dx)$
Differentiating Integrating

→ High Gain amplifier

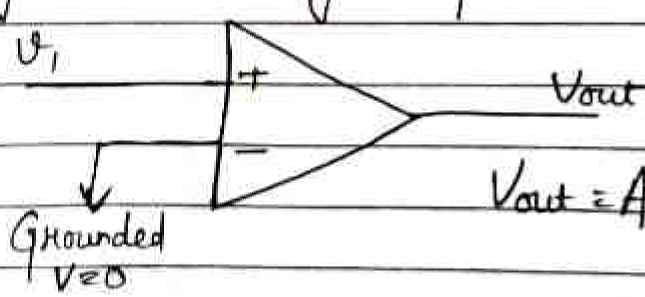
→ 2 I/P & O/P



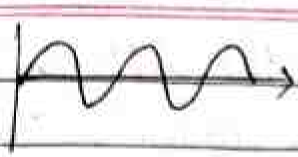
$V_{out} = A(v_1 - v_2)$

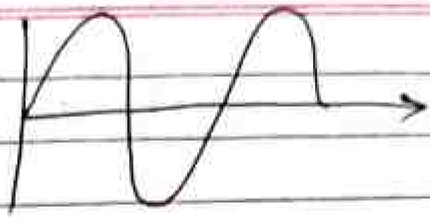
Here A = open loop gain

* Non-Inverting: No change in phase.

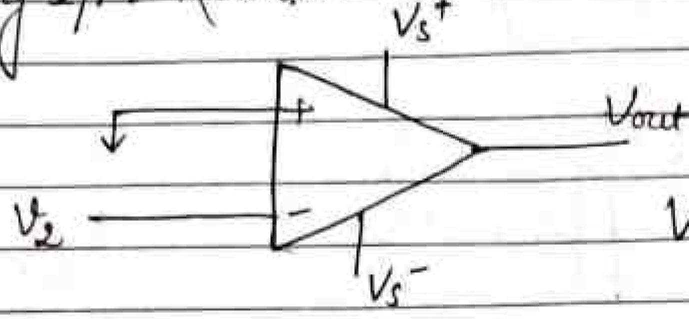


$V_{out} = A v_1$

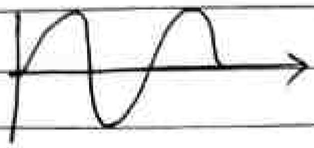


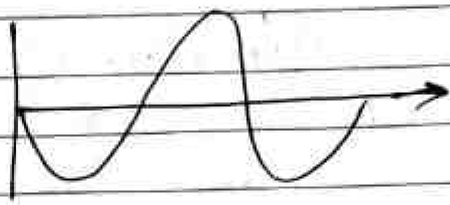


* Inverting I/P: Reversal

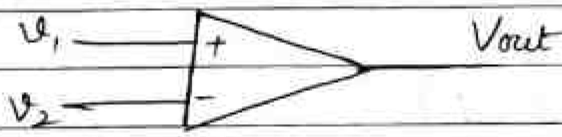


$V_{out} = -A v_2$.





$A = 10^5 - 10^6$



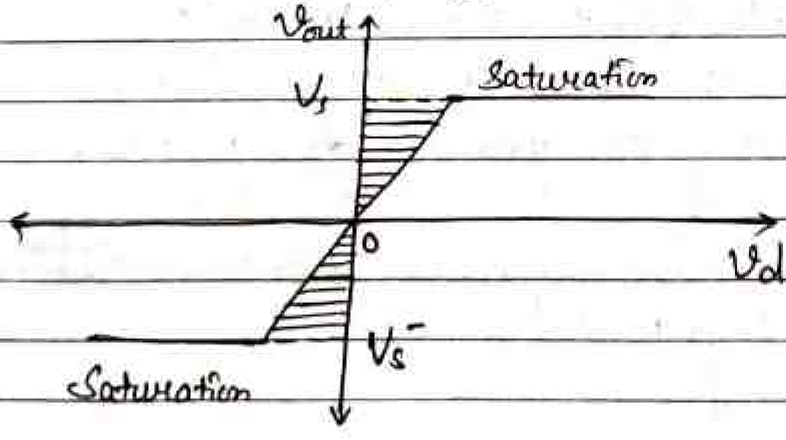
$v_1 - v_2 = 10 \mu V$

$A = 10^5$

$V_{out} = 10^6 \mu V = 1V$.

* Voltage Transfer Curve :→

$v_d = v_1 - v_2$



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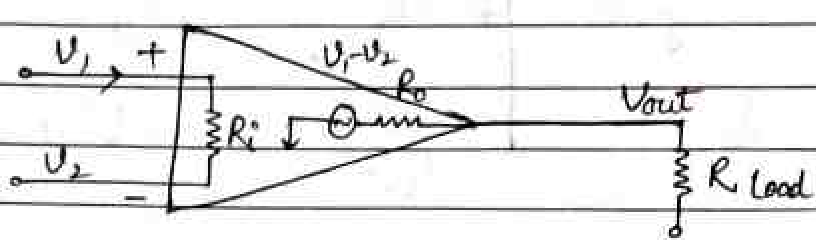
→ A operational amplifier will amplify the differential voltage V_d to a value less than or equal to supply voltage V_s or V_s^-

* **Equivalent Circuit of OPAMP :→**



$V_{out} = A(V_1 - V_2)$

Consideration: 1. $R_i >>> R_o$
$1M\Omega$ 1Ω

2. $A = 10^5 - 10^6$
3. $V_1 - V_2 = 1 - 100\mu V$ [Differential voltage]
4. Bandwidth = High
(Allow all frequency range I/P)

5. Slew rate $= \frac{\Delta V}{t}$ = High (as high as possible)

It is defined as rate of change of o/p voltage to a step change in time interval.

6. Common Mode Rejection Ratio (CMRR):
It is defined as the ratio of open loop gain in normal mode to that of the open loop gain in common mode.

→ Common mode is that mode ~~to~~ in which the both the terminals are grounded.

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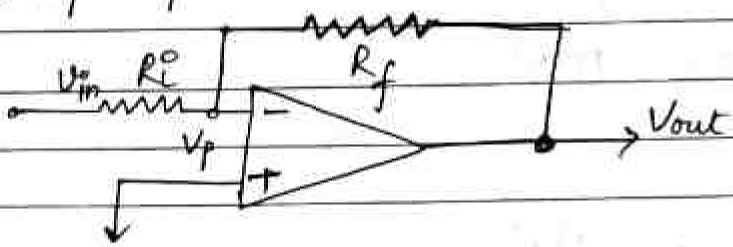
* Characteristics of an ideal opamp :→

1. $R_i = \infty$
2. R_o should be $= 0$
3. Bandwidth $= \infty$
4. Slew rate $= \infty$
5. CMRR $= \infty$
6. $A = \infty$

* Inverting Opamp Circuit :→

[Closed Loop]



→ We are using R_i in order to distinguish between V_{in} & V_p.
V_p = Virtual Grounded $\simeq 0V$

$$i = \frac{V_{in} - V_p}{R_i}$$

$$\Rightarrow i = \frac{V_p - V_{out}}{R_f}$$

$$\Rightarrow \frac{V_{in}}{R_i} = \frac{-V_{out}}{R_f}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{-R_f}{R_i}$$

$$\Rightarrow \boxed{A = -\frac{R_f}{R_i}}$$

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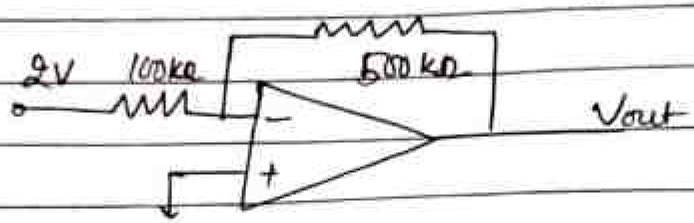
Que: In the fig. given below the value of $R_1 = 100\,k\Omega$, $R_f = 500\,k\Omega$. Calculate the V_{out} for an input voltage of 2V.



$$V_{out} = -\frac{R_f}{R_1} V_{in}$$

$$= -\frac{500}{100} \times 2$$

$$V_{out} = -10\,V$$

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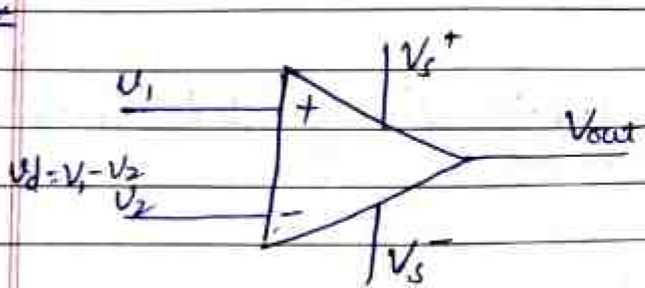
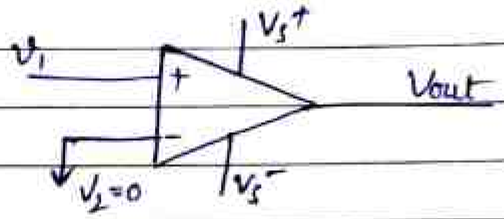
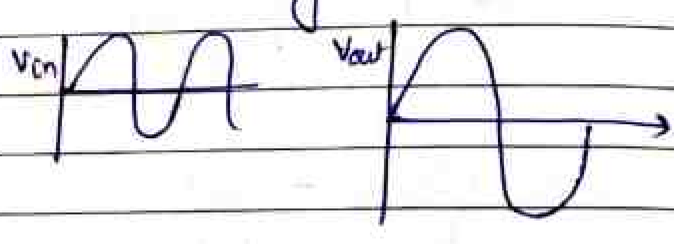
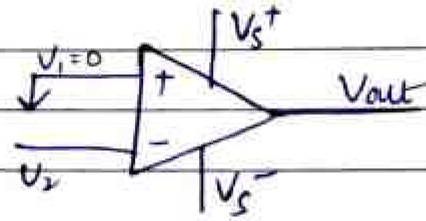


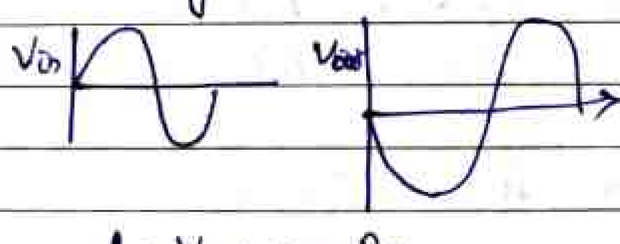


Non-Inverting





Inverting



$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}$$

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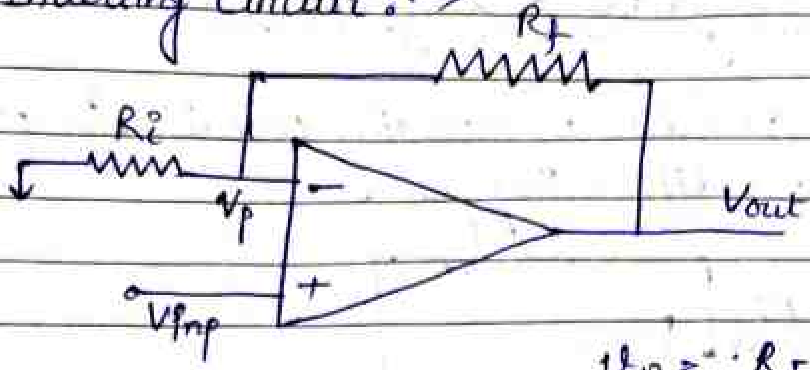
* Non-Inverting Circuit :→



$$v_p = \frac{R_I}{R_I + R_f} \cdot V_{out}$$

Imp. note → In case of inverting circuit v_p was made virtually ground. ($v_p = 0$). but

$$V_{out} = A(v_{inp} - v_p)$$

$$\Rightarrow V_{out} = A\left(v_{inp} - \frac{R_i}{R_f + R_i} \cdot V_{out}\right)$$

$$\Rightarrow V_{out} + \frac{AR_i}{R_i + R_f} V_{out} = A v_{inp}$$

$$\Rightarrow V_{out}\left(1 + A\frac{R_i}{R_i + R_f}\right) = A v_{inp}$$

$$\Rightarrow \frac{V_{out}}{V_{inp}} = \frac{A}{\left(1 + \frac{AR_i}{R_i + R_f}\right)} \qquad [A = 10^5 - 10^6]$$

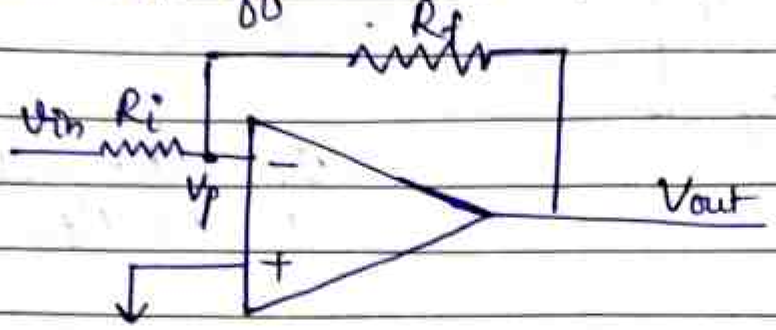
$$\Rightarrow \frac{V_{out}}{V_{inp}} = \frac{A}{\frac{AR_i}{R_i + R_f}}$$

$$\Rightarrow \frac{V_{out}}{V_{inp}} = \frac{R_i + R_f}{R_i}$$

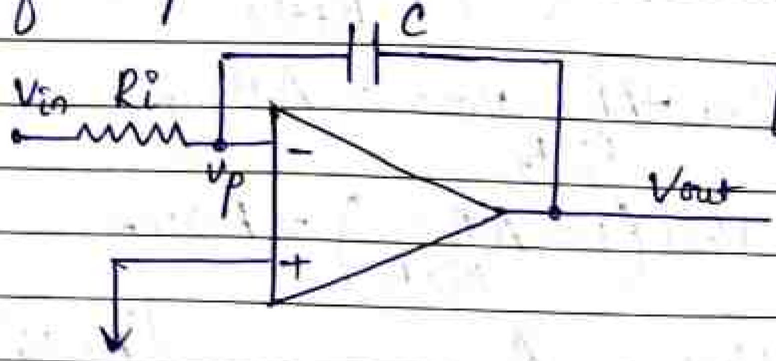
$$\Rightarrow \boxed{A = 1 + \frac{R_f}{R_i}}$$

* Opamp as Integrators & Differentiators :→

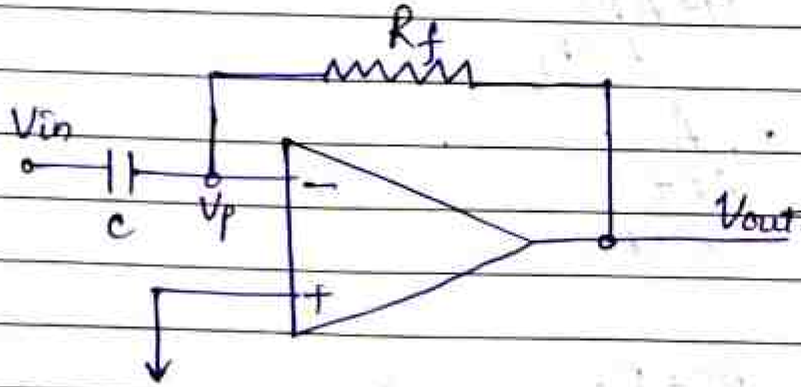
→ We always consider an Inverting circuit for performing Integrator and differentiator.



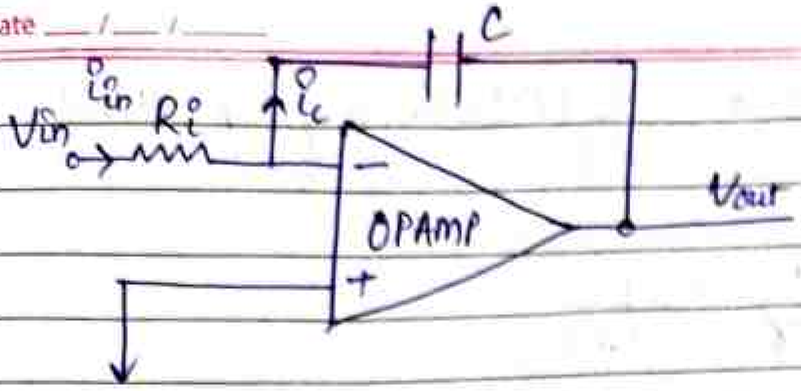
To perform opamp as differentiating element and Integrating element modification in the basic circuit is imposed by the use of a capacitor.



