SERVOMOTORS : TWO PHASE (AC) ⑤
- DC
  - ARMATURE CONTROLLED
  - FIELD CONTROLLED.

— req. max. acceleration (particularly at 0 Torque)
— req. torque to be reduced to 0 when angular velocity = 0.

For max. accln., J min. so same T delivered.

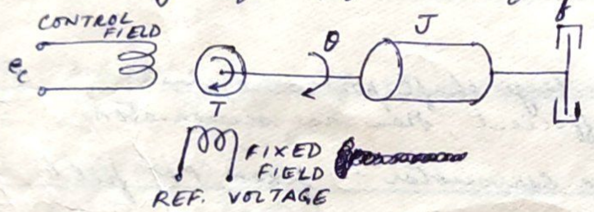
$J_{eq} = J_m + n^2 J_L$ $\quad n < 1$ = gear ratio bet. motor and load

$f_{eq} = f_m + n^2 f_L$

If $n^2 J_L$ & $n^2 f_L$ are small compared to $J_m, f_m$, then neglect.

TWO PHASE (AC) SERVOMOTORS: ~ to 2 $\phi$ I.M. with small dia to length ratio ∴ J small.

— rugged & reliable, used in instrument servomechanisms
— power range frac. of W to few 100 W.




Reliance
$T = \dfrac{J_{eq} \times f(\text{rpm})}{308 \times t} \approx J\ddot{\theta}$

t = accelerating time

(usually freq. 50 Hz / 400 Hz / 1000 Hz)
general, military, aerospace

(i) Control signal: suppressed carrier signal 90° phase-shifted w.r.t. fixed phase voltage — ~~see~~ $e_c(t)$ and $E_c(t)$ in figure below

(ii) CONTROL winding & Fixed field windings in space quadrature

Both done to maximize Torque generated (efficiency)

Usually 2 $\phi$ power supply used, else use C in path of ~~control~~ fixed phase winding while control winding directly.

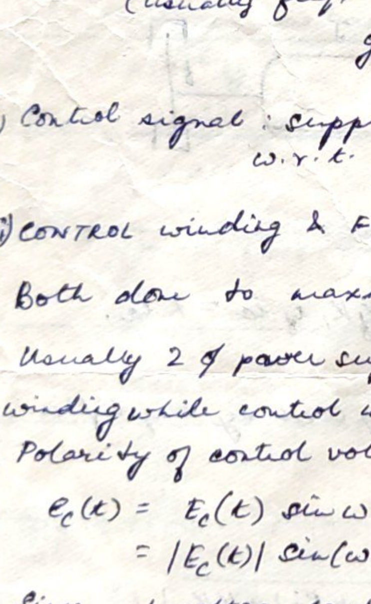
Polarity of control voltage determines direction of rotation.

$e_c(t) = E_c(t) \sin \omega t \quad \forall E_c(t) > 0$

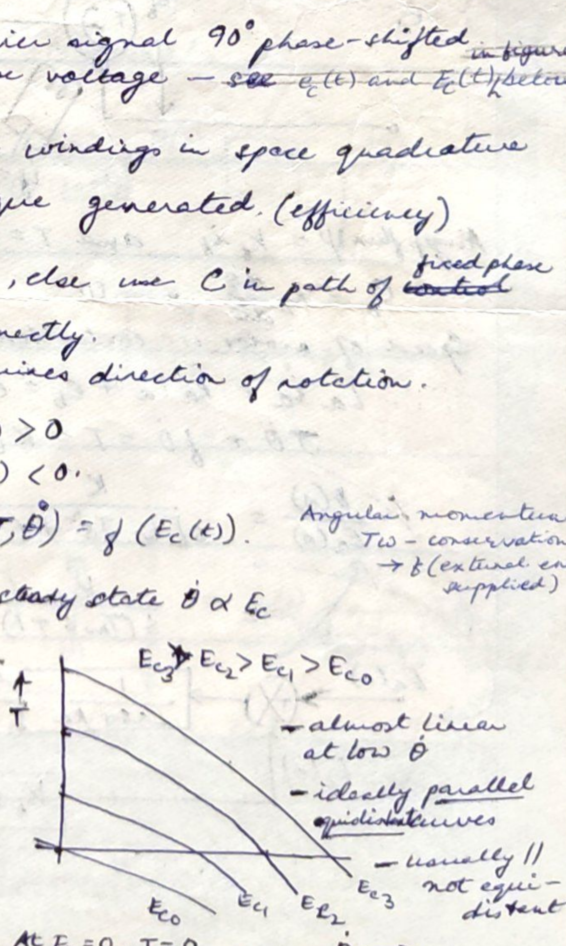
$\quad = |E_c(t)| \sin(\omega t + \pi) \quad \forall E_c(t) < 0.$

Since ref. voltage constant ∴ $(T, \dot{\theta}) = f(E_c(t))$.

