

MEASUREMENT & MEASURING

INSTRUMENTS

1. Sensitivity: - $\frac{\text{Change in Output.}}{\text{Change in input.}}$ Should be high.
 $\frac{2}{V}$

Voltmeter $\rightarrow$ Reciprocal of f.s.d. & current

2. Accuracy: - ~~Value~~ Degree of closeness to true value.

It may change due to temp, humidity.

$$| \text{Accuracy} | = | \text{Error} |$$

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3. Precision: - Precise means clearly or sharply defined (very low value)

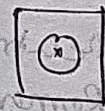
measure of the reproducibility of the measurement for a given fixed value. Repeatability

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4. Resolution: - Smallest change in a measured variable to which an instrument will respond.

Main parts of operating inst. mech. of an

$\rightarrow$ Driving System, Braking System, Registering System.



Accurate



Not Accurate



Accurate & Precise

Rectifier type inst. is not free from frequency error.

Induction w/h meter free from freqⁿ error.

~~Most accurate~~

Meter Const $\uparrow \rightarrow$ Accuracy $\uparrow$

1200 rev/kWh $\rightarrow$ More Accurate

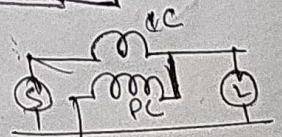
Dyn. type wattmeter $\rightarrow$ Uniform Scale

$\rightarrow$ Damping $\rightarrow$ Air friction Damping

Correction factor = $\frac{\text{True wattmeter reading}}{\text{Actual wattmeter reading}}$

FoCo $\rightarrow$ Current Coil

M.C $\rightarrow$ Pressure Cell (Amm lead)



CRO $\rightarrow$ Aquadag $\rightarrow$ To collect secondary emission electron

⊗ Megger - RPS $\rightarrow$ 3RPS / 160 RAM

⊗ If C_u shading band is on shunt magnet is removed then the ind. type energymeter will read REACTIVE POWER.

⊗ Heart of Multimeter $\rightarrow$ D'Arsonval ~~Co~~ Inst.

⊗ Brightness of image of CRT controlled by $\rightarrow$ Control Grid.

Capacitor Testing by Analog Ohmmeter.

① Ohmmeter reads zero and stay there $\rightarrow$ Cap. is S. cktd.

② low resistance momentarily $\rightarrow$ and back off to a very high R $\rightarrow$ Good.
 $\hookrightarrow$ n deflects towards zero. then back to $\infty \rightarrow$

⊗ PMMC voltmeter connected with AC $\rightarrow$ Indicate 0.

⊗ Two wattmeter method $\rightarrow$ Bal & Unbal load $\rightarrow$ 3- ϕ 3 wire

⊗ Damping force acts ~~on~~ when pointer is moving

⊗ DEAD-BEAT - when degree of damping is correctly adjusted

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Sl. No.	Phase Angle (ϕ)	Power Factor ($\cos \phi$)	W_1	W_2	Relation.
1.	0°	unity	$W_1 = W_2$	$W_1 = W_2$	Equal Total = $(2W_1)$
2.	30° (lag)(lead)	0.86 (lag)(lead)	$W_1 = 2W_2$	$W_2 = \frac{1}{2}W_1$	Half. Total = $(W_1 + W_2)$
3.	60° (lag)(lead)	0.5 (lag)(lead)	$W_1 = W$	$W_2 = 0$	One is zero. Total = W
4.	90° (lag)(lead)	0 (lag)(lead)	$W_1 = +W$	$W_2 = -W$	One +ve one -ve Total = $(W_1 - W_2)$ $W_1 + (-W_2)$

$$\phi = \tan^{-1} \sqrt{3} \frac{(W_2 - W_1)}{(W_2 + W_1)}$$

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+ve for lagging
-ve for leading.

Reading Accuracy of Steel Rule $\rightarrow 0.5 \text{ mm}$

AC panel voltmeter powered by $\rightarrow$ AC supply

Multiplying factor of wattmeter $\rightarrow$ (PT sec voltage = 110V)
$$= \text{CT Ratio} \times \text{PT Ratio}$$

Mid point of ohmmeter is most accurate.

Dyn. type P.f. meter is sensitive to frequency.

Dead Time $\rightarrow$ Time required by the inst. to begin to respond to a change in measurand

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When P & N are interchanged in energy meter $\rightarrow$ rotates in same direction. correct.

Top most scale in ~~analog~~ AMM (Analog) $\rightarrow$ Resistance

Vibration reed freq. meter $\rightarrow$ vibration of desired frequency depends on length of the reed.

Accuracy Class of Industrial & Panel Board Inst.

Class = 1. (Error - 1% in f.s. deflection)

High Resistance $\rightarrow$ Megger.

Medium $\rightarrow$ Wheatstone Bridge

Low

$\rightarrow$

Kelvin's Double Bridge, Potentiometer, A-V method

Braking torque produced in energy meter $\rightarrow$

to maintain steady speed and equal to driving torque

Thermocouple inst. $\rightarrow$ RMS value

PP meter phase diff between two currents $\rightarrow 90^\circ$ exact.

PIC part of Digital energymeter

Megger ∞ to 0

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Type	Can Measure	Symbol	Deflecting Torque Effect	Damping Tq.	Starting Tq.	Scale Controlling Tq.	Scale	Cost	Use
PMMC (Average value)	V, I		Magnetic (D'Arsonval)	Eddy-Current	High	Spring	Uniform	↑	DC (only)
MI (RMS value)	V, I, (Tachometer)		Magnetic (D'Arsonval)	Air-Friction	High	Spring or Gravity	(ramped)	↓	DC AC
EDM (Same as DC Motor with Avg)	V, I, P		Magnetic (D'Arsonval)	Eddy-Current	High	Spring	V.I. Gen. W-Unit.	↑	DC AC
Hot Wire (RMS)	V, I		Heating (D'Arsonval)	Eddy-Current	High	Spring	Camped	↓	DC AC
Induction (RMS)	V, I, P, E		Induction	Eddy-Current	High	Spring	Camped	↑	AC (only)
Electrostatic	V, I, P		Electrostatic	Air-Friction	Low	Spring or Gravity	Camped	↓	AC & DC
Thermocouple Inst.	Temp, I, V		Thermoelectric Heating			Spring	Camped		RMS AC & DC

Shunt type ohmmeter ③ zero → Left side of scale

F.S.D → Right ③

Megger

zero → Right ③

∞ → Left ①

High Rate Discharge Tester → Low range voltmeter ③

↳ Battery discharger

Critically damped → Pointer moves quickly to its final deflected position

Precision type Electrodynamometer inst. used in stat. process of potentiometer → So it is called Transfer inst.

Thermocouple inst. should be free from skin effect.