[Integration]



[Differentiation]



By Kirchoff's law, $I_{in} = I_c$

$$\frac{V_{in} - V_p}{R_i} = \frac{C\,dv_c}{dt}$$

We know,

$$Q = CV$$

$$\frac{dQ}{dt} = C\frac{dV}{dt} + V\frac{dC}{dt}$$

$$i_c = C\frac{dV}{dt}$$

$$\Rightarrow \frac{V_{in}}{R_i} = C\frac{dv_c}{dt}$$

$$\Rightarrow \frac{V_{in}}{R_i} = C\frac{d(V_p - V_{out})}{dt}$$

$$\Rightarrow \frac{V_{in}}{R_i} = -C\frac{dV_{out}}{dt}$$

$$\Rightarrow \frac{V_{in}}{-R_iC} = +\frac{dV_{out}}{dt}$$

Integrating, we get

$$\int \frac{V_{in}}{-R_iC} = \int \frac{dV_{out}}{dt}$$

$$\boxed{V_{out} = \frac{-1}{R_iC}\int V_{in}\,dt}$$

→ Opamp as integrating element signifies that the output voltage from the opamp is expressed as integral of all the input voltage in the inverting circuit.

→ If we take non-inverting circuit, there will be an extra V_p and $V_p \neq 0$ in this case.

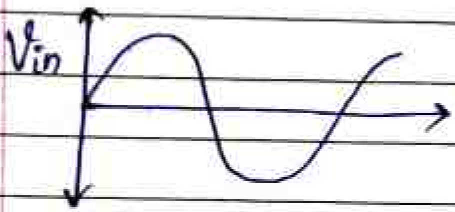
Gain, $A = -\frac{R_f}{R_i} = -\frac{X_c}{R_i}$ [Reluctance of capacitor]

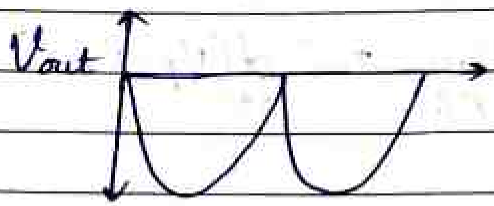
$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

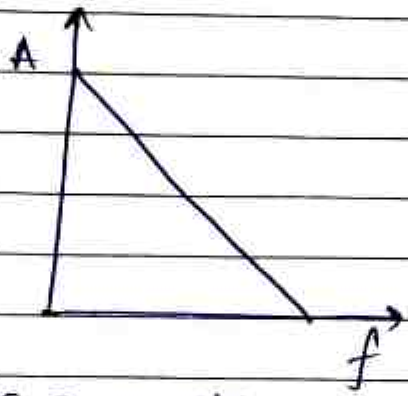
(f ↓ freq. of the signal)

$$\boxed{A \propto \frac{1}{\text{frequency}}}$$

→ For a sinosoidal curve,

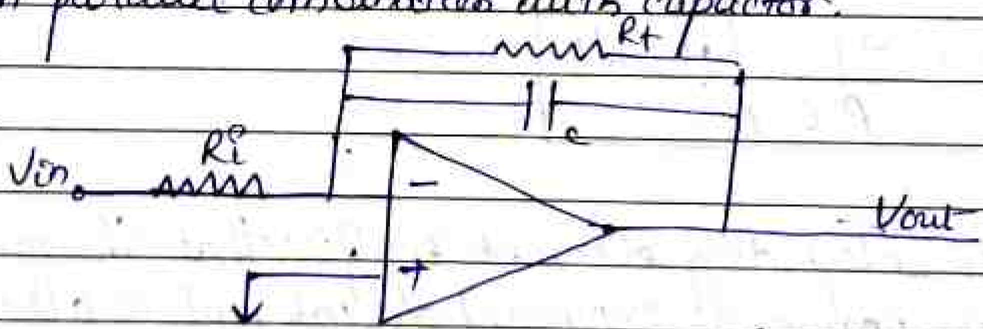


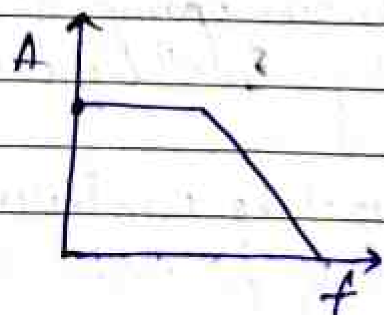




⇒ This plot is not desired because at negligible freq. the gain is on order 10^5 – 10^6.

⇒ To eliminate this effect, we add a feedback resistance R_f in parallel combination with capacitor.





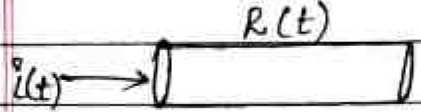
Date 09/04/2022 Mechanical O/P

⇒ Current Sensitive circuits
⇒ Voltage sensitive circuits
⇒ Ballast sensitive circuits
⇒ Voltage dividing circuits
⇒ Potentiometer

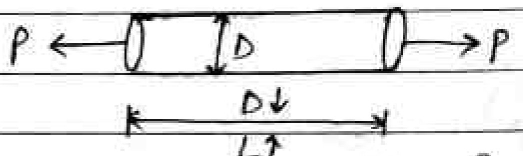
} Strain Gauge.

* Strain Gauge :→

Electrical I/P = Mechanical O/P



(Conducting wire)



Length ↑
Diameter ↓

$$R = \rho \frac{l}{A}$$

≃ Strain.

$$\epsilon_x = \frac{\Delta L}{L}, \quad \epsilon_y = \frac{\Delta D}{D}$$

$$\mu = \frac{-\epsilon_y}{\epsilon_x} = -\frac{\Delta D/D}{\Delta L/L}$$

We know, $R = \rho \frac{l}{A}$

$$A = CD^2 \qquad \begin{bmatrix} A \propto D^2 \\ A = CD^2 \end{bmatrix}$$

where $C = \frac{\pi}{4}$ (circular), $C = 1$ (square)

$$\therefore R = \rho \frac{l}{CD^2}$$

$$dR = \frac{CD^2(\rho\, dL + L\, d\rho) - \rho l(2CD\,dD)}{(CD^2)^2}$$

Saathi

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$$\Rightarrow dR = \frac{CD^2}{(CD^2)^2}[\rho dl + l d\rho] - \frac{\rho l \cdot 2CD dD}{(CD^2)^2}$$

$$\Rightarrow dR = \frac{1}{CD^2}[\rho dl + l d\rho] - \frac{2\rho l dD}{CD^3}$$

$$\Rightarrow dR = \frac{1}{CD^2}[\rho dl + l d\rho] - \frac{1}{CD^2} 2\rho l \frac{dD}{D}$$

Dividing the eq. by R,

$$\frac{dR}{R} = \frac{\frac{1}{CD^2}[\rho dl + l d\rho]}{\frac{\rho l}{CD^2}} - \frac{\frac{1}{CD^2} 2\rho l \frac{dD}{D}}{\frac{\rho l}{CD^2}}$$

$$\Rightarrow \boxed{\frac{dR}{R} = \frac{dl}{l} + \frac{d\rho}{\rho} - 2\frac{dD}{D}}$$

Divide by dl/l,

$$\Rightarrow \boxed{\frac{dR/R}{dl/l} = 1 + \frac{d\rho/\rho}{dl/l} + 2\mu}$$ ← Gauge factor (R_g / F_g / G_F)

$$\boxed{dR/R = G_F \epsilon_x}$$

The change in the resistance of conducting wire wrt the original resistance is directly proportional to the strain developed in the wire.

This expression co-relate an electrical parameter with a mechanical output.

→ All the circuits mentioned above works on this principle.

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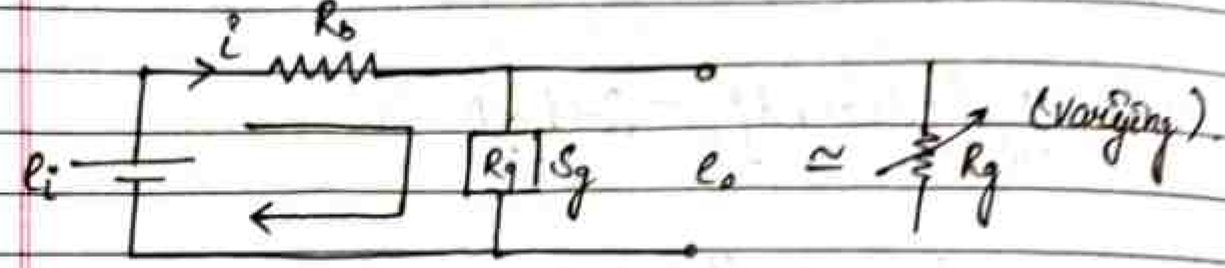
* Ballast Circuit :→



S_g is the strain gauge used to measure strain & has its own resistance.

R_b is balance resistance.

$$i = \frac{e_i}{R_b + R_g} \quad , \quad e_o = i R_g$$

$$e_o = \frac{e_i}{R_b + R_g} \cdot R_g$$

$$e_o = \frac{R_g}{R_b + R_g} \cdot e_i$$

$$\Rightarrow \frac{de_o}{dR_g} = \frac{(R_b + R_g) - R_g \cdot 1}{(R_b + R_g)^2} e_i$$

$$\Rightarrow \frac{de_o}{dR_g} = \frac{R_b}{(R_b + R_g)^2} \cdot e_i$$

$$\rightarrow de_o = \frac{R_b \, dR_g \, e_i}{(R_b + R_g)^2}$$

Multiply & divide R_g

$$\Rightarrow de_o = \frac{R_b R_g}{(R_g + R_b)^2} \frac{dR_g}{R_g} e_i$$

$$\Rightarrow de_o = \frac{R_b R_g}{(R_b + R_g)^2} \cdot G_f \, \epsilon \, e_i$$

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To get mechanical o/p, we put $R_b = R_g = 1\Omega$

$$de_o = \left(\frac{G_F}{4}\right) \epsilon e_i$$

→ In a Ballart circuit, to corelate the o/p voltage in terms of mech. strain the value of R_b is taken equal to R_g i.e 1Ω or equal.

→ The change in the o/p voltage is directly proportional to the mech. strain developed in the conducting wire.

/04/22

* Voltage Sensitive Circuit :→

Que: A strain gauge with nominal resistance of 120Ω and gauge factor 2 undergoes strain of 10^{-5}. What is the change in resistance in response to strain

Given, $R_i = 120\Omega$

$G_F = 2$

$\epsilon = 10^{-5}$

$$G_F = \frac{\frac{\Delta R}{R}}{\epsilon} =$$

$$\Rightarrow \Delta R = G_F R_i \epsilon = 2 \times 120 \times 10^{-5} = 240 \times 10^{-5}\Omega$$

$$\Rightarrow \boxed{\Delta R = 2.4 \times 10^{-3}\Omega}$$

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Que: Consider a single strain gauge of resistance 120 Ω mounted on the axial direction of an axially loaded specimen of steel ($E = 200\ GPa$). If the percentage change in the length of the rod due to load is 3% and the corresponding change in the resistivity is 0.3%, estimate the percentage change in resistance of gauge strain and its gauge factor. ($\mu = 0.3$)

Ans: Given, $E = 200\ GP$, $\Delta L = 3\%$, $\%\Delta\rho = 0.3\%$

$\epsilon = 0.03$, $\frac{\Delta L}{L} = 0.03$, $\frac{\Delta\rho}{\rho} = 0.003$

$$G_f = 1 + \frac{\Delta\rho/\rho}{\Delta L/L} + 2\mu$$

$$= 1 + \frac{0.003}{0.03} + 2\times 0.3$$

$$\boxed{G_f = 1.7}$$

$$G_f = \frac{\Delta R/R}{\epsilon} \qquad E = \frac{\sigma}{\epsilon}$$

$$\Rightarrow \sigma = E\times\epsilon = 200\times 10^9\times 0.03$$
$$= 6\times 10^9\ N/m^2$$

$$\Rightarrow \Delta R = G_f\times\epsilon\times R$$

$$\Rightarrow \Delta R = 1.7\times 0.03\times 120 = 6.12\ \Omega$$

$$\%\Delta R = \frac{6.12}{120}\times 100 = 5.1\%$$

$$\boxed{\%\Delta R = 5.1\%}$$

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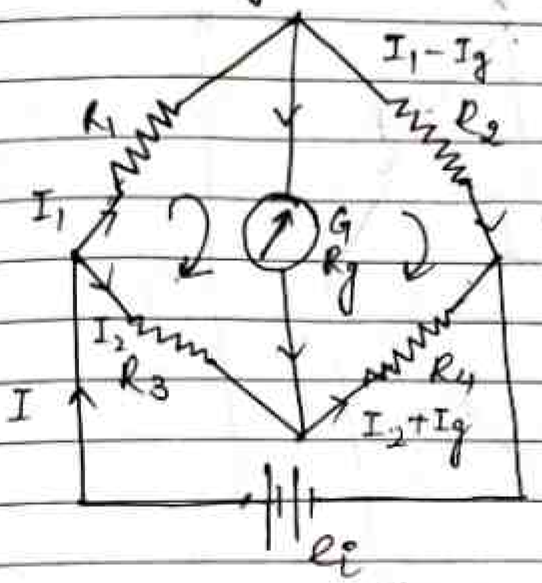
* Wheatstone Bridge :→ It is also called as resistance bridge.



$I = I_1 + I_2$

* When $I_g = 0$, then [Physics]

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Mech. — Impedence of G ↑, $I_g = 0$

Let, $I_g = 0$

Applying Kirchoff Voltage law in loop.

$$I_1 R_1 - I_2 R_3 = 0$$

$$\Rightarrow I_1 R_1 = I_2 R_3 \quad \text{——— (1)}$$

and $I_1 R_2 - I_2 R_4 = 0$

$$\Rightarrow I_1 R_2 = I_2 R_4 = 0 \quad \text{——— (2)}$$

Dividing (1) & (2), we get

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_4}$$

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

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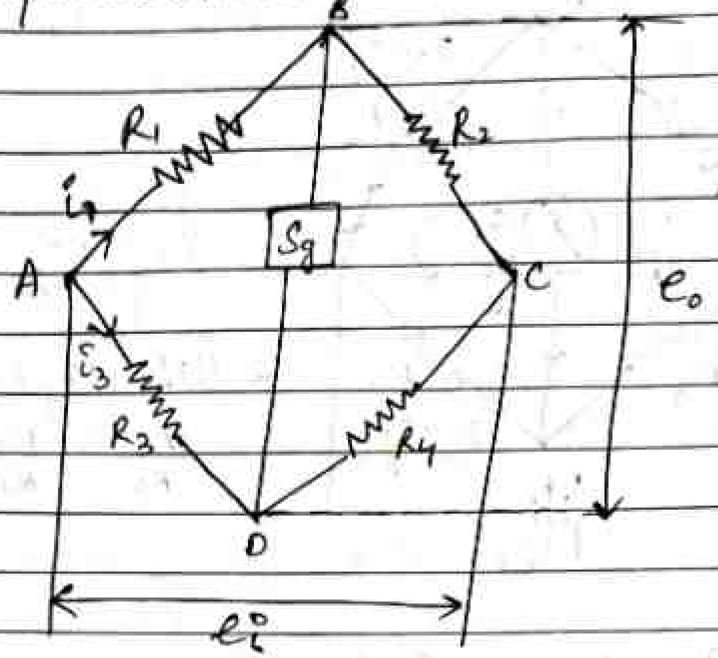
* Voltage Sensitive Circuit :→



In this circuit, the impedence of strain gauge is consider to be too high.