Angular momentum $T\omega$ — conservation → f(external energy supplied)




At steady state $\dot{\theta} \propto E_c$




At $E_c = 0$, $T = 0$

CONSERVATION OF ~~ENERGY~~ ANG. MOMENTUM

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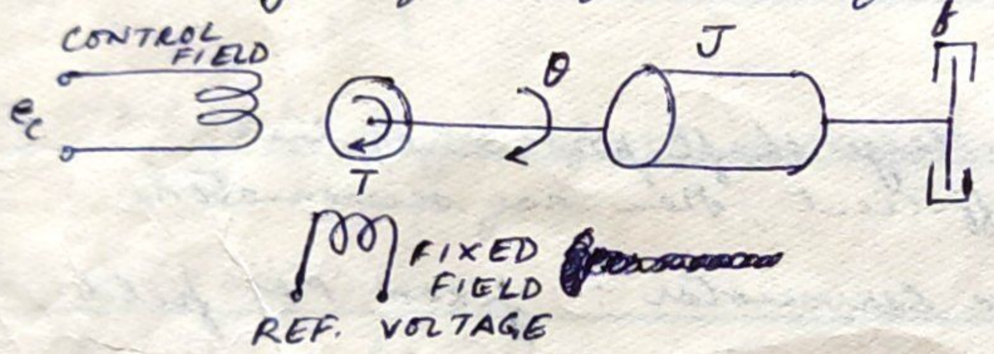


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... indirectly.

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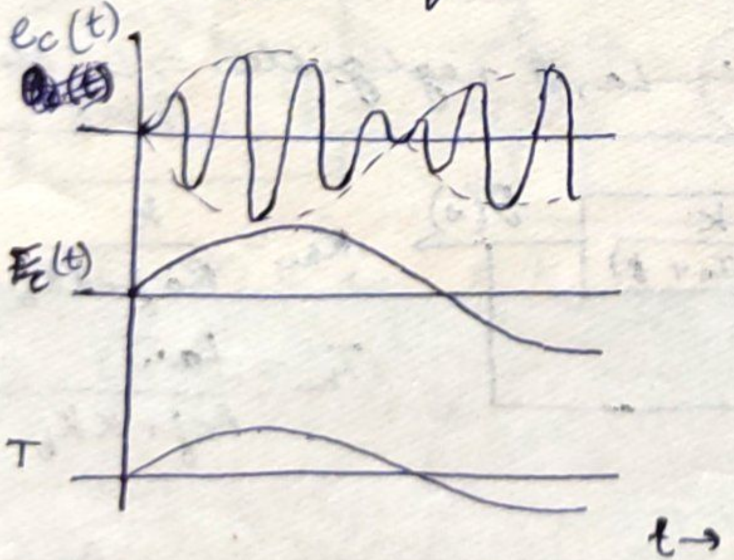
Angular momentum
$T\omega$ - conservation
$\rightarrow f$(external energy supplied)

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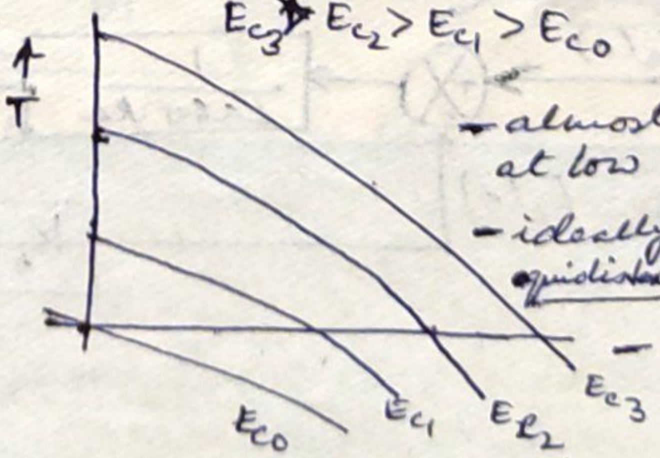



- almost linear at low $\dot{\theta}$
- ideally parallel equidistant curves
- usually // not equidistant

At $E_c = 0$, $T = 0$

$\dot{\theta} \longrightarrow$

CONSERVATION OF ~~ENERGY~~ ANG. MOMENTUM

— Usually servomechs. operate at low $\dot{\theta}$ when curves ∥ & equidistant

— $\theta E_c(t) \Rightarrow \theta T$ ∴ motor develops torque to stop rotation.