D'Arsonval inst. measures → Average value

Inductance measuring Inst:-

- ① Maxwell Inductance Bridge $[0 < Q < 1]$
 - ② Maxwell Inductance / Capacitance Bridge $[1 < Q < 10]$
 - ③ Hey's Bridge $[Q > 10]$
 - ④ Anderson's Bridge
 - ⑤ Owen's Bridge
- ElectricalNotebook.com
- } [In any Q factor]

Mutual Inductance measuring Inst:-

- ① Heaviside Bridge (To find M , known L)
- ② Campbell Bridge (To find L , known M)

Capacitance

- ① Schering Bridge
- ② De Sauty's Bridge
- ③ Wien's Bridge

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Dielectric Loss & ϵ_r

- ① Schering Bridge

Frequency

- ① Wien's Bridge

Low Resistance ($0 - 1 \Omega$)

- ① Kelvin's Double Bridge
- ② V-A meter method
- ③ Potentiometer

Medium Resistance ($1 - 10 K \Omega$)

- ① Wheatstone Bridge
- ② Substitution Method
- ③ V-A method

High Resistance ($> 10 K \Omega$)

- ① Megger
- ② Loss of charge

R

Lochentz Method.
Weber method.

LCRQ meter $\rightarrow L, C, R, Q, D$

Blondel's Theorem

Type of load	Star 3- ϕ 3-wire	Star 3- ϕ 4-wire	Delta 3- ϕ 3-wire
Balanced	2	1, 2, 3	2
Unbalanced	2	2, 3	2

Force Current Analogy: ElectricalNotebook.com

	Mech. System		Electrical System
	Translational	Rotational	
1.	Force	Torque	Current.
2.	Mass	MI	Capacitance (C)
3.	Displacement.	Ang. Displacement.	Mag. Flux Linkage (Φ)
4.	Velocity (v)	Ang. Velocity (ω)	Voltage.
5.	Viscous friction (Co-eff. n) (f) Damper		$\frac{1}{R}$ (Conductance)
6.	Spring Stiffness (K)		$\frac{1}{L}$ (Rec. of Ind.)

Force - Voltage Analogy:

Sl. No.	Mechanical System		Elect. System.
	Translational	Rotational	
1.	Force	Torque	Voltage.
2.	Mass	MI	Inductance (L)
3.	Displacement	Ang. Displacement.	Charge (q)
4.	Velocity	Ang. Velocity.	Current.
5.	Viscous friction (Co-eff. n) (f) Damper		R (Resistance)
6.	Spring Stiffness (K)		$\frac{1}{C}$ (Rec. of Cap.)

Critically Damped, ξ (Damping Ratio) = 1
 Under n , $\xi < n$
 Over n , $\xi > n$

Sl. No.	Material Item	Material	Sl. No.	Item	Material
23.	Sodium Vap. Lamp.	Gas $\rightarrow$ Neon.	25.	Porcelaine	China Clay
24.	Commutator seg. Insulated by	Mica,	26.	RF Shielding	$\rightarrow$ Copper $\rightarrow$ Soft Iron.
27.	Cable Joint	B. Thermosetting compound,	28.	Make & Break point of Iron Thermostat	$\rightarrow$ Silver

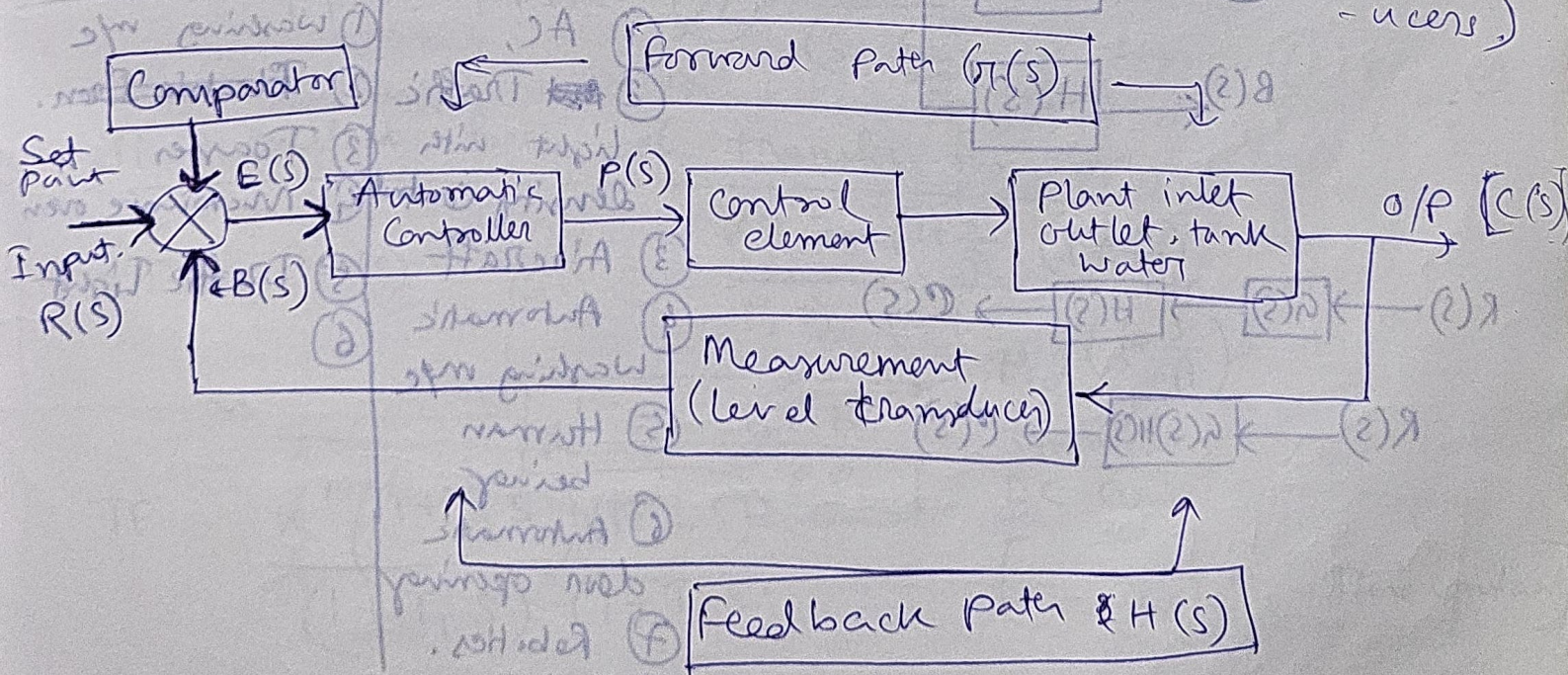
CONTROL SYSTEM

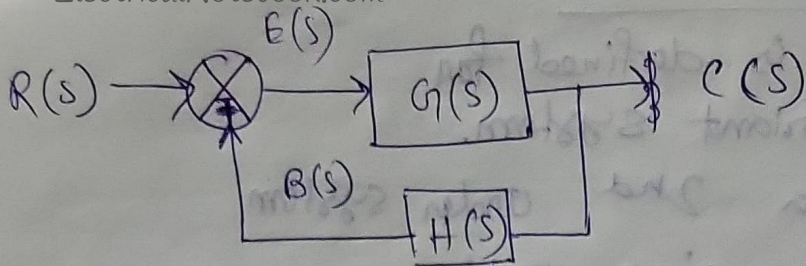
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- # The Transfer function is defined for Linear & time-invariant system.
- # Peak overshoot of a 2nd order system
→ Depends on damping ratio.
- # No. of state eqⁿ are required to represent a system described by 3rd order diffⁿ eqⁿ
→ 3.
- # Rise time of underdamped system
→ time taken to reach 95% of the response
- # Critically Damped System → Osc. are sustained.
- # For repetitive type project, mostly used mgt technique is
CPM (Critical Path Method)
PERT - Project Evaluation & Review Technique
- # Transportation method is → Quantitative Management Techn.
- ⊗ Different mode of controller →
 - P (Proportional)
 - PI (Proportional-Integral)
 - PID (Proportional-Integral-Differential)

⊗ Basic control loop.