Loop ABC / ADC

$$e_0 = i_{ABC} R_1 - i_{ADC} R_3$$

$$\Rightarrow e_0 = \frac{e_i}{R_1+R_2} \cdot R_1 - \frac{e_i}{R_3+R_4} \cdot R_3$$

$$\Rightarrow e_0 = e_i \left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4} \right)$$

$$\Rightarrow e_0 = e_i \left[\frac{R_1 R_4 - R_3 R_2}{(R_1+R_2)(R_3+R_4)} \right]$$

Consider a small change in the resistance R_1 lead to a change in output e_0 i.e. Δe_0

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$$\frac{e_0}{e_i} = \frac{R_1R_4 - R_2R_3}{(R_1+R_2)(R_3+R_4)}$$

$$\Rightarrow \frac{e_0 + \Delta e_0}{e_i} = \left[\frac{(R_1+\Delta R_1)R_4 - R_2R_3}{(R_1+\Delta R_1+R_2)(R_3+R_4)}\right]$$

Divide by R_1R_4;

$$= \left[\frac{1 + \frac{\Delta R_1}{R_1} - \frac{R_2R_3}{R_1R_4}}{\frac{R_3}{R_4} + 1 + \frac{\Delta R_1 R_3}{R_1R_4} + \frac{\Delta R_1}{R_1} + \frac{R_3R_2}{R_1R_4} + \frac{R_2}{R_1}}\right]$$

Consider the $R_1 = R_2 = R_3 = R_4 = R$

$$\frac{e_0 + \Delta e_0}{e_i} = \frac{\frac{\Delta R_1}{R}}{4 + 2\frac{\Delta R_1}{R}}$$

The change in the resistance R_1 is assumed due to very small current passing through the strain gauge.
It acts as a strain gauge so we can replace, $\Delta R_1 = \Delta R_g$

$$\frac{e_0 + \Delta e_0}{e_i} = \frac{\frac{\Delta R_g}{R_g}}{4 + 2\frac{\Delta R_g}{R_g}}$$

$$\frac{e_0 + \Delta e_0}{e_i} = \frac{G_f \epsilon}{4} \qquad \left[\because 2\frac{\Delta R_g}{R_g} \lll 4\right]$$

→ In the voltage sensitive circuit the output voltage is direct proportional to strain i.e.

output ~~voltage~~ voltage $\propto \epsilon$

$$\boxed{e_o \propto \epsilon}$$

→ The G_f of given circuit is constant, the only variable is the strain developed.

Que: In a voltage sensitive circuit the gauge factor is 2. The strain developed in resistor is 3%. Calculate the output voltage developed if the input voltage is 6 V.

Ans: Given, $G_f = 2$, $\epsilon = 0.03$, $e_i = 6V$

$$\frac{e_o + \delta e_o}{e_i} = \frac{G_f \epsilon}{4}$$

$$\frac{e_o + 0}{6} = \frac{2 \times 0.03}{4}$$

$$\boxed{e_o = 0.09V}$$

13-04-22

Potentiometer
Vacuum tube Voltmeter
Cathode Ray Tube (CRT) & Cathode Ray Oscilloscope (CRO) ✓

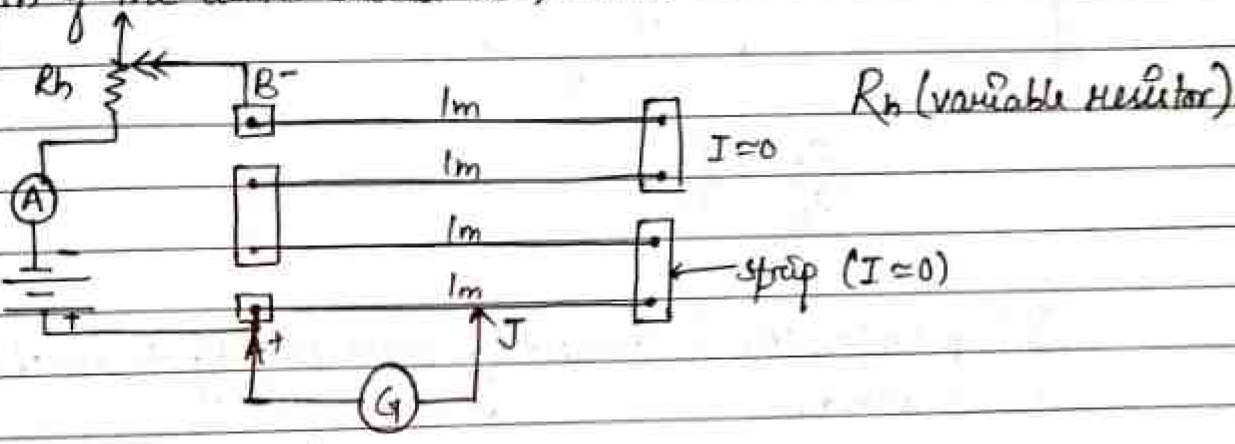
Saathi

Date __/__/____

* Potentiometer / POT :→
Works on the principle of meter bridge.

→ Measure the potential difference
→ Compare the unknown emf of two batteries.
If the emf of one battery is known then the other can be find.
→ Potentiometer is an accurate measurement device. (negligible error)
→ Voltmeter / Ammeter : approximately reading.

* Construction :→
Length of the wire should be > 10 m



Wire : Magnium / Constantan.

In the construction there are parallel wires (Constantan / Magnium) of each equal length (say 1 m each). At the conjuncture, strips are placed to avoid the flow of current & they are made up of material having higher electrical resistance. A variable resistor (rheostat) is used to control the current in the circuit. and the objective is to maintain constant current in the circuit.

We know, $V = IR$ (Ohm's law)

$$\Rightarrow V = I \cdot \rho \frac{l}{A}$$

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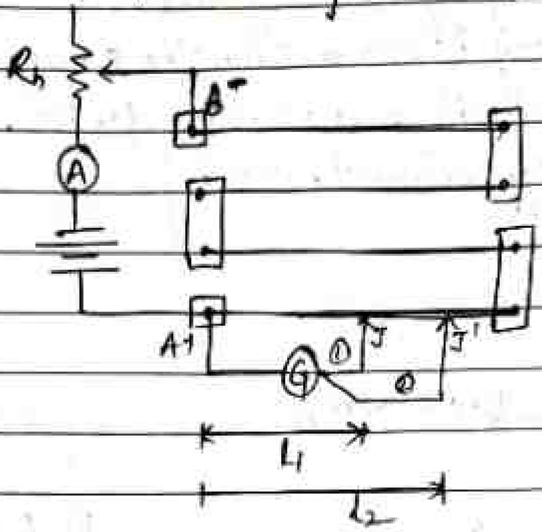
$\Rightarrow \boxed{V \propto l}$

This is the principle of working/operation of a potentiometer.

→ The voltage generated or emf is directly proportional to the length.



$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

This potentiometer is converting electrical i/p to mechanical o/p or vice versa.

* Vacuum Tube Voltmeter [VTVM] :→

→ It is also used to measure voltage, current & resistance in the circuit.

→ It is also used for amplification & rectification (diode)

→ This is preferred over other voltage measuring devices because it consumes very less power for its operation.

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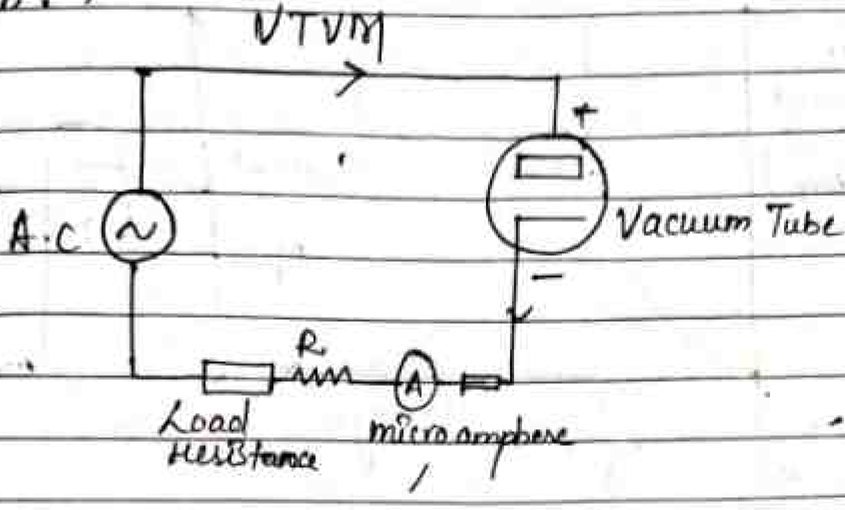
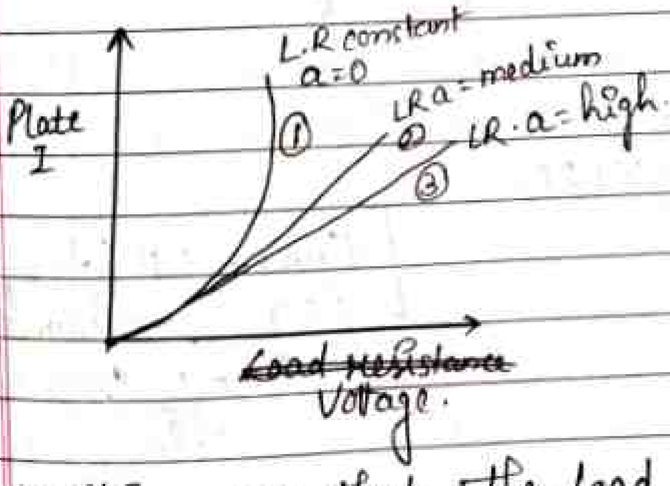
Construction :→



→ In the construction, AC supply is provided to the circuit, current flows in the vacuum tube (acts as a diode). There is a load resistor.

→ Vacuum tube is basically a diode that allows the current to flow only in one direction that means when the +ve voltage is applied across the terminal, plate current increases as the input supply of voltage increases & when the polarity of voltage is reversed there is no conduction of current in the circuit.



→ This means that the load resistance in the circuit is increased as long as the o/p (plate current) is directly proportional (linear) wrt the i/p voltage

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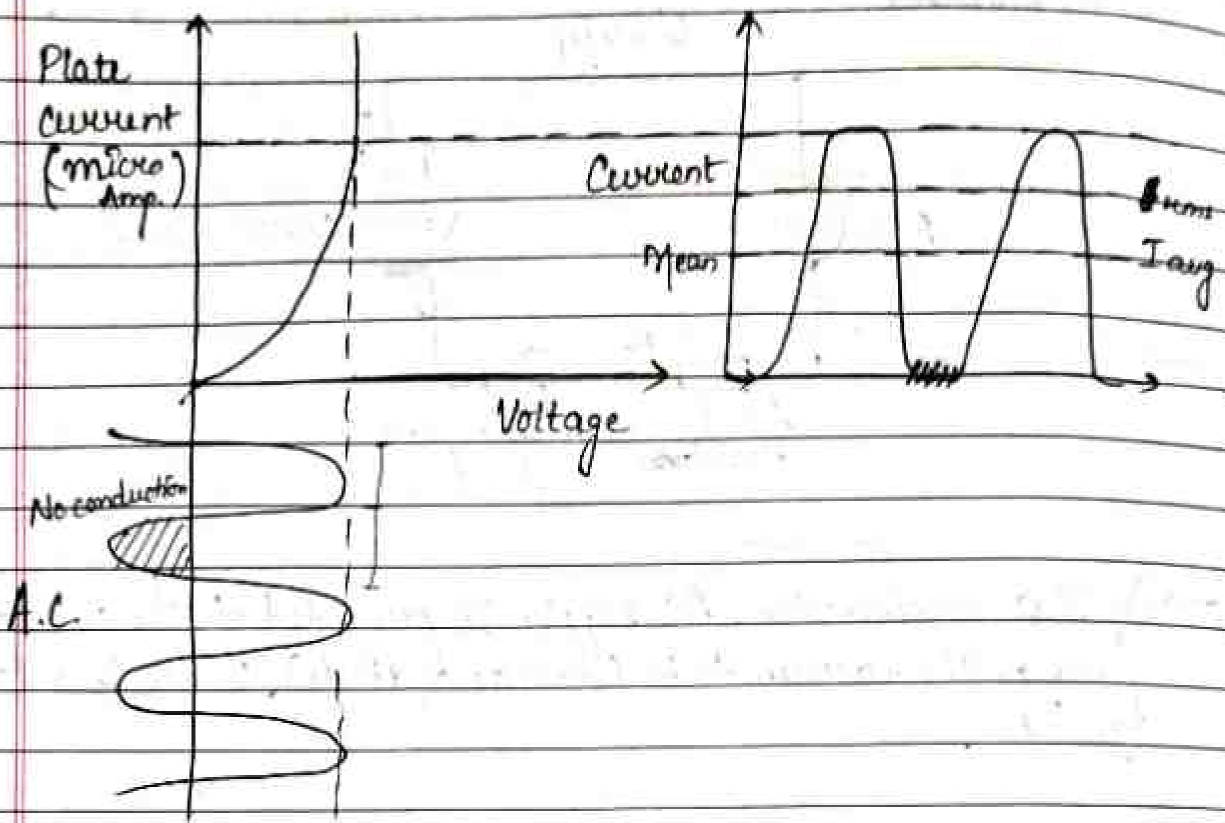

→ The graph b/w current & voltage is shown as above. It may be noted that the vacuum tube conducts current only in the +ve half cycle.

Let, $E_0 \sin \omega t$ is the nature of voltage
or
$E_0 \cos \omega t$

$$I_{avg} = \frac{E_{avg}}{2R_l} = \frac{E_{rms}}{2 \times 1.11 R_l}$$

$$\left[\frac{E_{rms}}{E_{avg}} = 1.11 \text{ (form factor) vacuum tube} \right]$$

$$= \frac{1}{\sqrt{2}} \text{ (resistor/capacitor)}$$

$$\Rightarrow I_{avg} = \frac{0.45 E_{rms}}{R_l}$$

$$\text{Power} = \frac{E_{avg}^2}{2R_l}$$

→ Power consumption is very less as E_{avg} is small.

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In a vacuum tube voltmeter, voltage (elec. i/p) to plate current of vaccum tube (which is of the order of μA) resulting in a very small amount of emf. which further generates a very less power.

* Advantages :→
1. Very less power consumption.
2. It has got a very high sensitivity in comparison to other voltage/current measuring devices.
3. Easy to operate & simple in construction.

* Cathode Ray Oscilloscope [CRO] :→

→ It is an electronic device used to measure :
i) frequency
ii) phase angle / shift
iii) voltage
iv) current
v) It can be used to test the component (diode/capacitor/resistor/transistor)

→ It is a device that converts electrical i/p into pictorial representation of its parameters on a screen.

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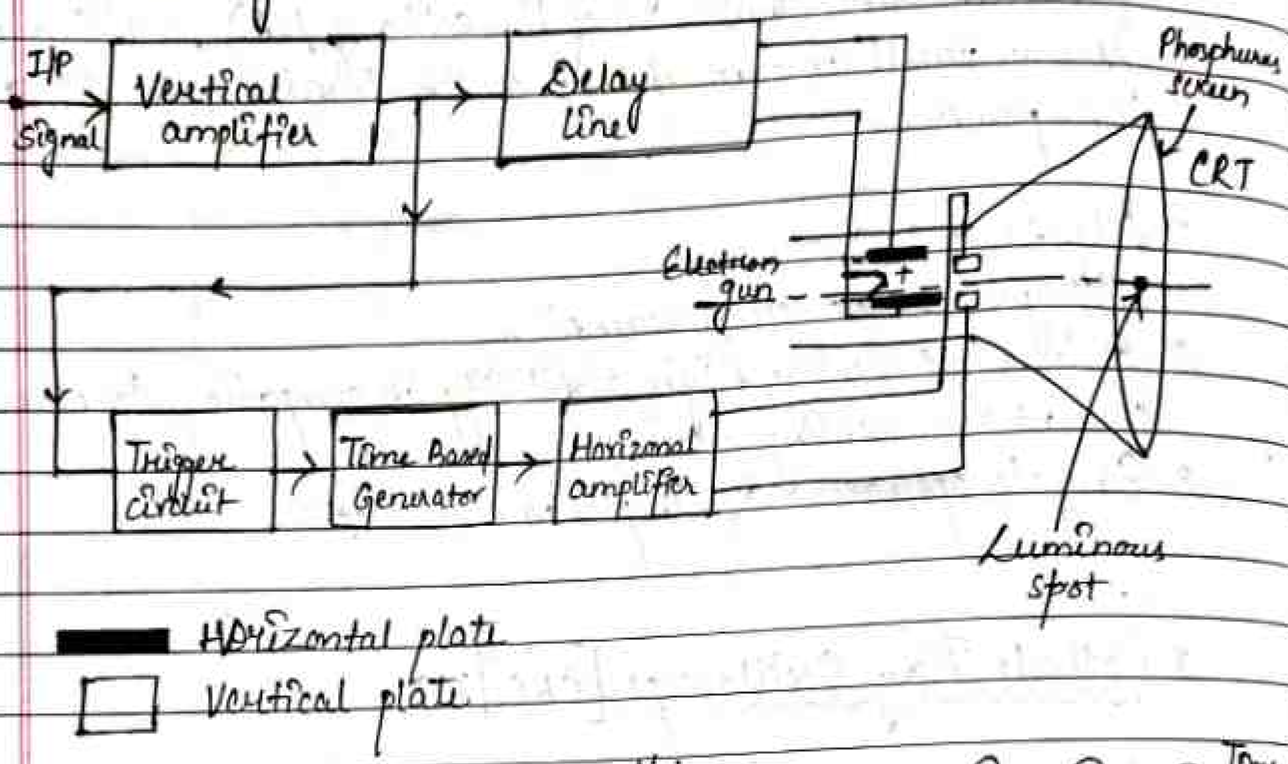
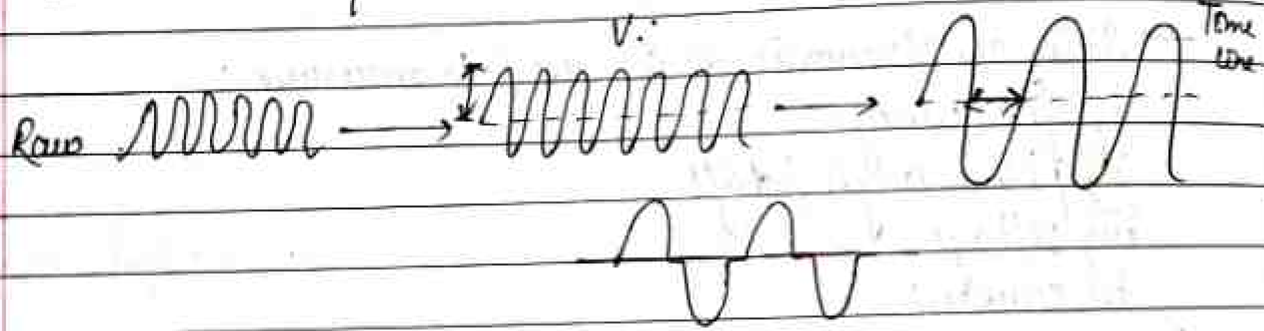
Block Diagram:





→ Trigger circuit is used to find out those points for which there is no appreciable output. This circuit synchronises i/p signal to wave form.