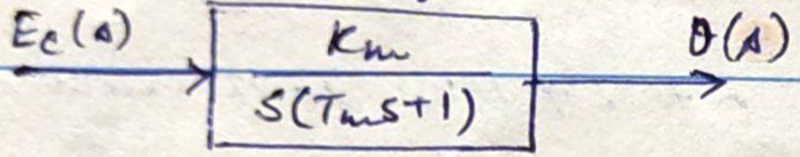
$$T = -K_n\dot{\theta} + K_c E_c = J\ddot{\theta} + f\dot{\theta}$$

$$\Rightarrow J\ddot{\theta} + (f + K_n)\dot{\theta} = K_c E_c$$

$$\therefore \frac{\theta(s)}{E_c(s)} = \frac{K_c}{Js^2 + (f+K_n)s} = \frac{K_m}{s(T_m s+1)}$$

where $K_m = \dfrac{K_c}{f + K_n}$ ; $T_m = \dfrac{J}{f+K_n}$ = motor time constant

= motor gain constant

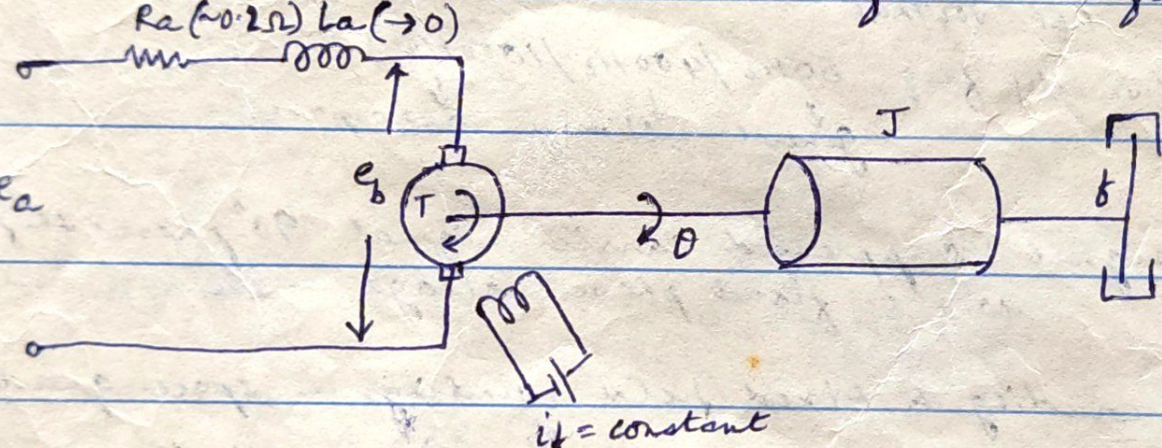



— For steeper $K_n$ (negative of slope of T-speed curves), damping of motor is more. Note: unity f/b yields typical 2nd order system

— If J low, then $|T_m s| \ll 1$, then servomotor as INTEGRATOR.

DC Servomotors : when large shaft power required.
- more efficient than ac servomotors

Armature controlled dc servomotor : fixed PM field




Airgap flux $\Psi = K_f i_f$ and $T = K_1 i_a \Psi = K_f K_1 i_f i_a = K i_a$.

$$e_b = K_b \frac{d\theta}{dt} \quad \text{— (1)}$$

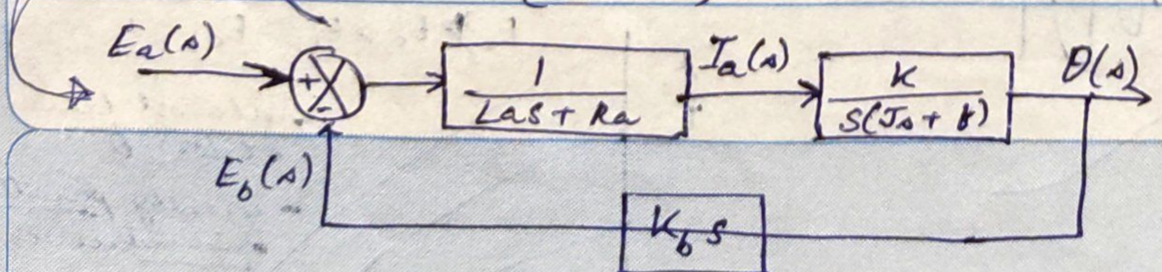
Speed of motor is controlled by $e_a$ supplied by amplifier.