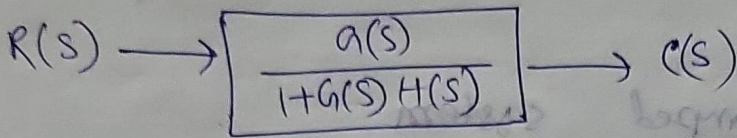
① Closed loop feedback control system (Feedback sensors or transducers.)





$E(s)$ - Error signal gen.
after comparing

Eqv. mathematical form



$$\text{System gain} = \frac{C(s)}{R(s)}$$

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

$$\frac{C(s)}{G(s)} = R(s) - H(s)C(s)$$

$$C(s) = G(s)R(s) - G(s)H(s)C(s)$$

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

$$H(s) = \frac{B(s)}{C(s)}$$

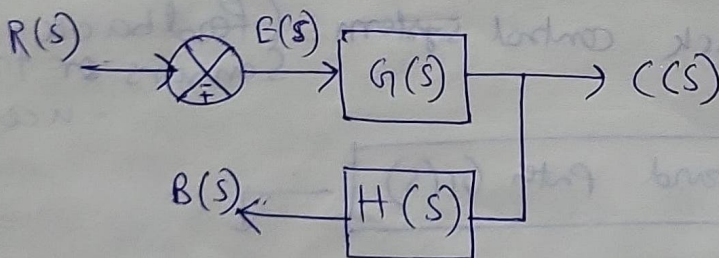
$$E(s) = \frac{C(s)}{G(s)}$$

$$B(s) = H(s)C(s)$$

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

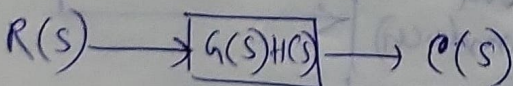
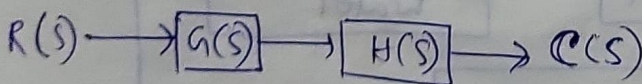
$$\text{System gain} = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

Open loop Control system



Close Loop C.S.

Open Loop C.S.



① AC,

② ~~AC~~ Traffic

light with

density control

③ Aircraft

④ Automatic

washing m/c

⑤ Human

being

⑥ Automatic

door opening

⑦ Robotics,

⑧ Radar

⑨ Iron

① Washing m/c

② ~~Electric~~ Fan

③ Toaster

④ Microwave oven

⑤ Traffic Light

⑥

Transfer Function.

A mathematical model representing a control system Rotating
i/p and o/p in the form of a ratio. $o/p / i/p = TF$

Example

Apply KVL

$$V_i = Ri + L \frac{di}{dt}$$

$$\Rightarrow V_i(s) = R i(s) + sL i(s)$$

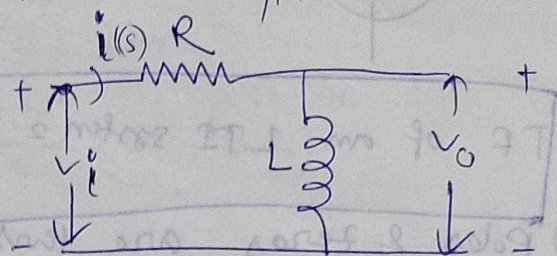
$$\Rightarrow V_i(s) - R i(s) - sL i(s) = 0$$

$$\Rightarrow i(s) [R + sL] = V_i(s)$$

$$V_o(s) = sL i(s)$$

$$\frac{V_o(s)}{V_i(s)} = \frac{sL}{R + sL}$$

$$\frac{i(s)}{V_i(s)} = \frac{1/L}{s + R/L}$$



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$$\frac{V_o(s)}{V_i(s)} = TF = \frac{i(s)}{V_i(s)} = T.F.$$

ST Response for $i(s)$ or $V_i(s)$

$1/L \rightarrow$ Gain [s⁻¹]

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

Numerator $\rightarrow$ Zeros.

Denominator $\rightarrow$ Poles.

$K =$ System Gain.

$$T.F. = F(s) = \frac{1/L}{(s + R/L)}$$

$$= \frac{K(s+z_1)(s+z_2)(s+z_3)}{(s+p_1)(s+p_2)(s+p_3)}$$

Zeros
Poles

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Time constant form of transfer function:

$$TF = F(s) = \frac{C(s)}{R(s)} = \frac{K z_1 z_2 (1 + \frac{s}{z_1}) (1 + \frac{s}{z_2})}{P_1 P_2 (1 + \frac{s}{P_1}) (1 + \frac{s}{P_2})}$$

$$K' = \frac{K z_1 z_2}{P_1 P_2}$$

$$TF = \frac{K' (1 + T_a s) (1 + T_b s)}{(1 + T_1 s) (1 + T_2 s)}$$

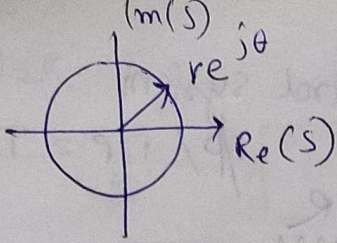
System or DC Gain.

$[T_a, T_b, T_1, T_2 \rightarrow$ Time Constant]

$$T_a = \frac{1}{z_1} \quad T_b = \frac{1}{z_2}$$

$$T_1 = \frac{1}{P_1} \quad T_2 = \frac{1}{P_2}$$

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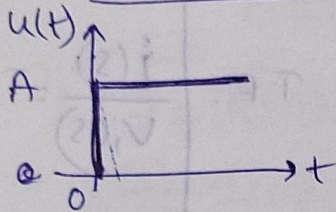
s plane or space plane
where $\theta = 0^\circ$ to 360°
and $\theta = \lim_{R \rightarrow \infty} \text{Re } e^{j\theta}$

LTI - Linear time invariant.

⊗ T.F. of an LTI system = $\frac{\text{Laplace t.f. of o/p.}}{\text{Laplace t.f. of i/p.}}$

⊗ Poles & zeros are those complex & critical freqⁿ which make the T.F. infinity or zero.

Step signal.