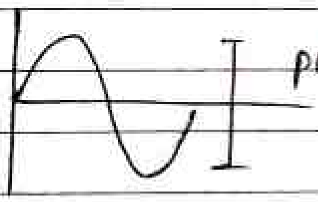
→ Time based generator is used to create the base line required for horizontal amplification.

→ After the signal has been vertical & horizontal amplified the signal is taken into a cathode ray tube. The time taken for horizontal amplification is greater than vertical amplification. and it is required to fed the signal into the cathod ray tube at same time.

Date __/__/____

→ The main components of CRT are
i) electron gun
ii) Control grid
iii) horizontal & vertical deflection plate
iv) accelerating anode.
v) focusing anodes
vi) heater (cathode)

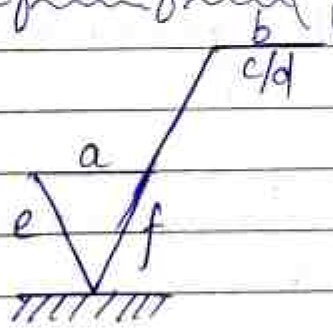
→ Heater is used to heat up the cathode, electrons will be emitted This electrons are passed through a very narrow path by means of a control grid which are further accelerated by means of the accelerating and focusing anodes.
The movement of the electrons are projected onto the phosphor screen. The deflection of electrons due to the plates



peak to peak → voltage measurement

1/04/22

* Measurement of Surface Roughness :→



a = Roughness (µm)
b = production method
c = sampling length
d = Other values related to surface roughness (∇)
e = machine allowance
f = pattern of the surface (⊥, ||)

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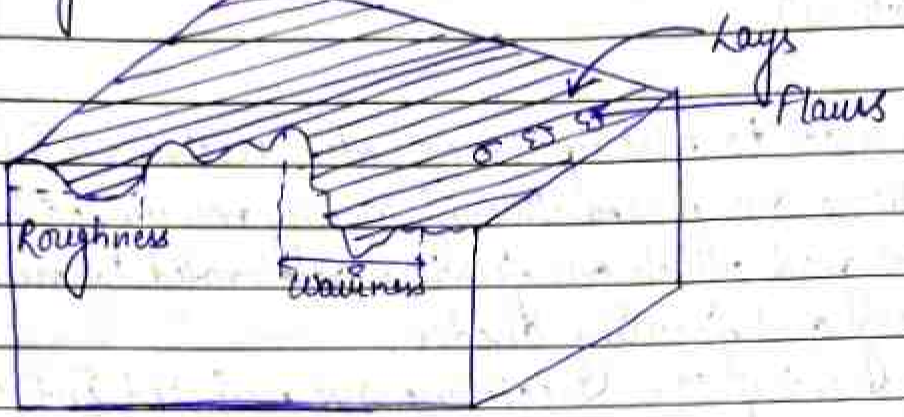
* Surface roughness / surface finish / surface texture :→

→ Surface texture is the repeatative or random variations from the nominal surface.

→ No surface ~~which~~ is perfectly smooth. There exist irregularities (micro or macro).



→ Surface texture may be classified into four types -

a) Surface roughness
b) Waviness
c) Lays
d) Flaws

a) Surface Roughness :→

It is the microirregualities present on the surface.

b) Waviness :→

There are the macro irregularities present on the surface.

c) Lays :→

It refers to the surface pattern or direction of irregularities present on the surface.

Saathi

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d) Flaws :→

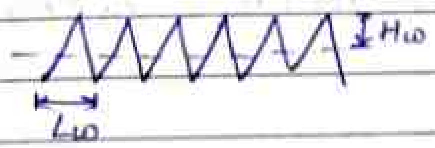
These are the defects present on the surface in the form of impurities / hard inclusions etc.

* **Causes of Surface Irregularities :→**

i) The types of machining process.
ii) Material of the workpiece
iii) Vibration
iv) Rigidity of the machine tool.
v) Cutting conditions (speed, feed, depth of cut)
vi) Deformations due to surface pattern of w/p.
vii) Type, form, material or design of clamping or holding devices
viii) Type of coolant / lubricant used.

* **Surface Roughness Vs Waviness :→**

Waviness



$\frac{L_w}{H_w} > 50$

Roughness

$\frac{L_r}{h_r} < 50$

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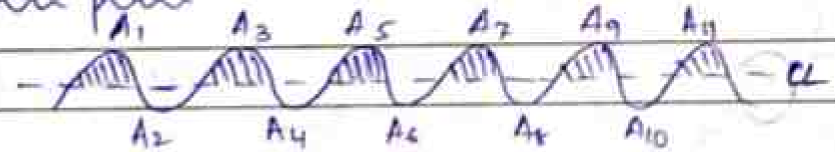
Causes of Waviness :→

i) Inaccuracy in the slide.
ii) Misalignment of centres.
iii) Wear & tear of guides.
iv) Non-linear feed motion
v) Deformation of the w/p under the action of cutting forces.
vi) Vibrations of any kind.

Methods of Computing Surface Roughness :→

There are two method of determining surface roughness :-
a) Centre Line Average (CLA)
b) Root Mean Square (RMS)

a) CLA Method :→



$A_1 + A_3 + A_5 + A_7 + A_9 + A_{11} = A_2 + A_4 + A_6 + A_8 + A_{10}$

CLA

The steps of obtaining the surface roughness using CLA :
i) A centre line is drawn in such a way that the sum of the areas above & below the centre line ~~are~~ becomes equal

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ii) The height of the individual peaks are calculated.
iii) Finally, the CLA is taken as :-

$$CLA = \frac{|h_1| + |h_2| + \dots + |h_n|}{n}$$

b) RMS Method :-
In this method, the steps of determining the ∇ remains the same only the final value is computed as shown below:-

$$RMS = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \dots + h_n^2}{n}}$$

* Measurement of surface roughness :→
i) Comparision method
ii) Direct method

Comparision method is further segregated into -
a) Touch Inspection
b) Visual inspection
c) Scratch inspection
d) Magnified inspection
e) Surface photograph.
f) Micro Interferometer
g) Reflection of light
h) Absorption of gas or liquid
i) Wallace surface dynamometer

This comparisons method are not recommended.

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ii) Direct Method :→

a) Profilometer – Results are inaccurate.

b) Tomlinson's surface meter

c) Taylor Hobson Talysurf ✓

d) Sigma Microtest

Dt. 21-04-2022

e) Robert Mercin Roughness Indicator.

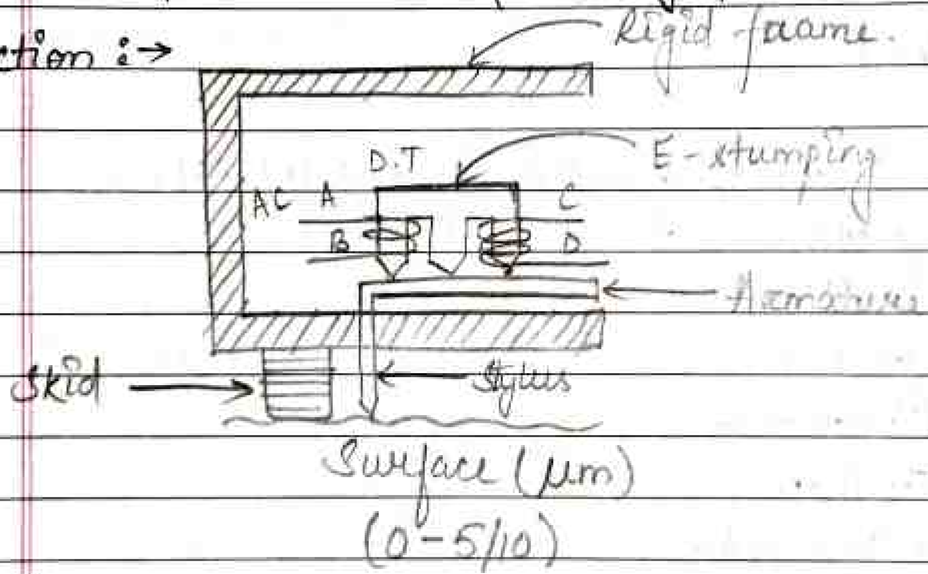
* Taylor Hobson Talysurf :→

→ Most accurate results.

→ Rapid response (Highly sensitive) (Time constant is very less) $\propto K_c$

→ Principle : Carrier Modulating principle.

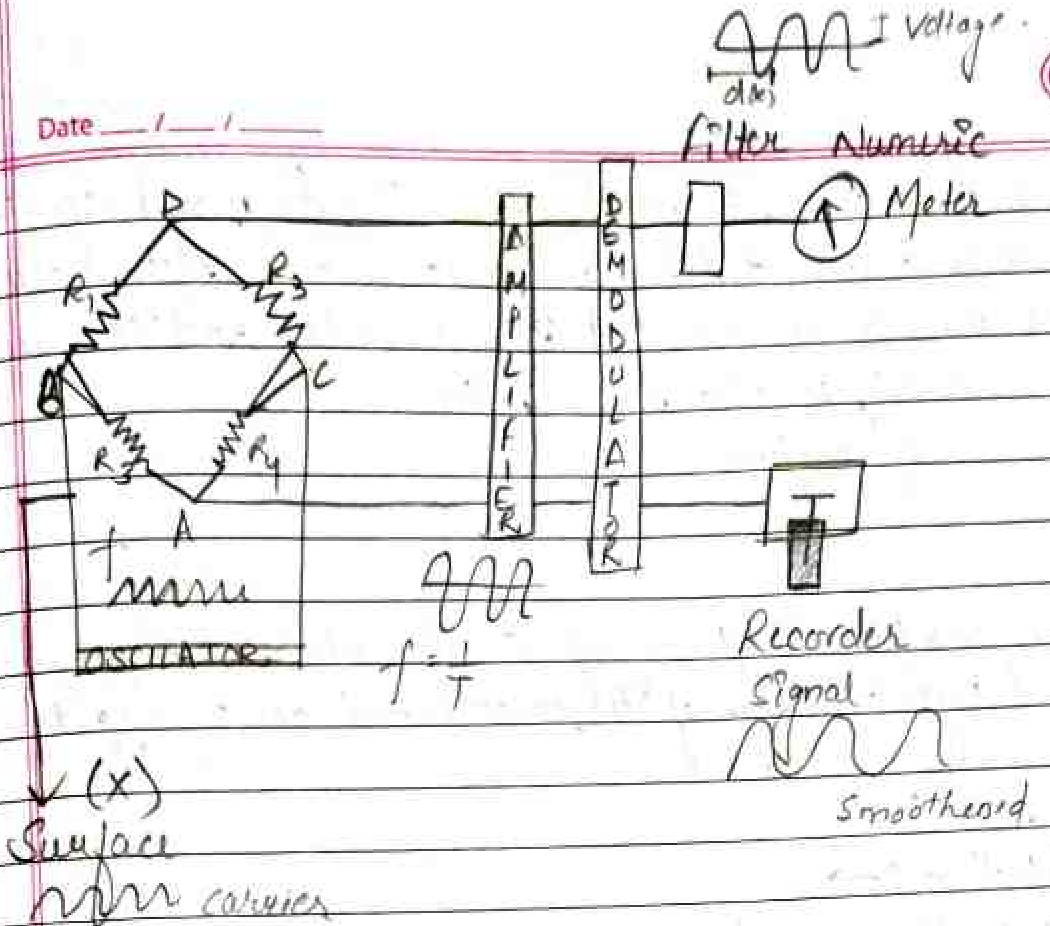
Construction :→



Δ amp ∝ disp.

D.T- Differential transducer

→ If surface roughness is more than 10 µm it can damage the instrument.



Working :→

In Taylor Hobson Talysurf a stylus is moved across a surface whose roughness is to be measured. The tip of the stylus is of 2 μm or less. A skid is placed in the arrangement to guide the stylus over the surface. The skid is operated by a motorised driving unit. The stylus will pick up the signal from the surface (carrier). So this signal (carrier) is modulated and demodulated by means of a E-stamping arrangement.

In a E-stamping there are two coils in which AC current flows and the central leg is pivoted on the armature. The objective of pivoting the central leg is that when the armature moves or displaces the air gap b/w the two legs (1&2) varies resulting in a change of amplitude in the current flowing in the E-stamping.

This change in the amplitude of current is directly proportion to disp of stylus.

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The inside circuit as shown in the figure helps to modulate & demodulate and also smoothened the carrier signal which is recorded in a recorder and the numerical assessment of roughness is also shown in the meter.

→ The surface roughness of the demodulated signal is defined by the range of its smoothened curve / pitch.

Limitation :→

→ Its size is very less so we need disp the stylus over longer range to get the readings.

This may cause wear & tear of stylus over a period of time resulting in inaccurate readings.

⇒ Stylus :

a) Tip radius is 2μm or less

b) Tip is made up of diamond.

Diamond is used as cutting tool as it has highest thermal conductivity (K), K = 4516 W/m²K, toughness is high.

$K_{solid} > K_{liq.} > K_{gas}$

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* Measurement of fluid flow :→

1. Pitot tube – dynamic pressure / velocity
2. Venturimeter
3. Orificemeter
4. Sonic Nozzle
5. Rotameter.

} Bernoli's eq.

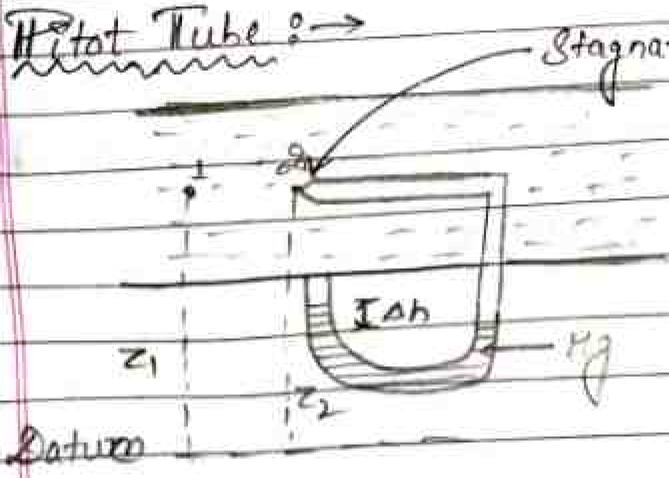
$$\frac{P}{\rho} + \frac{V^2}{2} + gz = \text{constant}$$

→ Measurement of fluid flows required very high precision instruments and selection of the instrument depends on many factor including cost.

→ Selection of instrument depends on coefficient of discharge Cd.