$$\therefore \; L_a \dot{i}_a + R_a i_a + e_b = e_a \quad \text{— (2)} \qquad I_a(s) = \frac{E_a(s)}{sL_a + R_a}$$

$$J\ddot{\theta} + f\dot{\theta} = T = K i_a \quad \text{— (3)} \qquad K_T I_a(s) = s(sJ+f)\,\theta(s)$$

$$\therefore \; \frac{\theta(s)}{E_a(s)} = \frac{K}{s\left[L_a J s^2 + (L_a f + R_a J)s + R_a f + K K_b\right]}$$

$$= \frac{K_m}{s(T_m s + 1)} \qquad \because \; L_a \text{ negligible} \Rightarrow L_a J \text{ also negligible } \& \; L_a f$$




$$K_m = \frac{K}{R_a f + K K_b}$$

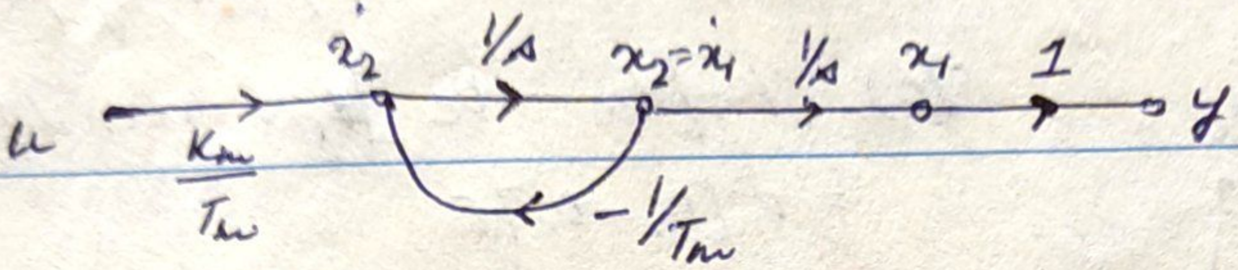
$$T_m = \frac{R_a J}{R_a f + K K_b}$$

$$\ddot{\theta} + \frac{1}{T_m}\dot{\theta} = \frac{K_m}{T_m} e_a$$

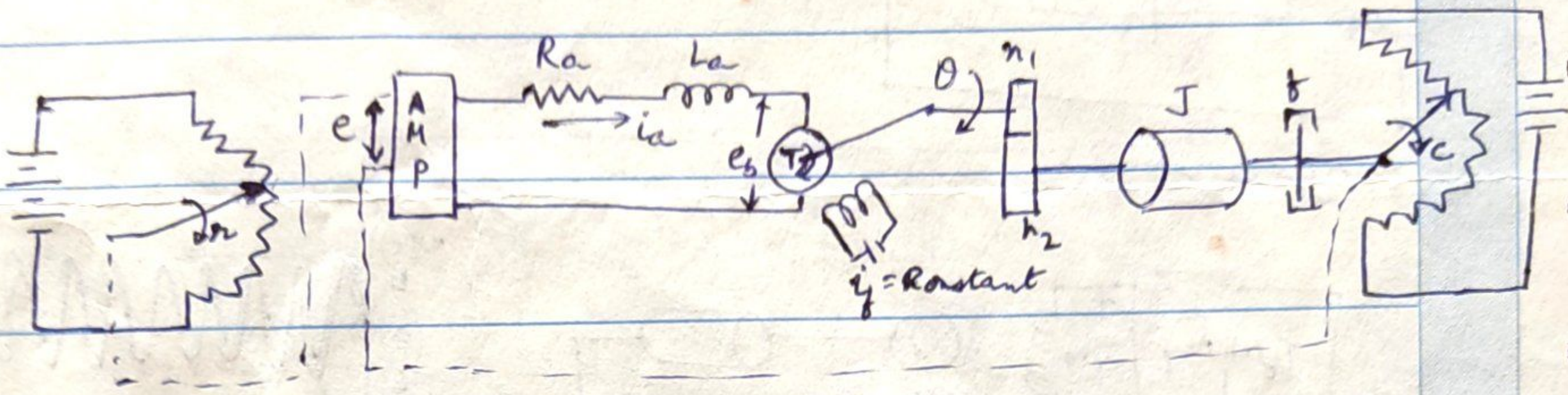
Let $x_1 = \theta \qquad x_2 = \dot{\theta}$

$$\therefore \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{1}{T_m} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_m}{T_m} \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + 0 \cdot u \qquad \because y = \theta, \quad u = e_a.$$



Ex




Tutorial

$K_1 = 7.64$ V/rad = gain of pot. error detector

$K_p = 10$ V/V = amp. gain

$K_b = 0.055$ V-s/rad.