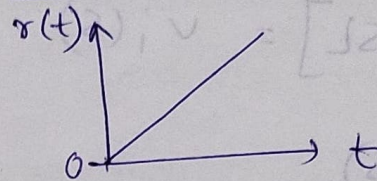
$$r(t) = A u(t)$$

$$\dot{r}(t) = A \quad t > 0$$

$$= 0 \quad t < 0$$

L.T. $R(s) = A/s$

Ramp signal.



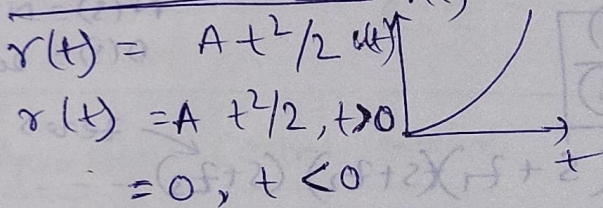
$$r(t) = At u(t)$$

$$r(t) = At \quad t > 0$$

$$= 0 \quad t < 0$$

L.T. $R(s) = A/s^2$

Parabolic signal.



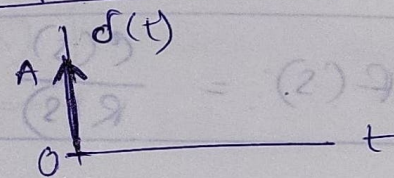
$$r(t) = A t^2 / 2 u(t)$$

$$r(t) = A t^2 / 2, t > 0$$

$$= 0, t < 0$$

L.T. $R(s) = A/s^3$

Impulse signal



$$r(t) = 1, t = 0$$

$$= 0 \quad t \neq 0$$

L.T. $R(s) = 1.$

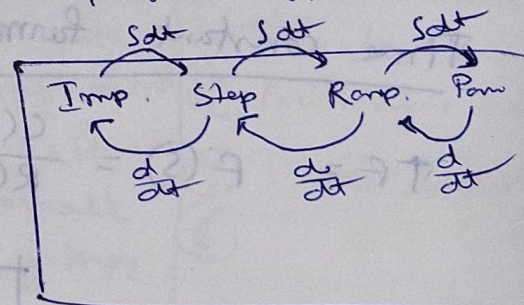
⊗ $r(t) = \text{input.}$

if i/p is impulse input the $c(t) = \text{Impulse response}$

$$\frac{c(t)}{r(t)} = \text{T.F.}$$

$$\mathcal{L} \{ c(t) \} = \text{T.F. } r(t)$$

$$\mathcal{L} \{ c(t) \} = c(s) = \text{T.F. } 1.$$



$\mathcal{L} \{ \text{Impulse Response} \} = \text{Transfer function}$

$\frac{d}{dt}$ (Parabolic response) = Ramp Response

$\frac{d}{dt}$ (Ramp response) = Step Response

$\frac{d}{dt}$ (Step response) = Impulse Response.

Q. If $\frac{C(s)}{R(s)} = \frac{5(s+10)(s+20)}{(s+2)(s+3)}$ is the T.F. of the system

what is the system DC gain

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- (a) 5 (b) 1000 (c) 1000/6 (d) None

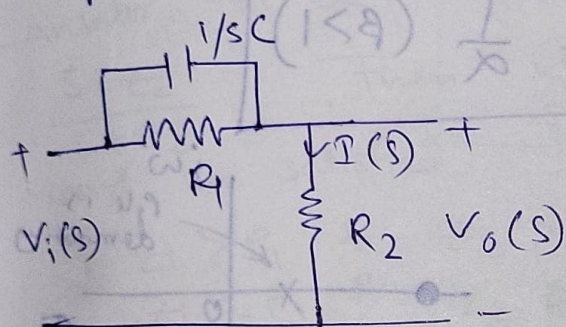
Ans $\rightarrow K' = \frac{5 \times 10 \times 20}{2 \times 3} = \frac{500}{3} = \frac{1000}{6}$ (DC gain)

TF for compensator.

Compensator are used for improving the performance specifications. i.e. transient and steady state response characteristics.

They are 3 types:

- ① Lead Compensators: $\rightarrow$ It is used for improving the transient state or the speed of response of the system.



$V_i(s) = I(s)$

$\frac{V_o(s)}{V_i(s)}$

$$I(s) \left[\frac{R_1 \times \frac{1}{sC}}{R_1 + \frac{1}{sC}} + R_2 \right] \quad \text{--- (I)}$$

$V_o(s) = I(s) \cdot R_2 \quad \text{--- (II)}$

$= \frac{R_2(R_1 sC + 1)}{R_1 + R_2 + R_1 R_2 sC}$

$$\left(\frac{R_1 + R_2}{R_1 + R_2} \right) \left[1 + \frac{R_1 R_2 sC}{R_1 + R_2} \right]$$

$T = R_1 C$

$\alpha = \frac{R_2}{R_1 + R_2} \quad (\alpha < 1)$

$$\frac{V_o(s)}{V_i(s)} = \frac{\alpha [1 + TS]}{[1 + \alpha TS]}$$

zero at $S = -\frac{1}{T}$

pole at $S = -\frac{1}{\alpha T}$

$1 + TS = 0$
 $S = -\frac{1}{T}$

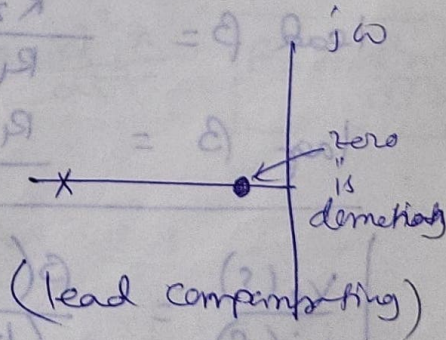
(zero)
(larger magnitude)

$1 + \alpha TS = 0$

$S = -\frac{1}{\alpha T}$

(pole)

$\alpha < 1$



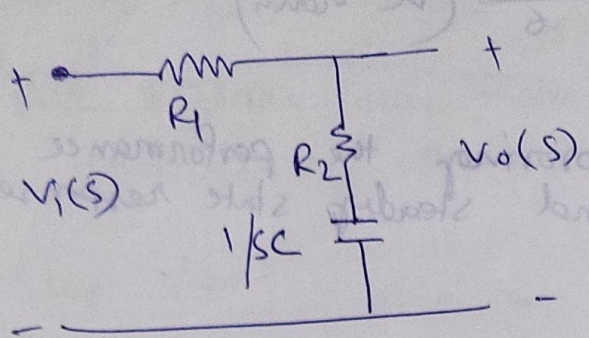
(lead compensating)

ZERO DOMINATING $\rightarrow$ LEAD COMPENSATOR

② Adding a zero to a system T.F. in terms of compensator represent lead compensator.

Lag Compensator :- It is used for improving steady state response characteristics of the system. i.e. elimination of steady state error between input & o/p.