Venturimeter ≃ 0.96 - 0.98
Pitot tube < 0.8
Orificemeter 0.6 - 0.8

* Pitot Tube :→



$v_2 \simeq 0$

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2} + gZ_1 = \frac{P_2}{\rho_2} + \frac{V_2^2}{2} + gZ_1$$

$$\Rightarrow \frac{V_1^2}{2} = \frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}$$

$$\Rightarrow v_1 = \sqrt{2\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right)}$$

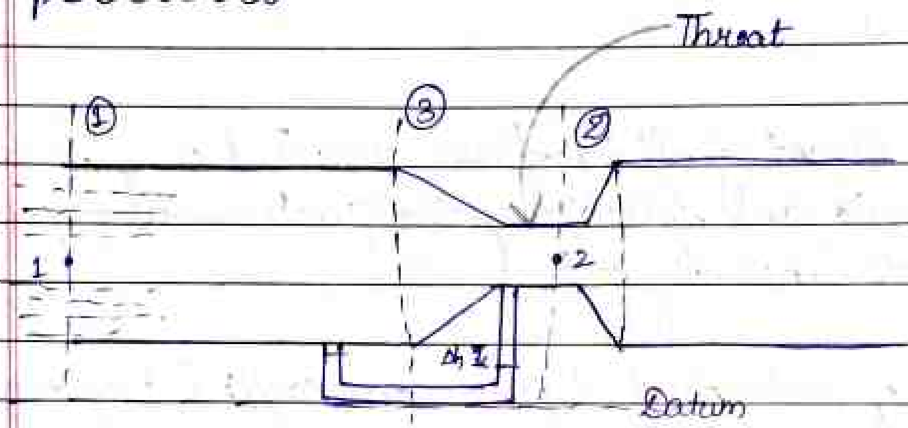
$$\rho_1 = \rho_2 = \rho$$

$$\Rightarrow \boxed{v_1 = \sqrt{\frac{2(P_2 - P_1)}{\rho}}}$$

23/04/2022

* Flow Meter / Obstruction Meters:

2 Venturimeter: →



Schematic diagram

→ Velocity (v_2)

→ Mass flow rate

→ Volumetric flow rate

→ Ventrimeter works on the principle of Bernoulli's theorem.

Applying Bernoulli's eq in ① & ②,

$$\frac{P_1}{\rho_1} + \frac{v_1^2}{2} + z_1 = \frac{P_2}{\rho_2} + \frac{v_2^2}{2} + z_2$$

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Continuity equation, $\rho_1 v_1 A_1 = \rho_2 v_2 A_2$

$$\Rightarrow v_2 = \frac{\rho_1 v_1 A_1}{\rho_2 A_2}$$

The flow is incompressible, $\rho_1 = \rho_2 = \rho$

$$\boxed{v_2 = \frac{A_1}{A_2} v_1}$$

$$\boxed{v_1 = \frac{A_2}{A_1} v_2}$$

So, $$\frac{P_1}{\rho_1} + \frac{(A_2/A_1)^2 v_2^2}{2} = \frac{P_2}{\rho_2} + \frac{v_2^2}{2}$$

$$\Rightarrow \frac{v_2^2}{2} - \frac{(A_2/A_1)^2 v_2^2}{2} = \frac{P_1 - P_2}{\rho} = \frac{\Delta P}{\rho}$$

$$\Rightarrow v_2^2\left[1 - \left(\frac{A_2}{A_1}\right)^2\right] = \frac{2\Delta P}{\rho}$$

* Manometer is different arrangement attached to the venturimeter for the calculation of ΔP.

$$\Rightarrow v_2 = \sqrt{\frac{2\Delta P/\rho}{1 - \left(\frac{A_2}{A_1}\right)^2}}$$

→ Mass flow rate = $\rho A v$

→ Volumetric flow rate = $A v \times C_d$

→ Mass flow rate at 2, $= \rho A_2 \sqrt{\frac{2\Delta P/\rho}{1 - \left(\frac{A_2}{A_1}\right)^2}}$

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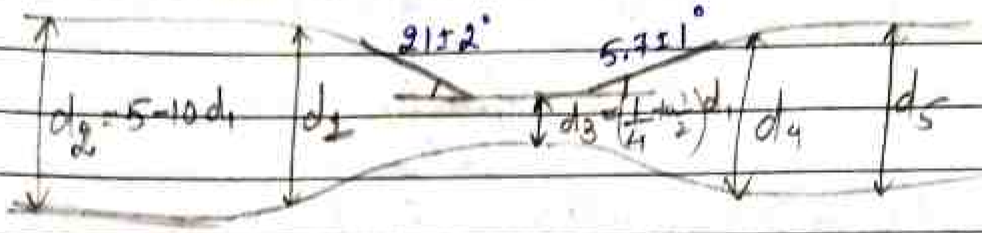
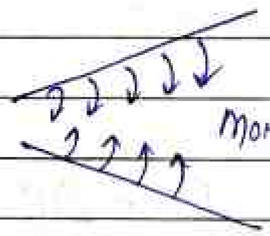


$d_2 = (5 \text{ to } 10) d_1$, $d_3 = \left(\frac{1}{4} \text{ to } \frac{1}{2}\right) d_1$

→ In a venturimeter, converging angle is greater than diverging angle because if the diverging angle is more then there will be more pressure loss.



Advantages:

a) Easy to install in any angle

b) Coefficient of discharge is very high. ($C_d = 0.8 - 0.9$)

c) Pressure recovery is high.

d) No clogging problem.

e) Well established characteristics.

Limitation: →

a) Long laying length, hence the space requirement is more.

Application: →

a) It is ideally suited for large flow rates, process fluids, Industrial wastes & suspended particles.

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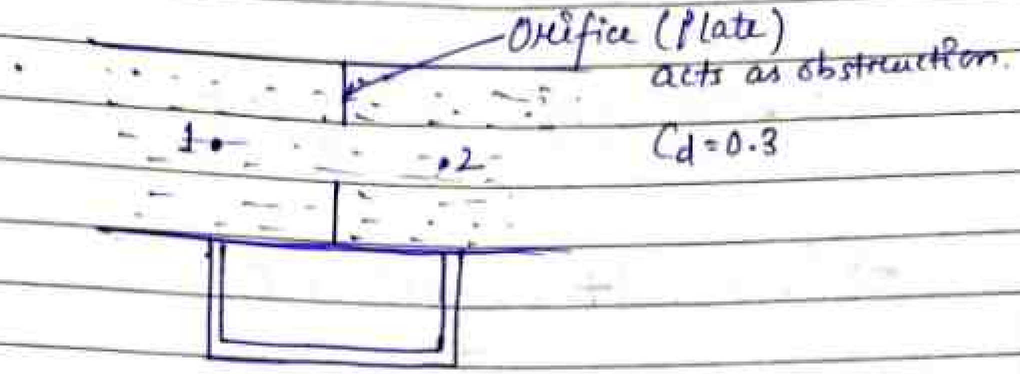
3. Orificemeter :→



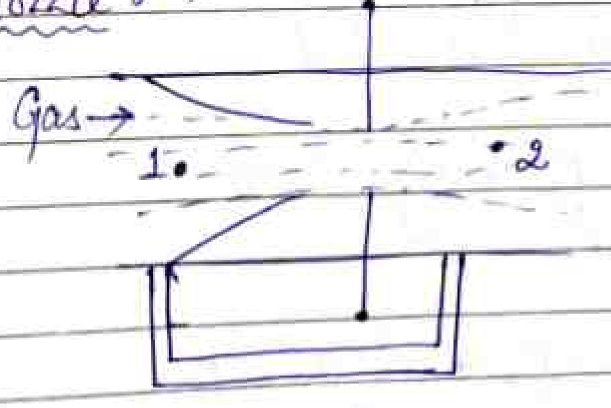
→ This is a device whose Cd is very less i.e. 0.3 and here the pressure loss is very high almost 40-90% of more than venturimeter.

→ It has one advantage, we can used this setup for larger diameter pipe.

$\frac{1}{2}''$ - 2 ft (100 cm maximum).

NOTE: The material used for any flow meter is selected as brass because its friction is very less hence the pressure loss in the system due to fluid is less.

4. Sonic Nozzle :→



We apply the 1st law of open system.

$$h + \frac{v^2}{2} + z = \text{constant}$$

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$$h + \frac{v^2}{2} + z = \text{const.} \qquad , h = U + PV$$

$$h_2 + \frac{v_2^2}{2} + z_2 = h_1 + \frac{v_1^2}{2} + z_1$$

$$\Rightarrow (h_2 - h_1) + \frac{v_1^2 - v_2^2}{2} = 0$$

$$\Rightarrow U_2 + P_2V_2 + \frac{v_2^2}{2} = U_1 + P_1V_1 + \frac{v_1^2}{2} \qquad \left[V_2 = \frac{1}{\rho_2}\right]$$

specific volume

$$\Rightarrow U_2 + \frac{P_2}{\rho_2} + \frac{v_2^2}{2} = U_1 + \frac{P_1}{\rho_1} + \frac{v_1^2}{2}$$

We know, $U = \frac{R}{\gamma - 1}(T_1 - T_2) =$

$$\Rightarrow = \frac{1}{\gamma-1}(RT_1 - RT_2)$$

$$= \frac{1}{\gamma-1}(P_1V_1 + P_2V_2)$$

$$U = \frac{1}{\gamma-1}\left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2}\right)$$

$$\Rightarrow U_1 - U_2 + \frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} + \frac{v_1^2 - v_2^2}{2} = 0$$

$$\Rightarrow \frac{1}{\gamma-1}\left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2}\right) + \frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} + \frac{v_1^2 - v_2^2}{2} = 0$$

$$\Rightarrow \left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2}\right)\left[\frac{1}{\gamma-1} + 1\right] + \frac{v_1^2 - v_2^2}{2} = 0$$

$$\Rightarrow \frac{\gamma}{\gamma-1}\left(\frac{p_1}{\rho_1}-\frac{p_2}{\rho_2}\right)+\frac{v_1^2-v_2^2}{2}=0$$

Now using continuity eq. $\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

The final expression as,

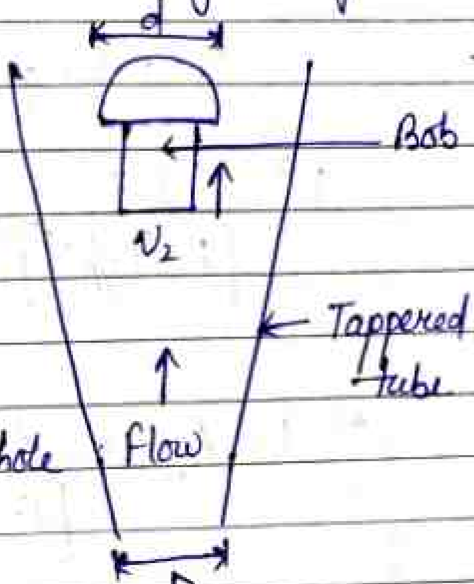
$$V_2 = \sqrt{\frac{\frac{2\gamma}{\gamma-1}\cdot\frac{p_1}{\rho_1}\left(1-\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right)}{1-\left(\frac{A_2}{A_1}\right)^2\left(\frac{\rho_2}{\rho_1}\right)^2}}$$

[Compressible gas flow]

5. Rotameter :→

Rotameter

The rotameter consist of a taperal tube mounted vertically with the tube diameter increasing upwards. The tube carries a float usually called bob. When the fluid is not flowing, the bob rests at the bottom of tube & its max^m diameter is so selected that it locks the small end of the tube almost completely. When the flow begins, the bob rises till the annular passage between the inner wall of the tappered tube and the tube peripherial of the bob is large enough to allow all the flow coming through the pipe. The bob then comes to rest in dynamic equilibrium & its position in the tappered hole is a moment of the flow rate.



Let, D = Dia of smaller end of smaller hole
α = tappered angle.
d = max. dia. of the bob
V = Volume of the bob
ρ_f = density of the flowing fluid
ρ_b = density of the bob material
A_e = Effective projected area of the bob.

As the rest position in dynamic equilibrium, the float is under the action of following forces:

- Wt. of the bob acting downward = $\rho_b V g$
- Buoyancy force acting upward = $\rho_f V g$
- Force due to pressure difference acting upward = $(P_1 - P_2) A_e$
- Viscous forces, which are very small in magnitude hence neglected.

At dynamic equilibrium,

$$(P_1 - P_2)A_e = (\rho_b - \rho_f)Vg \quad \text{—— (1)}$$

Assuming Incompressible flow & $Z_1 = Z_2$.
The outgoing viscosity of the fluid & obtained from.
Bernoulli's eq^n -

$$\therefore V_2^2 = \frac{2g}{1-(A_2/A_1)^2}\left(\frac{P_1 - P_2}{\rho_f}\right) \quad \text{—— (2)}$$

Putting the value of $(P_1 P_2)$ from eq. (1) in eq. (2), we get

$$V_2^2 = \frac{1}{[1-(A_2/A_1)^2]^{1/2}}\left[\frac{(\rho_b - \rho_f)Vg \times 2}{A_e \rho_f}\right]^{1/2}$$

$$\text{Ideal} - A_2 V_2 = \frac{A_2}{[1-(A_2/A_1)^2]^{1/2}}\left[\frac{(\rho_b - \rho_f)2Vg}{A_e \rho_f}\right]^{1/2} \quad \text{—— (3)}$$

where, A_1 = area of the tube
A_2 = angular area between the . of the tappered tube & the periphery of the tube

$$= \frac{\pi}{4}\left[(D + 2\alpha y)^2 - d^2\right] \simeq \pi D \alpha y$$

[$\because$ neglecting $\alpha^2 y^2$ term]

when 'y' is the vertical distance of the bob from the entrance & $d \simeq D$.

Date 29/04/2022

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* Measurement of Temperature :→

→ Resistance Thermometer – used on the basis of change of resistance.
Semiconductor – R↑, T↓
Metallic conductor – R↑, T↑

→ Thermistor – Thermometer used to measure resistance of semiconductor

→ RTD [Resistance Thermometer Detector]: measure the resistance of metallic conductor.

$$R_t = R_0 [1 + \alpha (t - t_0)]$$

→ Resistance of metallic conductor (Ni, Cu, Pt) shows linear variation with temp.

→ Construction of RTD :→ There is stainless steel & mica body where wires are arounded. Ceramic power is present between well & mica body for insulation.

Thermistor – highly sensitive, highly non-linear characteristic

PTC – Positive temp coeffecient

NTC – Negative temp coefficient

$$R_T = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

For thermistor, a very high negative temp coefficient is required

* Thermocouple :

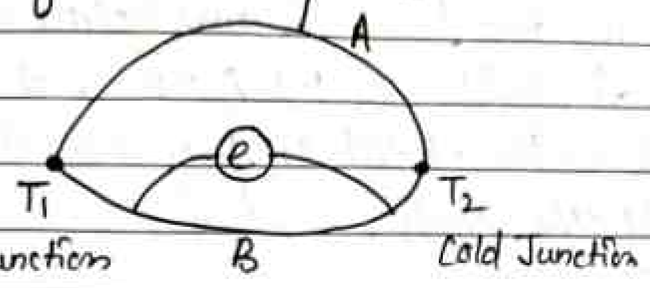
It is a device which is used to measure temp difference

Copper-constantan

Date 30/04/2022.

Saathi

* Laws of Thermocouple (4 Laws)

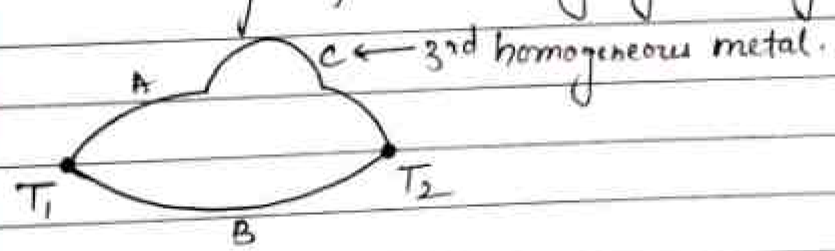


$T_1 > T_2$

- A & B are dissimilar metals
Seibeg effect
e is very small (in mV)

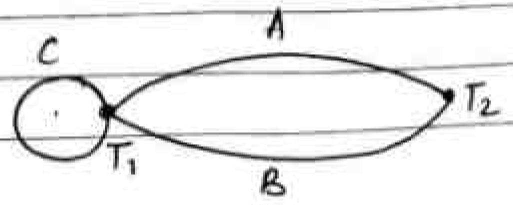
* 1st Law: The emf e remains unaltered as long as the two dissimilar metals are homogeneous.

* 2nd law: It states that e remains constant even after a 3rd homogeneous metal is introduced & T_1 & T_2 are like temp (fixed or not going to change).



* 3rd Law: It says that even If we are getting a 3rd homogenous metal at any of the junction

If an isothermal 3rd homogenous metal is Inserted at any of the junction, emf is not going to change as long as the 3rd homogeneous metal maintains the same temp as that of common junction i.e. T_1.