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$$V_i(s) = I(s) \cdot \left[R_1 + R_2 + \frac{1}{Cs} \right]$$

$$= I(s) \left[\frac{R_1 Cs + R_2 Cs + 1}{Cs} \right]$$

$$V_o(s) = I(s) \cdot \left[R_2 + \frac{1}{Cs} \right]$$

$$= I(s) \left[\frac{R_2 Cs + 1}{Cs} \right]$$

$$\frac{V_o(s)}{V_i(s)} = \frac{R_2 Cs + 1}{R_1 Cs + R_2 Cs + 1}$$

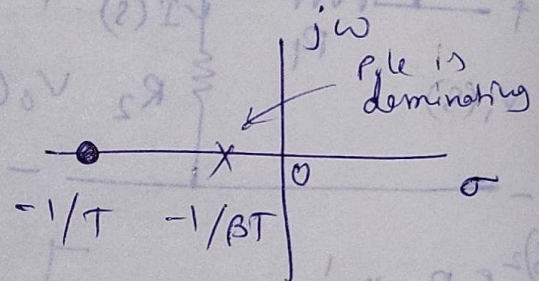
$$T = R_2 C$$

$$\beta = \frac{R_1 + R_2}{R_2} = \frac{1}{\alpha} \quad (\beta > 1)$$

$$\frac{V_o(s)}{V_i(s)} = \frac{(1 + Ts)}{(1 + \beta Ts)}$$

zero at $s = -\frac{1}{T}$

pole at $s = -\frac{1}{\beta T} \quad \beta > 1$



Adding pole $\rightarrow$ lag compensator

POLE DOMINATING $\rightarrow$ LAG COMPENSATOR

LEAD-LAG Compensator :- It improves both transient & steady-state response characteristics.

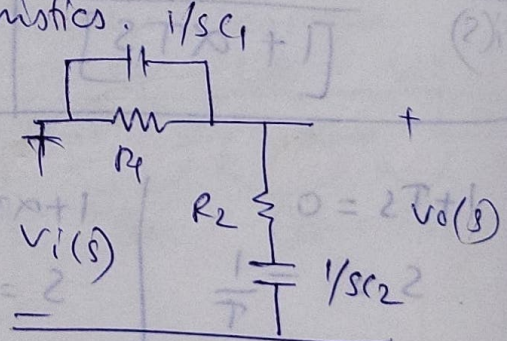
It exhibit both lead & lag characteristics.

lead $\beta = \frac{R_2}{R_1 + R_2}$

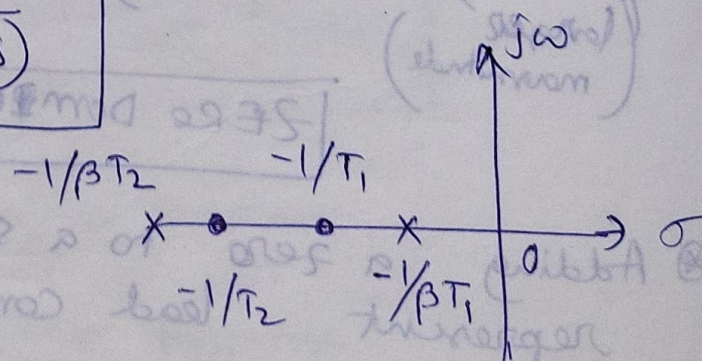
$T_1 = R_1 C_1$

lag $\beta = \frac{R_1 + R_2}{R_2}$

$T_2 = R_2 C_2$



$$\frac{V_o(s)}{V_i(s)} = \frac{\beta (1 + T_1 s) (1 + T_2 s)}{(1 + \beta T_1 s) (1 + \beta T_2 s)}$$



⊗ There is no dominating element in this

Q. An R-C. N/w has the T.F. :- $G_c(s) = \frac{s^2 + 10s + 24}{s^2 + 10s + 16}$

The n/w could be used as.

① Lead compensator. ② Lag compensator ③ Lead-lag compensator.

which of the above is/are correct.

① 1 only

② 2 only

③ 1, 2 & 3.

$$\Rightarrow \frac{s^2 + 10s + 24}{s^2 + 10s + 16} = \frac{s^2 + 6s + 4s + 24}{s^2 + 8s + 2s + 16} = \frac{(s+4)(s+6)}{(s+8)(s+2)}$$

Lead-lag compensator.

Q. The T.F. of phase lead compensator is found to be in the form of

$$\frac{s+z_1}{s+p_1}$$

and that of a lag comp-

-ensator to be in the form of

$$\frac{s+z_2}{s+p_2}$$

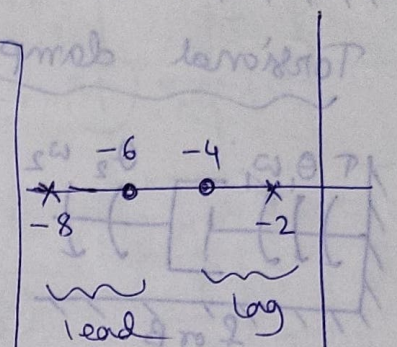
Then which of the following conditions must be satisfied.

① $z_1 > p_1$ & $z_2 > p_2$

② $z_1 < p_1$ & $z_2 < p_2$

③ $z_1 > p_1$ & $z_2 < p_2$

④ $z_1 < p_1$ & $z_2 > p_2$



Mechanical System:-

Two types $\begin{cases} \rightarrow \text{Translational} \\ \rightarrow \text{Rotational} \end{cases}$

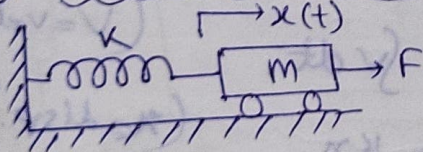
Mech. Translational System

Input $\rightarrow$ Force

Output $\rightarrow$ Linear displacement (x) or lin. velocity.

3 ideal elements.

① Mass Element (M)

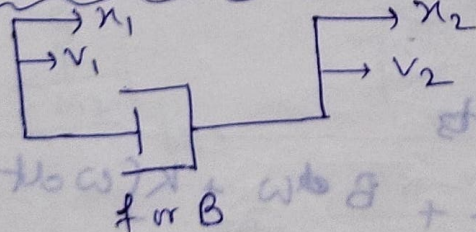


$$F = m \cdot a$$

$$F = m \cdot \frac{dv}{dt} = m \cdot \frac{d^2x}{dt^2}$$

$$F = m \frac{d^2x}{dt^2}$$

② Damper Element $\rightarrow$ To prevent oscillation.