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* 4th Law (Additive Law):
It states that if we are have thermoelectric emf e_1 & e_2 generated between dissimilar metal A & B and B & C respectively, then the total emf generated from A to C is sum of all the emfs.

$$e_{AC} = e_{AB} + e_{BC}$$

$$\Rightarrow e = e_1 + e_2$$

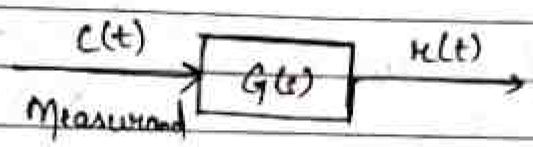
$\alpha l \Delta T = \delta L$ → Bimetallic strip.
Ambient temp = 25 - 30°C.

Date 05/05/2022

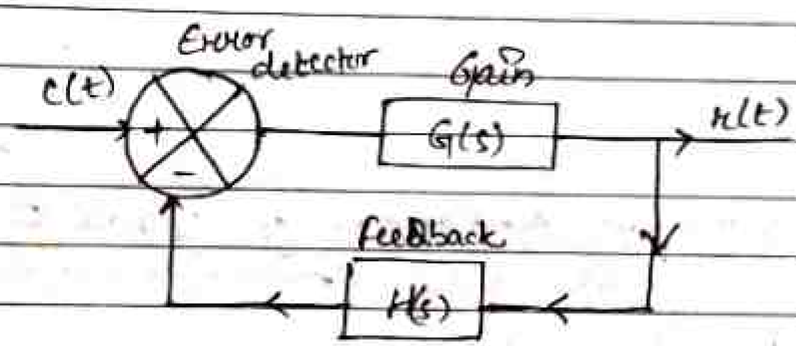
Control System

- → Block diagram
- → Transfer function
- → Block reduction technique
- → Mason's Gain formula
- → Routh Stability Criteria
- → Bode plot
- → Nyquist plot

Open System



Closed system



Open system	Closed system
1. No feedback.	1. Feedback is present
2. No error detector	2. Error detector is present
3. Simple in construct & easy to build.	3. Complex design & difficult to build
4. Disturbances are not controllable.	4. Not affected by any disturbances.
5. More stable	5. Less stable.
6. Economical	6. Expensive.
7. Small bandwidth.	7. Large bandwidth.
8. Less accuracy	8. More accurate
9. Response is slow.	9. Response is fast

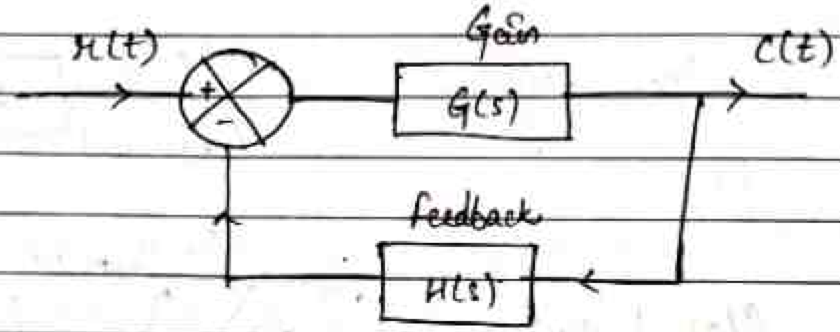
Date ___ / ___ / _____

Open System	Close System
10. Eg. 2 way traffic control, Automatic coffee maker	10. Eg. Automatic speed control system, automatic braking system

* **Control System :→**

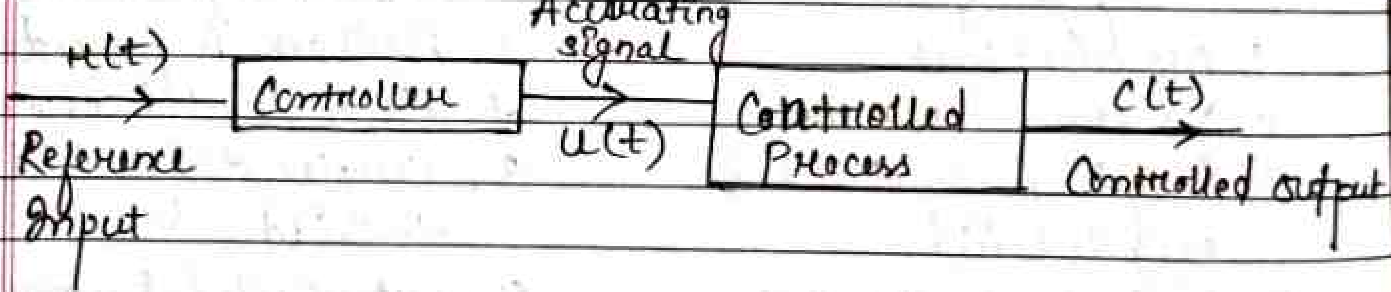
It is defined as an assemblage of devices and components connected or related so as to command direct or regulate itself or another system.

Closed system

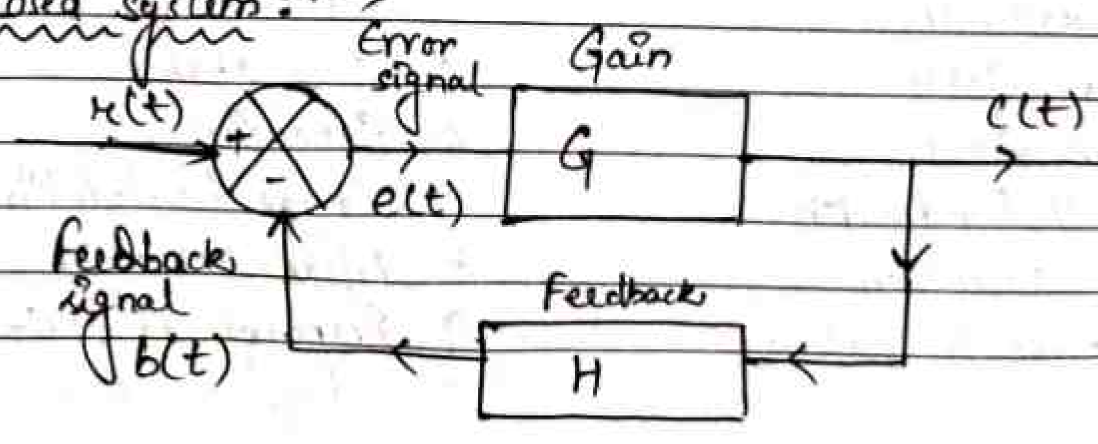


* **BLOCK DIAGRAM OF OPEN & CLOSED SYSTEM**

Open System :→



Closed system :→



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G is a combination of two blocks [Control element
Plant

$$e(t) = r(t) \mp b(t)$$

* Transfer Function :→

The transfer function of a linear time invariant system is defined as the ratio of the Laplace transform of the output signal to the Laplace transform of the input signal provided all the initial values are zeros.

$$L[f(t)] = F(s) = \int_0^{\infty} e^{-st} f(t)\,dt$$

$$s = \sigma + j\omega$$

Que: Consider the exponential function, $f(t) = e^{-\alpha t}$, $t \geq 0$ where α is the constant. Determine the Laplace of this function.

Ans. We know, $L[e^{-\alpha t}] = \int_0^{\infty} e^{-st} \cdot e^{-\alpha t}\,dt$

$$= \int_0^{\infty} e^{-(s+\alpha)t}\,dt$$

$$= \frac{1}{-(s+\alpha)} \left[e^{-(s+\alpha)t} \right]_0^{\infty}$$

$$= \frac{1}{-(s+\alpha)} \cdot [0 - 1] = \frac{1}{s+\alpha}$$

$$L[e^{-\alpha t}] = \frac{1}{s+\alpha}$$

Que Consider the function, $f(t) = e^{7t}$, $t \geq 0$. Determine its corresponding Laplace transform.

$$L[e^{7t}] = \int_0^\infty e^{-st} \cdot e^{7t} dt$$

$$= \int_0^\infty e^{(7-s)t} dt$$

$$= \frac{1}{7-s} \left[e^{(7-s)t} \right]_0^\infty$$

$$= \frac{-1}{7-s}$$

Que: $f(t)$ be a unit step function, $f(t) = U_s(t) = 1$, $t \geq 0$. Determine its Laplace transform.

$$L[1] = \int_0^\infty e^{-st} \cdot 1 \, dt$$

$$= \int_0^\infty e^{-st} dt$$

$$= \frac{1}{-s} \left[e^{-st} \right]_0^\infty$$

$$= \frac{1}{-s} [0 - 1]$$

$$= \frac{1}{s}$$

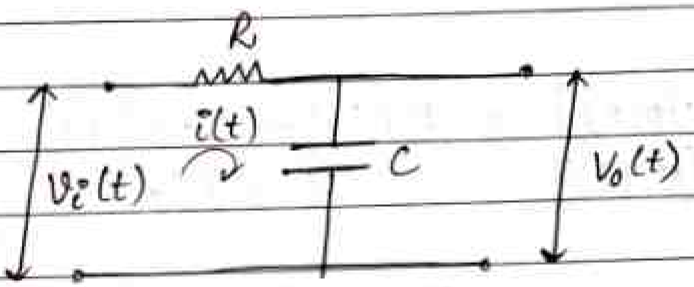
Date 06/05/2022.

Transfer function, $TF = \frac{L[f(\text{output})]}{L[f(\text{input})]}$

$$* \; L\left[\frac{d^n}{dt^n} f(t)\right] = S^n F(s) - [s^{n-1} f(0) - s^{n-2} f'(0) - \dots - f^{n-1}(0)] \rightarrow 0$$

$$* \; L\left[\int f(t)^n dt^n\right] = \frac{1}{S^n} F(s)$$

Ex. TF of circuit



$$v_i(t) = i(t) \cdot R + \frac{1}{C} \int_0^t i(t)\, dt$$

$Q = CV$
$\Rightarrow V = \frac{1}{C} \int_0^t i(t)\, dt$

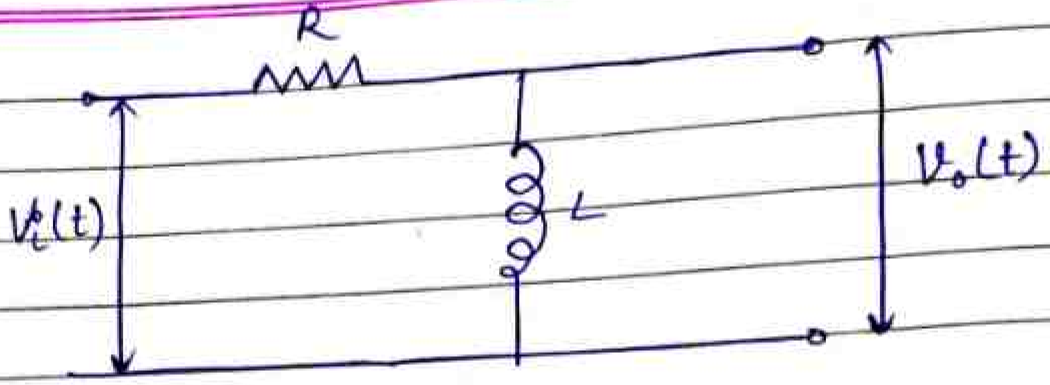
$$v_0(t) = \frac{1}{C} \int_0^t i(t)\, dt$$

$$TF = \frac{L[v_0(t)]}{L[v_i(t)]}$$

$$= \frac{\frac{1}{C} \cdot \frac{1}{S} I(s)}{R I(s) + \frac{1}{CS} I(s)}$$

$$= \frac{I(s)\left[\frac{1}{C} \cdot \frac{1}{S}\right]}{I(s)\left[R + \frac{1}{CS}\right]}$$

$$= \frac{1}{CS[RCS+1]} \cdot CS = \frac{1}{1+RCS}$$



$$v_i(t) = R \cdot i(t) + L\frac{di}{dt}$$

$$v_o(t) = L\frac{di}{dt}$$

$$\mathcal{L}[v_i(t)] = R I(s) + L S \cdot I(s)$$

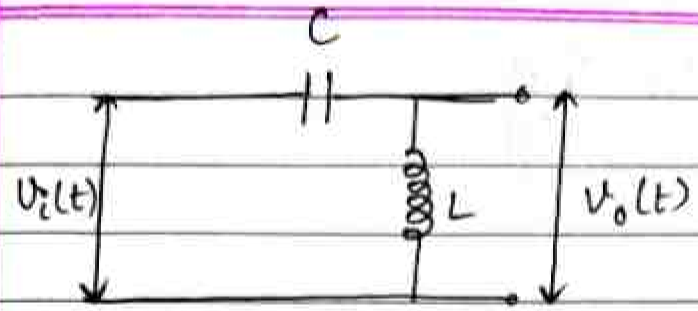
$$\mathcal{L}[v_o(t)] = L \cdot S I(s)$$

$$T.F. = \frac{\mathcal{L}[v_o(t)]}{\mathcal{L}[v_i(t)]} = \frac{RI(s) + LSI(s)}{LSI(s)}$$

$$= \frac{LSI(s)}{RI(s) + LSI(s)} \quad = \frac{I(s)[R + Ls]}{I(s)}$$

$$= \frac{I(s)[Ls]}{I(s)[R + Ls]}$$

$$= \frac{Ls}{R + Ls}$$



$$v_i(t) = \frac{1}{C}\int_0^t i(t)\,dt + L\frac{di}{dt}$$

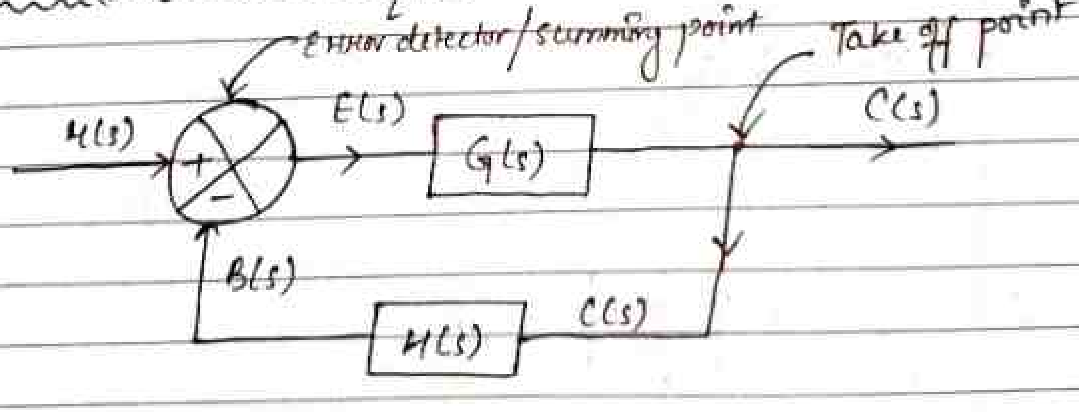
$$v_o(t) = L\frac{di}{dt}$$

$$T.F = \frac{L[v_o(t)]}{L[v_i(t)]} = \frac{LS\, I(s)}{\frac{1}{C}\frac{1}{S} I(s) + LS\, I(s)}$$

$$= \frac{I(s)\cdot LS}{I(s)\left[\frac{1}{CS} + LS\right]}$$

$$= \frac{LS\,CS}{1 + LSCS}$$

* **Block Reduction Technique** :→



G(s) : Forward path gain
H(s) : Feedback

→ Input always goes to +ve terminal of summing point.

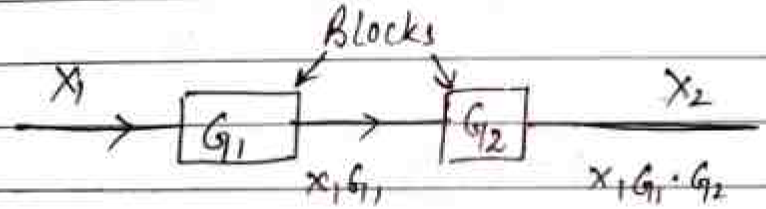
$G(s) = \frac{C(s)}{E(s)}$, $H(s) = \frac{G(s)}{C(s)}$

$E(s) = r(s) - B(s)$

$T.F = \frac{C(s)}{R(s)}$

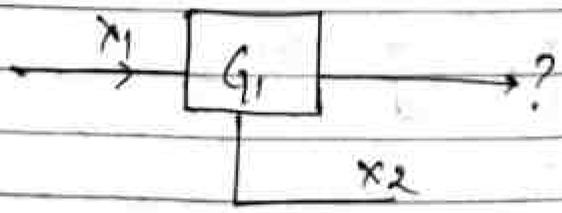
$\Rightarrow C(s) = G(s) \cdot E(s)$
$\Rightarrow C(s) = G(s) \cdot [R(s) - B(s)]$
$\Rightarrow C(s) = G(s) \cdot [R(s) - \{H(s) C(s)\}]$
$\Rightarrow C(s) = G(s) \cdot R(s) - G(s) H(s) C(s)$
$\Rightarrow C(s) [1 + H(s) G(s)] = G(s) R(s)$

$$\Rightarrow \boxed{\frac{C(s)}{R(s)} = \frac{G(s)}{1 + H(s) G(s)}}$$

1.


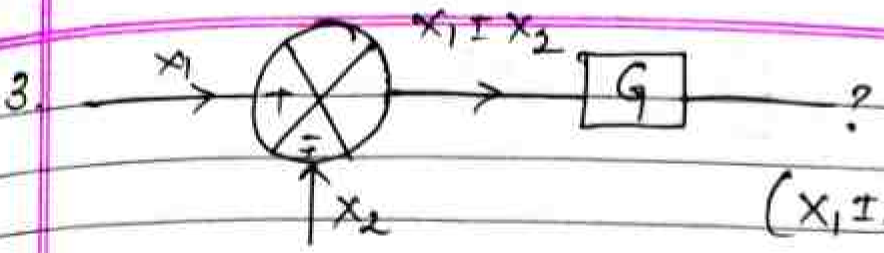
$X_1 G_1 G_2 = X_2$

$$\Rightarrow \boxed{\frac{X_2}{X_1} = G_1 G_2}$$

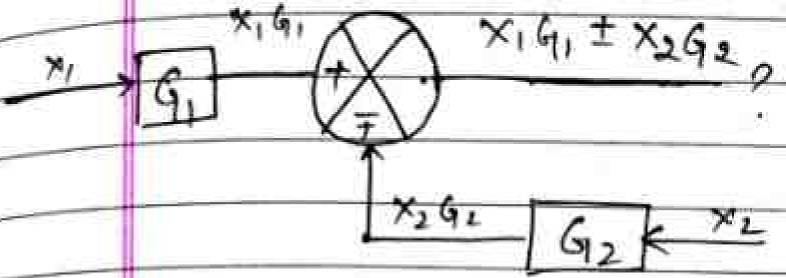
2.


$(X_1 + X_2) G_1$

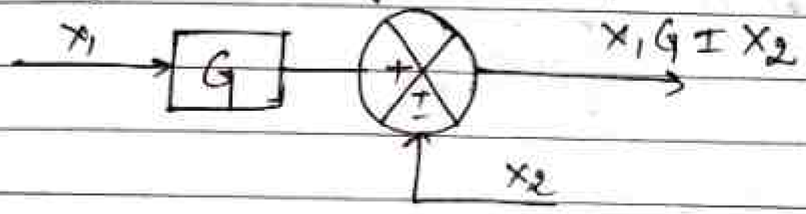
3.

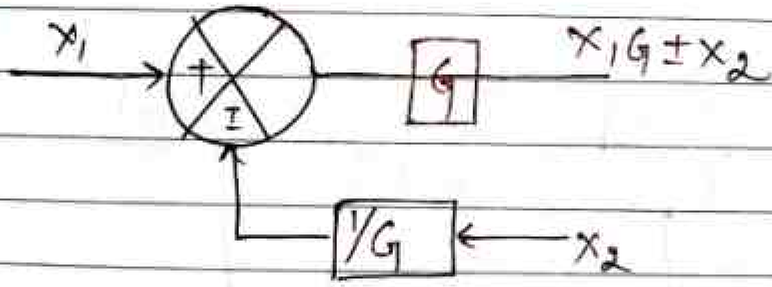


$(x_1 \pm x_2)G$



4. Moving a summing point before a block.



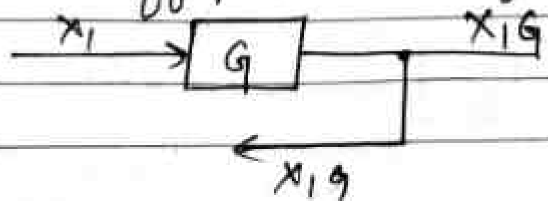


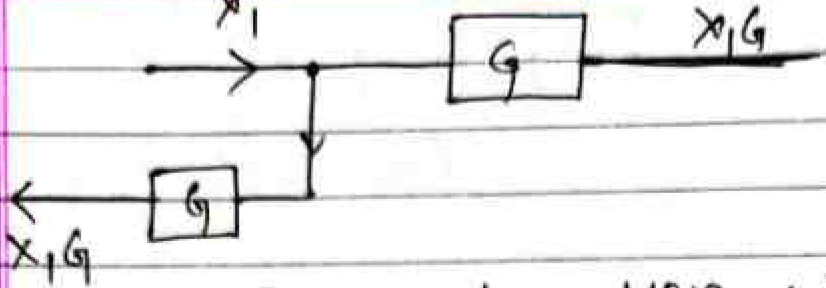
$x_1 G \pm \frac{1}{G} \times x_2 G$

$= x_1 G \pm x_2$

→ Here we introduce a additional block with the gain function equal to $\frac{1}{\text{forward path gain}}$

5. Moving a take off point ahead of a block.





Here we introduced a additional block with the same forward gain transfer function.

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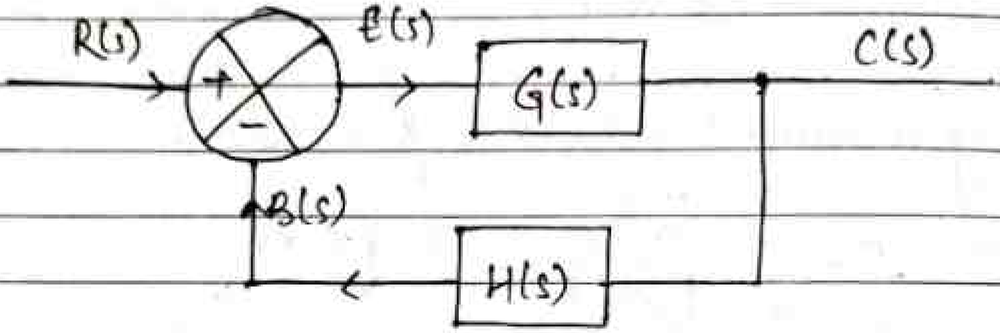
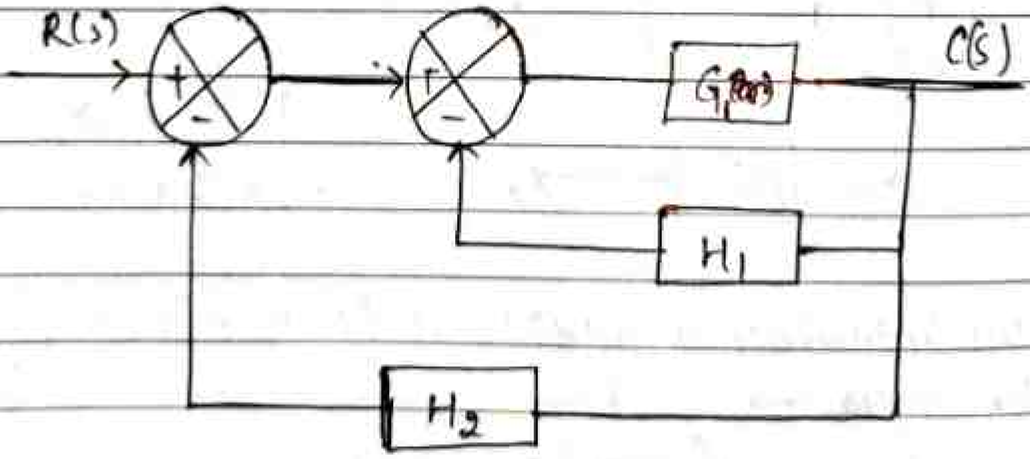
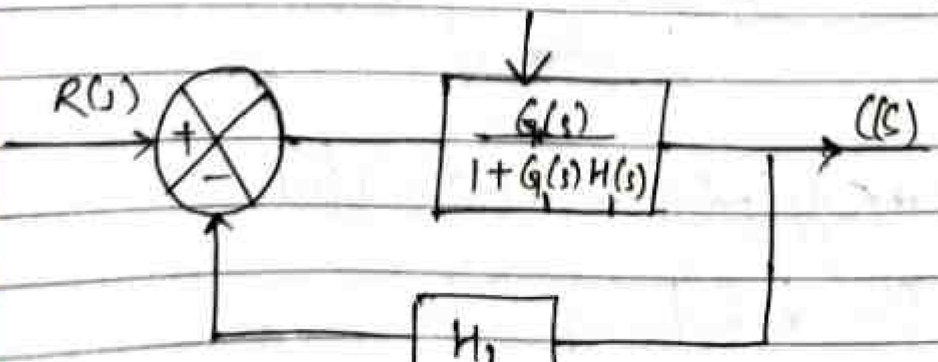


$$T.F = \frac{G(s)}{1+G(s)H(s)}$$

Ex:-

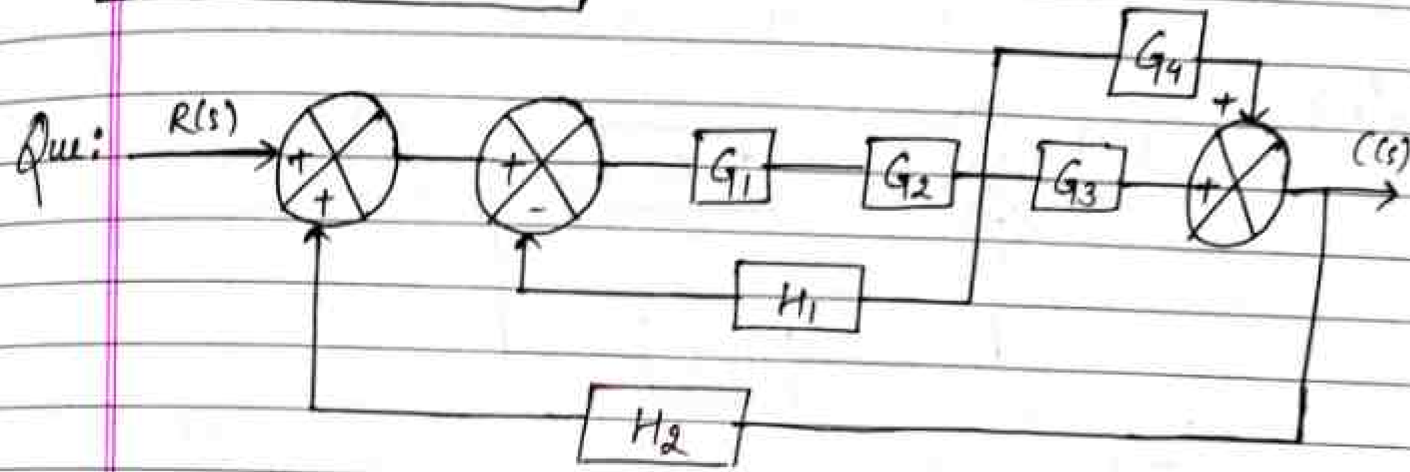




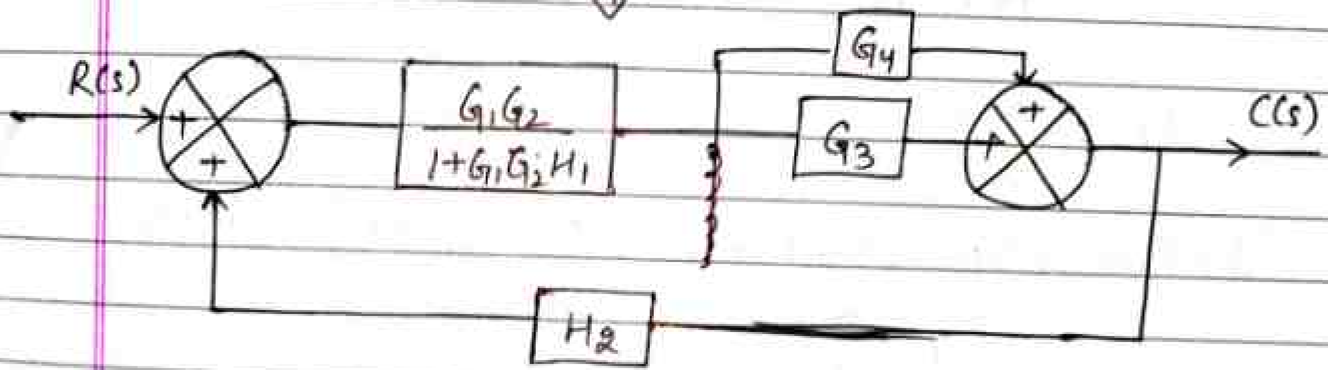
$$TF = \frac{\dfrac{G_1}{1+G_1H_1}}{1+\dfrac{G_1}{1+G_1H_1}\cdot H_2}$$

$$\boxed{TF = \frac{G_1}{1+G_1H_1+G_1H_2}}$$

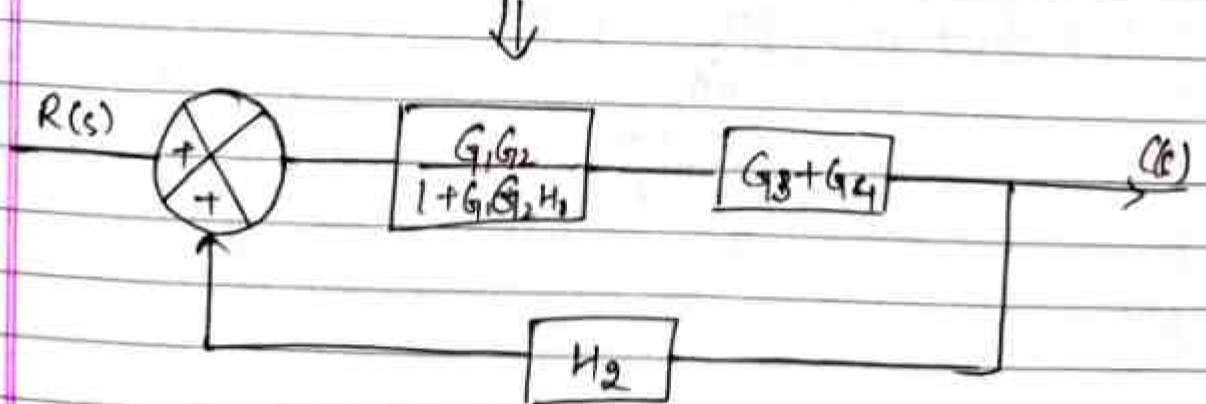
Que:



⇓



⇓

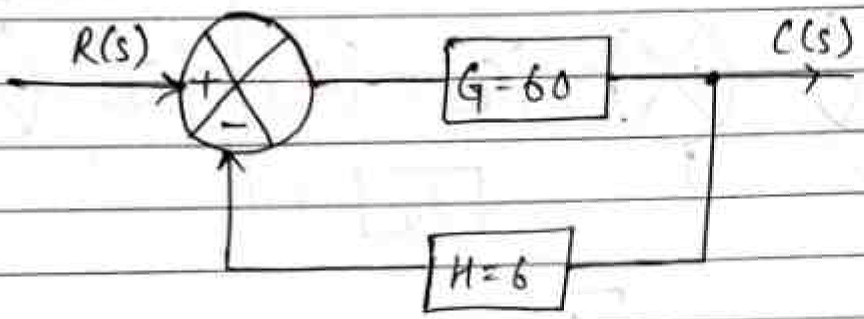


$$T.F = \frac{\dfrac{G_1G_2}{1+G_1G_2H_1}(G_3+G_4)}{1-\dfrac{G_1G_2}{1+G_1G_2H_1}(G_3+G_4)H_2}$$

$$TF = \frac{G_1 G_2 (G_3 + G_4)}{1 + G_1 G_2 H_1 + G_1 G_2 (G_3 + G_4) H_2}$$

Que: The forward path gain of an open loop system is 60. If the system is made into a close loop system with negative feedback of 6, Determine the percentage ~~change~~ reduction in the overall gain.

Ans:



$$T.F = \frac{G(s)}{1 + G(s)H(s)} = \frac{60}{1 + 60 \times 6} = \frac{60}{1 + 360} = \frac{60}{361}$$

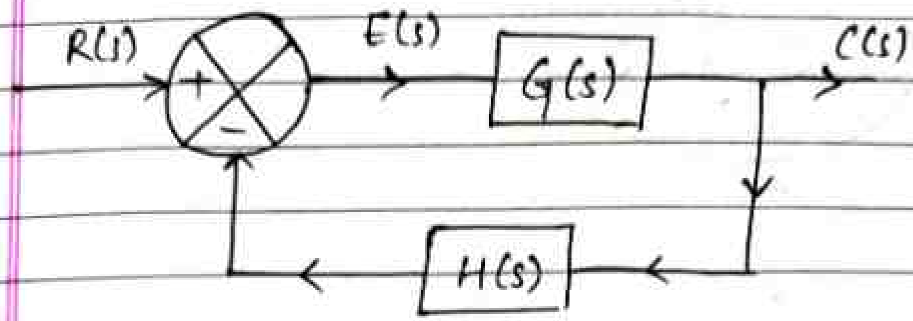
$$TF = 0.166$$

Reduction in overall gain (open system) $= 60 - 0.166 = 59.834$.