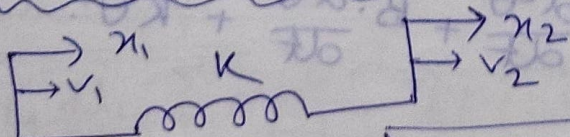


$$F = B \frac{dx}{dt}$$

$$F = B(v_1 - v_2) \quad (v = v_1 - v_2)$$

$$F = \frac{B \cdot dx}{dt} (n_1 - n_2) = B \frac{dx}{dt} \quad (n = n_1 - n_2)$$

③ Spring element (stiffness) (self damp out)



$$F = k(n_1 - n_2) \text{ or}$$

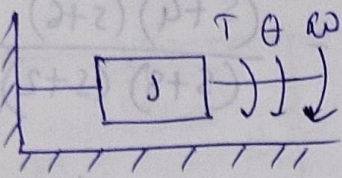
$$F = k \int (v_1 - v_2) dt = k \int v dt \quad (v = v_1 - v_2)$$

$$= k \cdot x \quad (n = n_1 - n_2)$$

Input $\Rightarrow$ Torque (T)

Output $\Rightarrow$ Angular Displacement (θ) or Ang. velocity (ω)

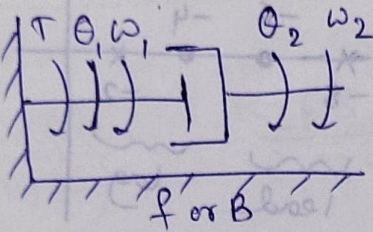
① Inertia element:-



$$T = J \frac{d^2\theta}{dt^2}$$

$$T = J \frac{d\omega}{dt}$$

② Torsional damper element:-



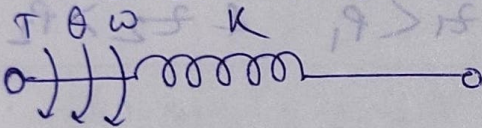
$$T = f(\omega_1 - \omega_2) \quad \text{or} \quad f \cdot \frac{d(\theta_1 - \theta_2)}{dt}$$

$$T = f\omega \quad (\omega = \omega_1 - \omega_2)$$

$$T = f \frac{d(\theta_1 - \theta_2)}{dt}$$

$$T = f \cdot \frac{d\theta}{dt} \quad (\theta = \theta_1 - \theta_2)$$

③ Torsional spring element:-

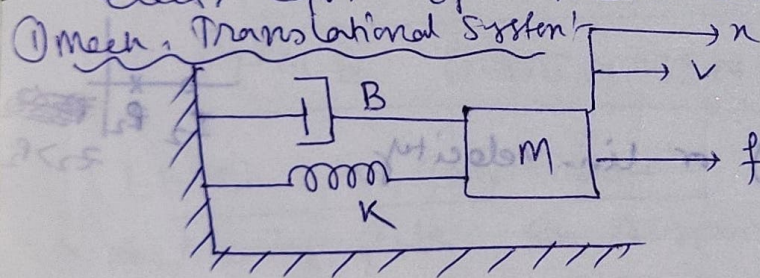


$$T = K \int \omega dt$$

$$= K\theta$$

Analogous System:-

elect. eqv. of meech element



$$F = m \frac{d^2x}{dt^2} + B \frac{dx}{dt} + Kx$$

~~Force on mass~~

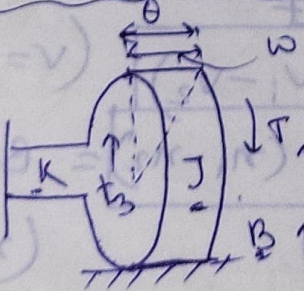
$$F = f_1 + f_2 + f_3 = m \frac{dv}{dt} + Bv + K \int v dt$$

(v = velocity)

$$= m \frac{d^2x}{dt^2} + B \frac{dx}{dt} + Kx$$

(x = disp.)

② Mech. Rotational System



$$T = t_1 + t_2 + t_3$$

$$= J \cdot \frac{d\omega}{dt} + B\omega + K \int \omega dt$$

$$= J \frac{d^2\theta}{dt^2} + B \frac{d\theta}{dt} + K\theta$$

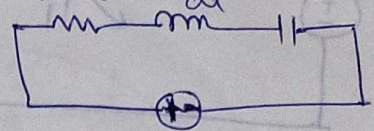
$$F = M \frac{d^2x}{dt^2} + B \frac{dx}{dt} + Kx$$

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$$v = L \frac{di}{dt} + R \cdot i + \frac{1}{C} \int i dt$$

Force -
Voltage
Analogy.

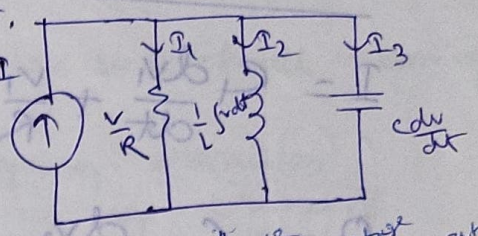
$F \leftrightarrow \text{emf}$
Mass $\leftrightarrow$ Inductance
 $v = Ri$ $v = L \frac{di}{dt}$ $v = \frac{1}{C} \int i dt$



$$F = M \frac{d^2x}{dt^2} + B \frac{dx}{dt} + Kx$$

$$i = C \frac{dv}{dt} + \frac{1}{R} v + \frac{1}{L} \int v dt$$

Force
Current
Analogy.



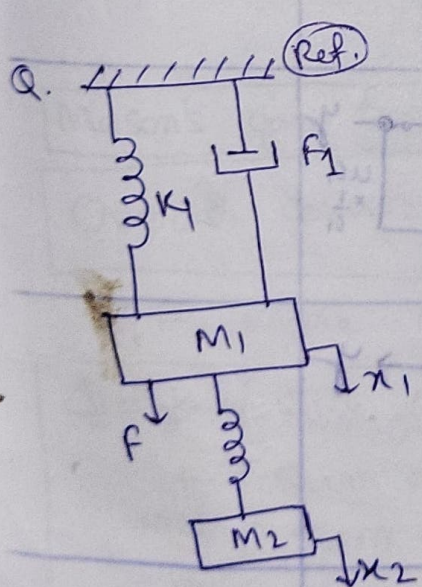
$$v = L \frac{d^2q}{dt^2} + R \frac{dq}{dt} + \frac{q}{C} \quad (q = \text{charge})$$

$$I = C \frac{d^2\phi}{dt^2} + \frac{1}{R} \frac{d\phi}{dt} + \frac{\phi}{L} \quad (\phi = \text{flux})$$

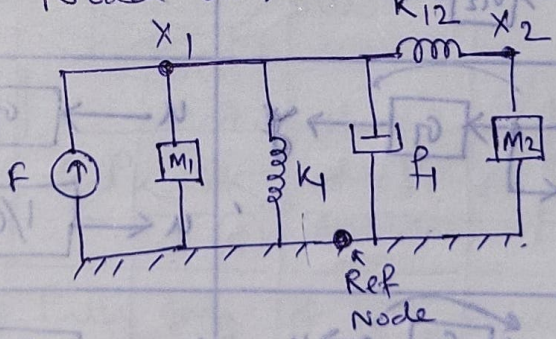
Force	Current	Voltage	Charge
F	T	V	Q
M	J	L	C
B	B	R	$\frac{1}{R}$
K	K	$\frac{1}{C}$	$\frac{1}{L}$
$\dot{v}$	ω	i	$\dot{v}$
x	θ	q	ϕ

Nodal Method:-

- ⊗ No. of nodes = No. of displacement.
- ⊗ Take an additional node (ref. node)
- ⊗ Connect mass/inertia element between principle node & ref. node
- ⊗ Connect spring & damper element either between principal nodes or between principal nodes and reference depending on their positions.
- ⊗ Obtain nodal diagram & write describing diffⁿ eqn at each node



Nodal diagram



At node X_1 ,

$$F = M_1 \frac{d^2x_1}{dt^2} + f_1 \frac{dx_1}{dt} + K_1 x_1 + K_{12} (x_1 - x_2)$$

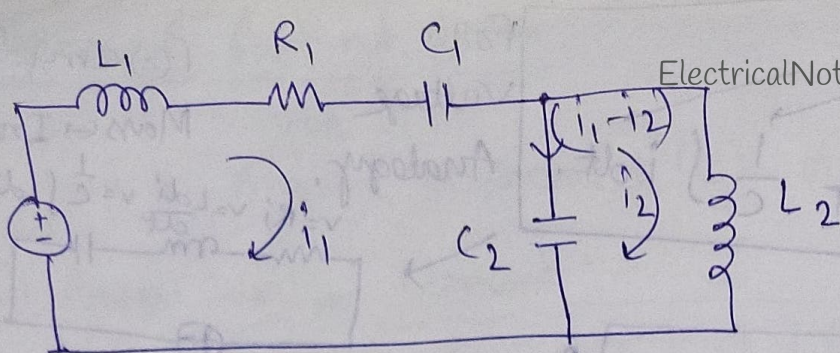
At node X_2 ,

$$0 = M_2 \frac{d^2x_2}{dt^2} + K_{12} (x_2 - x_1)$$

F-v analogy:-

$$v = L \frac{di_1}{dt} + R_1 i_1 + \frac{1}{C_1} \int i_1 dt + \frac{1}{C_{12}} \int (i_1 - i_2) dt$$

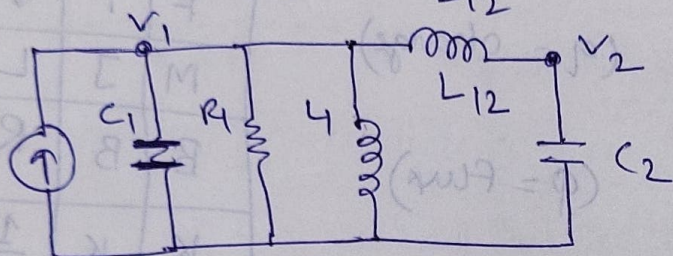
$$0 = L_2 \frac{di_2}{dt} + \frac{1}{C_{12}} \int (i_2 - i_1) dt$$



F-I analogy:-

$$I = C_1 \frac{dv_1}{dt} + \frac{v_1}{R_1} + \frac{1}{L_1} \int v_1 dt + \frac{1}{L_2} \int (v_1 - v_2) dt$$

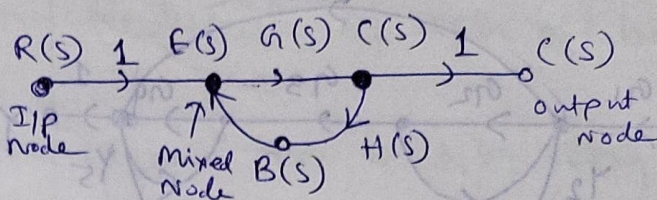
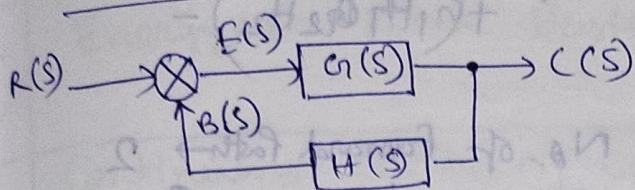
$$0 = C_2 \frac{dv_2}{dt} + \frac{1}{L_{12}} \int (v_2 - v_1) dt$$



Manipulation	Original Block Diagram	Equivalent Block Diagram	Equation
1. Combining Blocks in Cascade	$X \rightarrow [G_1] \rightarrow [G_2] \rightarrow Y$	$X \rightarrow [G_1, G_2] \rightarrow Y$	$Y = (G_1, G_2)X$
2. Combining Blocks in Parallel or Eliminating a Forward loop	$X \rightarrow \begin{cases} [G_1] \\ [G_2] \end{cases} \rightarrow Y$	$X \rightarrow [G_1 \pm G_2] \rightarrow Y$	$Y = (G_1 \pm G_2)X$
3. Moving a pickoff point behind a block	$u \rightarrow [G] \rightarrow Y$ Pickoff point after block	$u \rightarrow [G] \rightarrow Y$ Pickoff point before block, feedback path has $1/G$	
4. Moving a pickoff/take off point ahead of a block	$u \rightarrow [G] \rightarrow Y$ Pickoff point before block, feedback path has G	$u \rightarrow [G] \rightarrow Y$ Pickoff point after block, feedback path has $1/G$	
5. Moving a summing point behind a block	$u_1 \rightarrow \text{Summing} \rightarrow [G] \rightarrow Y$ Summing point before block	$u_1 \rightarrow [G] \rightarrow \text{Summing} \rightarrow Y$ Summing point after block	$Y = G(u_1 - u_2)$
6. Moving a summing point ahead a block	$u_1 \rightarrow [G] \rightarrow \text{Summing} \rightarrow Y$ Summing point after block	$u_1 \rightarrow \text{Summing} \rightarrow [G] \rightarrow Y$ Summing point before block	$Y = G u_1 - u_2$

Signal Flow Graph:- Graphical representation of c.f.s. in which nodes representing each of system variables are connected by the direct branches. ElectricalNotebook.com

SFG for closed loop c.f.s:-



Nodes: Rep. a system variable & is equal to the sum of all incoming signal

I/P node or source node:- Having only outgoing branches
O/P node or sink node:- Having only incoming branches
Mixed node or chain node:- Having both incoming & outgoing branches

Path:- series of nodes & branches. Node touch path.

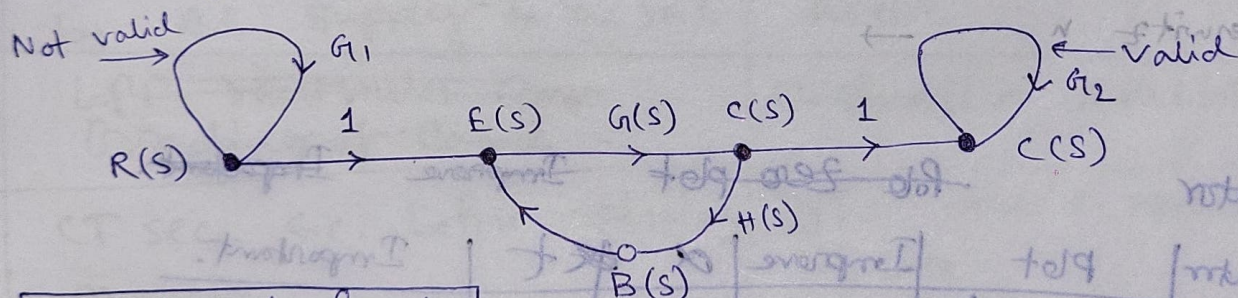
Forward Path:- I/P node to O/P node

ElectricalNoteBook.com

Loop:- Path which starts & ends at same node

⊗ Self loops on the defined input nodes are not valid loops.
 ⊗ Loops or self loops on the defined output nodes are valid loops.