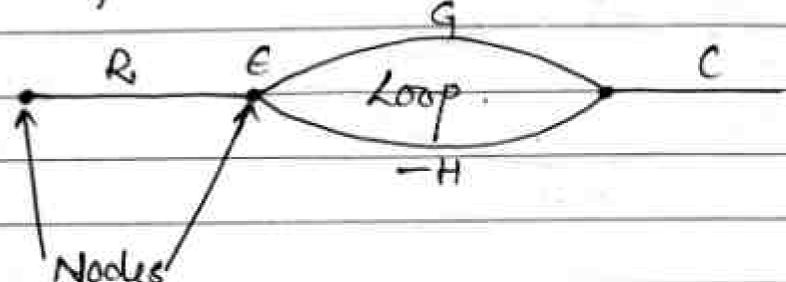
$$\% \text{ Reduction} = \frac{59.834}{60} \times 100$$

$$= 99.72\%$$

* Signal Flow Graph :→



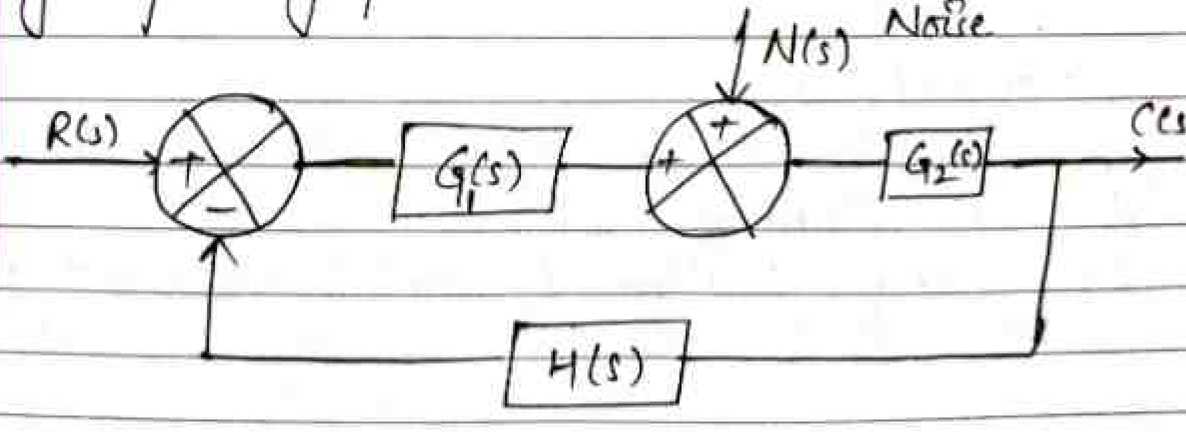
Signal flow:



(Meeting of two points.)

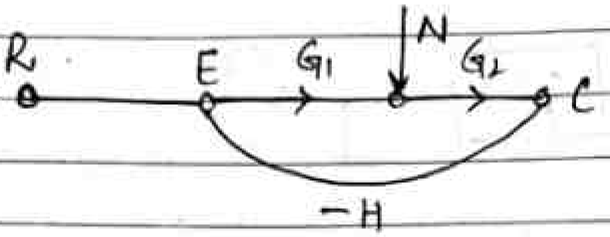
→ Converting block diagram into nodes & loops is known as a signal flow graph.

Que: Convert the following block diagram into its corresponding signal flow graph.

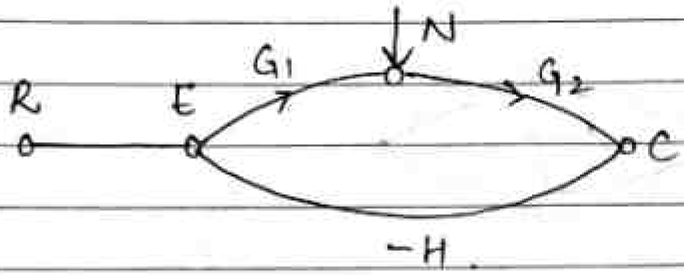


Sol

Ans:



OR,



* Mason's Gain Formula :→

It is a formula to solve the ~~transform~~ function of a closed loop system by drawing the equivalent signal flow graph.

$$P = \frac{1}{\Delta} \sum P_K \Delta_K$$

P = overall T.F

P_K = path gain of the ~~forw~~ k^{th} forward path

Δ = determinant of signal flow graph

Δ_K = value of determinant by removing the loops that touched the path P_K.

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$\Delta = 1 -$ (sum of all individual loop gains) + (sum of gain product of all the possible combinations of two non-touching loops) $-$ (sum of gain product of all possible combinations of 3 non-touching loops.)

Control System Important Questions:→

1. Difference b/w close & open system
2. Numerical question based on block reduction techinque
3. Numerical question based on Mason's gain formula
4. Calculation of TF of any circuit (electrical)
5. Numerical ques on stability of closed system.

Measurement Questions:→

1. Measurment of surface roughness on Taylor Hopsion Telesurf method
2. CRO, all fluid flow measurement device, Vacuum Tube voltmeter, strain gauges
3. Laws of thermocouple.
4. Pressure measurement technique (elastic transducers)
5. LVDT – construction, working, advantages, disadvantages, application.
6. 1st order system (derivation & numerical)
7. Static characteristics (Long question)
8. Classification of measuring instrumetes
9. Opamp as integrator & differentiator.
10. Displacement transducer ques.

11. Wheatstone bridge / voltage sensitive circuit / Ballart circuit / potentiometer

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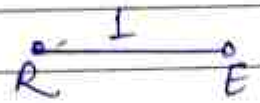
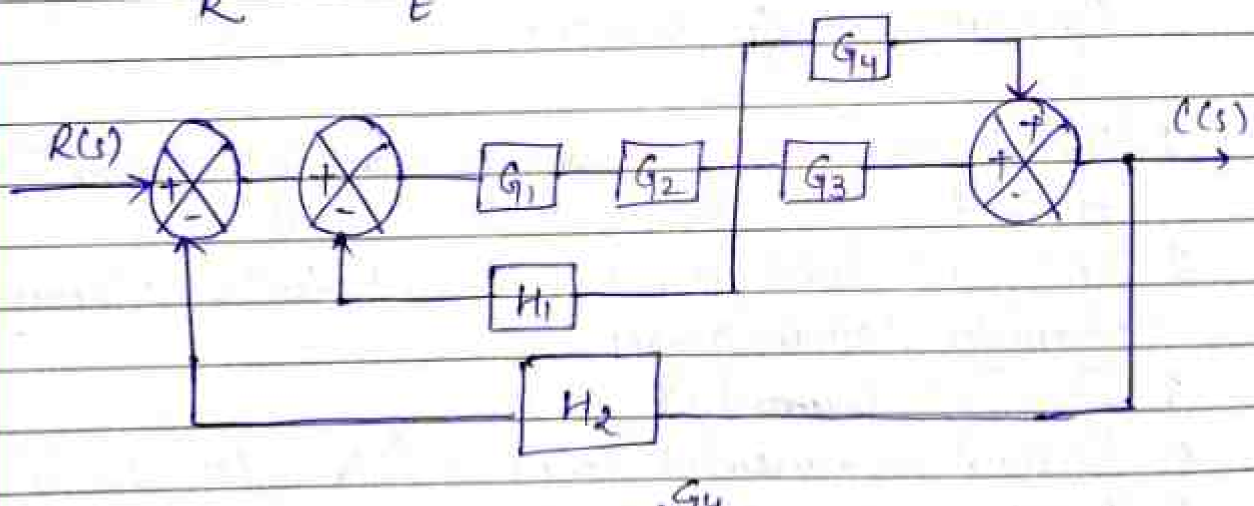
$\Delta = 1 -$ (sum of all individual loop gains) + (sum of gain products of all possible combinations of two non-touching loop) − (sum of gain products of all possible combinations of three non-touching loop) + ...

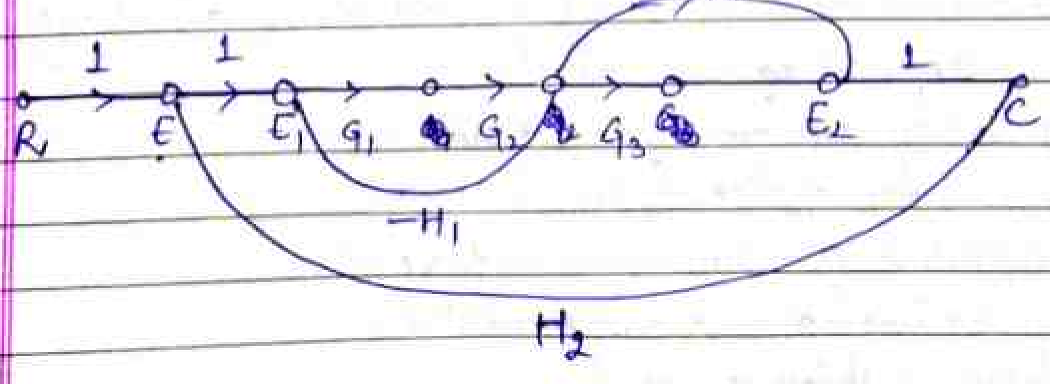
→ If there is no device present between R(s) & E(s) then we write it as 1



Que:



Ans.



$P_k = \overset{1\times 1\times}{G_1 G_2 G_3} \times 1 = G_1 G_2 G_3$, $1\times 1\times G_1 \times G_2 \times G_4 = G_1 G_2 G_4$.

$K = 2$.

Loops: $L_1 = G_1 G_2 (-H_1) = -G_1 G_2 H_1$.
$L_2 = 1\times G_1 G_2 G_3 \times 1 \times H_2 = G_1 G_2 G_3 H_2$

$\Delta = 1 - (L_1 + L_2) + 0 - 0 + \ldots$
$\Delta = 1 - (-G_1 G_2 H_1 + G_1 G_2 G_3 H_2)$

$= 1 + G_1 G_2 (H_1 - G_3 H_2)$.

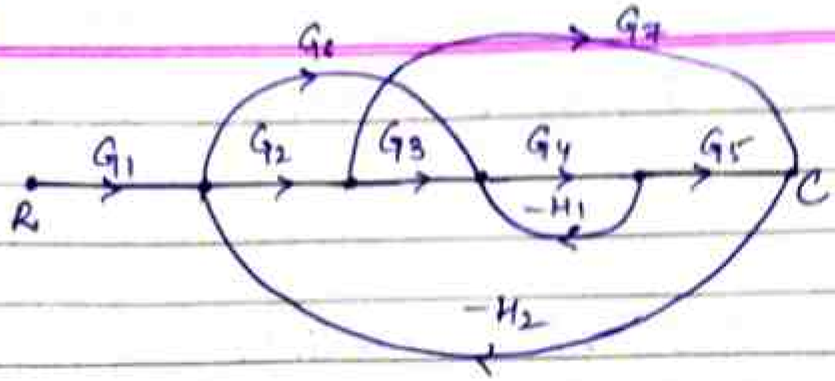
$\Delta_k = 1 - 0 = 1$
$\Delta_1 = 1 - 0 = 1$, $\Delta_2 = 1 - 0 = 1$

$P = \frac{1}{\Delta} \sum P_k \Delta_k = \frac{P_1 \Delta_1}{\Delta} + \frac{P_2 \Delta_2}{\Delta}$

$P = \frac{G_1 G_2 G_3 \times 1}{1 - (G_1 G_2 G_3 H_2 - G_1 G_2 H_1)} + \frac{G_1 G_2 G_4 \times 1}{1 - (G_1 G_2 G_3 H_2 - G_1 G_2 H_1)}$

$P = \frac{G_1 G_2 (G_3 + G_4)}{1 - (G_1 G_2 G_3 H_2 - G_1 G_2 H_1)}$

Que:



$P_k = G_1G_2G_3G_4G_5 \; , \; G_1G_6G_4G_5 \; , \; G_1G_2G_7$

$K = 3.$

Loops: $L_1 = -G_4H_1$

$L_2 = -G_2G_3G_4G_5H_2$

$L_3 = -G_2G_7H_2$

$L_4 = -G_6G_4G_5H_2$

$\Delta = 1 - (L_1 + L_2 + L_3 + L_4) + (L_1 \times L_3) - (0)$

$\Delta = 1 - (-G_4H_1 - G_2G_3G_4G_5H_2 - G_2G_7H_2 - G_6G_4G_5H_2) + (+G_4H_1G_2G_7H_2$

$\Delta_1 = 1 \; , \; \Delta_2 = 1 - L_3 = 1 + G_2G_7H_2 \; , \; \Delta_3 = 1 - (L_1 + L_4)$

$1 + G_4H_1 + G_6G_4G_5H_2$

$P = \frac{P_1\Delta_1}{\Delta} + \frac{P_2\Delta_2}{\Delta} + \frac{P_3\Delta_3}{\Delta}$

$= \frac{G_1G_2G_3G_4G_5 + G_1G_6G_4G_5(1 + G_2G_7H_2) + G_1G_2G_7(1 + G_4H_1 + G_6G_4G_5H_2}{1 + G_4H_1 + G_2G_3G_4G_5H_2 + G_2G_7H_2 + G_6G_4G_5H_2 + G_4H_1G_2G_7H_2}$

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* Routh Stability Criterion :→

Stability :-

Characteristic equation : $a_0 s^n + a_1 s^{n-1} + a_2 s^{n-2} + \dots + a_n = 0$

$n = 6$ (max. value)

$n > 6$ (complex)

Control System Array [CSA]

s^n	a_0	a_2	a_4	$a_6 \cdots$
s^{n-1}	a_1	a_3	a_5	$a_7 \cdots$
s^{n-2}	b_1	b_2	b_3	$b_4 \cdots$
$\vdots$	c_1	c_2	c_3	$c_4 \cdots$

$$b_1 = \frac{a_1 a_2 - a_0 a_3}{a_1}, \quad b_2 = \frac{a_1 a_4 - a_0 a_5}{a_1}, \quad b_3 = \frac{a_1 a_6 - a_0 a_7}{a_1}$$

$$c_1 = \frac{b_1 a_3 - a_1 b_2}{b_1}, \quad c_2 = \frac{b_1 a_5 - a_1 b_3}{b_1}, \quad c_3 = b.$$

→ If all the coefficients are all +ve or -ve i.e. no change in sign, then the system is stable.

Ex.1. Check whether the dosed control system is stable or not.

$$s^4 + 8s^3 + 18s^2 + 16s + 5 = 0$$

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Sol:→ n = 4

s^4	1	18	5
s^3	8	16	0
s^2	16	5	0
s^1	3.5	0	0
s^0	5	0	0

As all the elements in first column is +ve so it is stable.

Que. Test the stability of system having characteristic equation

$$3s^4 + 10s^3 + 5s^2 + 5s + 2 = 0$$

Ans. n = 4

s^4	3	5	2
s^3	10	5	0
s^2	3.5	2	0
s^1	-0.7	0	0
s^0	2	0	0

As there is a sign change in the column so the system is unstable.

Exceptional Case:

	3	4	1
	2	1	3
	2.5	-3.5	0
s^4	[3]	[2]	[1]
	0 (12)	0 (4)	0

In this case we will calculate auxillary equation

Auxillary eq. $F(s) = 3s^4 + 2s^2 + 1$

$$F'(s) = 12s^3 + 4s$$

Que: Test the stability of the system with characteristics equation

$$s^6 + 2s^5 + 8s^4 + 12s^3 + 20s^2 + 16s + 16 = 0$$

Ans. $n = 6$

s^6	1	8	20	16
s^5	2	12	16	0
s^4	2	12	16	0
s^3	0 (8)	0 (24)	0	0
s^2	6	16	0	0
s^1	2.6	0	0	0
s^0	16	0	0	0

$$F(s) = 2s^4 + 12s^2 + 16$$

$$F'(s) = 8s^3 + 24s$$

Since all the values of first column are positive, so the system is stable.

Short Questions:

1. Open system & closed system difference.
2. Thermocouple Laws.
3. Elastic transducer [Pressure measurement]
4. factors affecting surface roughness
5. Strain gauges theory
6. Potentiometer.
7. Difference between surface roughness & waviness.
8. Diff. methods of measuring surface roughness.
9.