Non touching loop:- Two or more loops are said to be non-touching if they do not have common node.



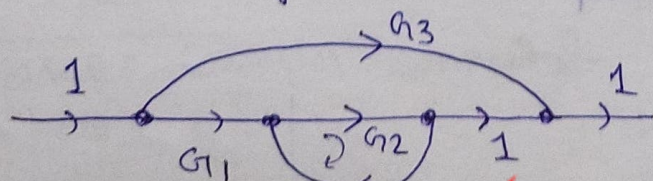
Mason's gain formula

$$\text{Overall gain} = \frac{\sum P_k \Delta_k}{\Delta} = \frac{P_1 \Delta_1 + P_2 \Delta_2 + \dots + P_k \Delta_k}{\Delta}$$

T.F., where P_k = Path gain of k^{th} forward path.

$$\Delta = 1 - [\text{Sum of loop gains of all includ. loops}] + [\text{Sum of gain products of all combination of 2 non-touching loops}] - [\text{Sum of gain products of all combination of 3 non-touching loops}] + \dots$$

Δ_k = value of Δ obtained by removing all the loops touching k^{th} forward path.

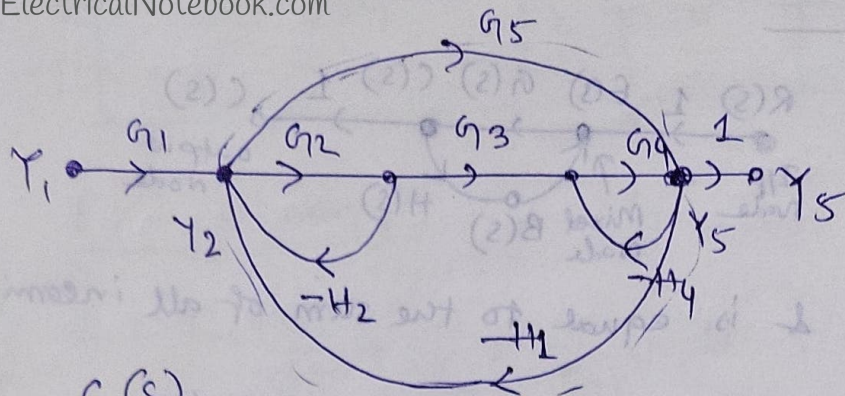
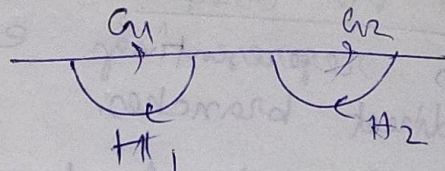


F/w path ① $G_1 G_2$
 ② $G_1 G_2 G_3$
 ③ $G_1 G_3$

$$P_1 \Delta_1 = G_1 G_2 [1 - 0] \leftarrow \Delta_1$$

$$P_2 \Delta_2 = G_3 [1 - G_2 H_1] \leftarrow \Delta_2$$

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$$+ (G_1 H_1 G_2 H_2) -$$

No. of Forward Path $\rightarrow 2$
No. of loop $\rightarrow 2$

$$\frac{C(s)}{R(s)} = \frac{G_1 G_2 G_3 G_4 + G_1 G_5}{1 - [-G_2 H_2 - G_4 H_4 - G_3 H_1 - G_2 G_3 G_4 H_1] + [G_2 H_2 G_4 H_4] - 0}$$

Non touching loop

in $G_1 G_2 G_3 G_4 \rightarrow$ No.
in $G_1 G_5 \rightarrow$ No.

$$\frac{C(s)}{R(s)} = \frac{G_1 G_2 G_3 G_4 + G_1 G_5}{1 + [G_2 H_2 + G_4 H_4 + G_3 H_1 + G_2 G_3 G_4 H_1] + [G_2 H_2 G_4 H_4]}$$

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Root Locus Technique $\rightarrow$ Time Domain char.

Bode Plot

Nyquist Criteria $\rightarrow$ Frequency Domain Chart $\rightarrow Z = N + P$

Routh Hurwitz $\rightarrow$

Compensator

Pole-zero plot Improve Important

Compensator	Plot	Improve	α	β	Important.
① Lag		Steady State error	$\frac{R_1 + R_2}{R_2}$	$\frac{R_2}{R_1 + R_2}$	Pole is Dominating
② Lead		Transient State error	$\frac{R_2}{R_1 + R_2}$	$\frac{R_1 + R_2}{R_2}$	Zero is Dominating
③ Lag-Lead		Both T/S & S/S.	Both	Both	lag system is Dominating

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Cause & Effect.

	Effect.	Cause
1.	Energy meter Rotate Faster	Reduced strength of brake magnet.
2.	Continuous chattering sound from armature of an Ac no volt coil	Open ckt in the Shading Ring. ElectricalNotebook.com
3.	Creeping in energy meter	① Wrong Compensation of friction ② Excessive voltage across P.C. ③ Stray magnetic field.
4.	Too small current is drawn by the coil and contactor will not operate.	220V DC Contactor coil connected to 220V AC
5.	Submersible pump can lift water from any depth	Suction pipe is not there
6.	Dense blackening of a fluorescent lamp	Starter is working improperly. ElectricalNoteBook.com
7.	Earth resistance is measured by A.C. supply to the soil	To eliminate electrolysis action
8.	LPF Wattmeter Comp Grading of Cable	Uniformity in dielectric stress.
9.	CT sec. s.c. before opening ammeter	① To avoid excessive heating of core ② High sec. emf ③ Increase Iron loss.
10.	DC Motor started with Jerk	Pitted starter Contact terminals
11.	In Mercury Arc Rectifier electrons are liberated	By shock ionization caused out due to bombardment made by heavy ions.
12.	Sparkings in DC M/C	Reactance voltage
13.	Brush shifting is done in DC M/C	To neutralize the cross magnetizing effect.
14.	220V DC Contactor connected with 220V AC.	Too small current drawn by coil and operation of the contactor is no longer certain.

Skewing in Rotor slot $\rightarrow$ Suppressing undesirable harmonics.

ElectricalNotebook.com

O/p filter cap. open $\rightarrow$ Make humming noise.

DC Resistance $<$ AC Resistance $\Rightarrow$ Skin effect & Proximity "

closed

Improve pf. in IM $\rightarrow$ ~~open~~ & semi-~~open~~ ^{closed} slots.

In ac m/c & Synchronous m/c $\rightarrow$ open slots are used

$\rightarrow$ Large ^{HP} motor. $\rightarrow$  Open slots.

Small ^{HP} " $\rightarrow$ Closed "