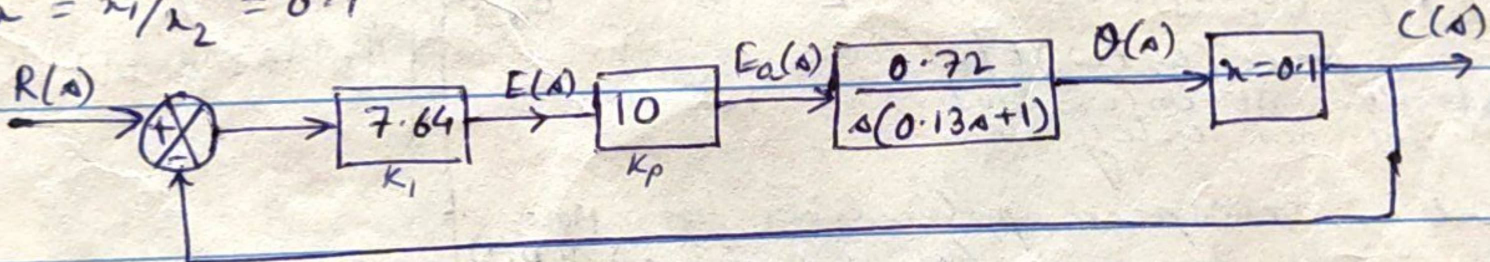
$R_a = 0.2\,\Omega$ , $L_a \to 0$.

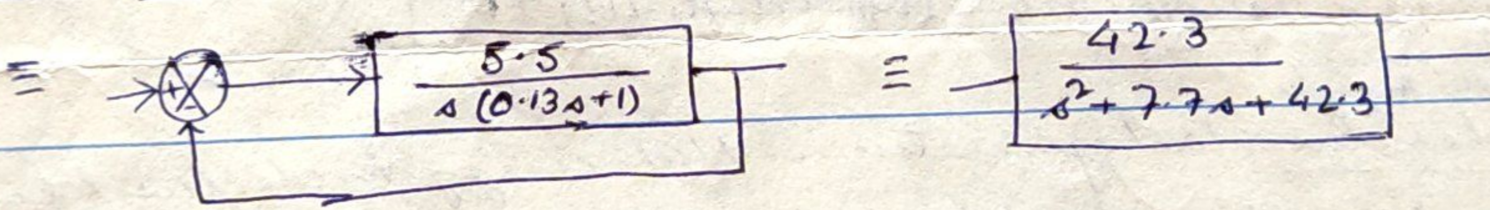
k = motor torque constant = $6 \times 10^{-5}$ N-m/V

$J_m = 1 \times 10^{-5}$ kg m$^2$ $\quad f_m \to 0 \quad J_{eq} = J_m + n^2 J_L \,;\, f_{eq} = f_m + n^2 f_L$

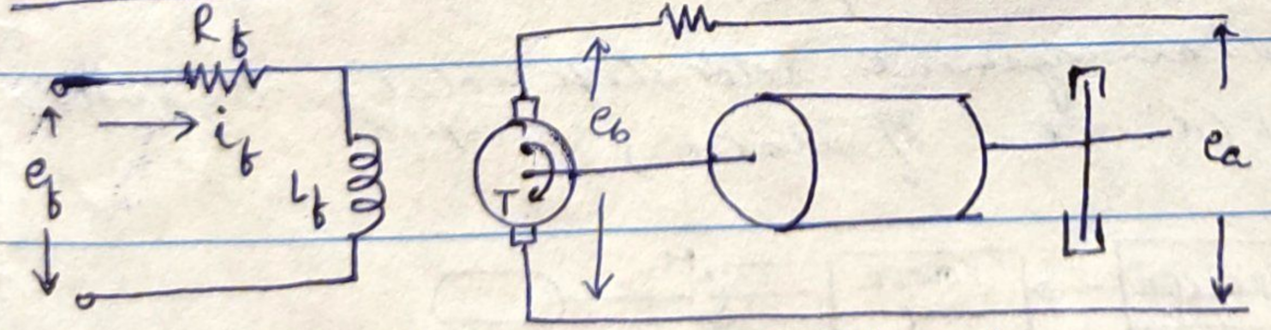
$J_L = 4.4 \times 10^{-3}$ kg m$^2$ $\quad f_L = 4 \times 10^{-2}$ Nm/rad/s

$n = n_1/n_2 = 0.1$



## Field controlled dc servomotor:

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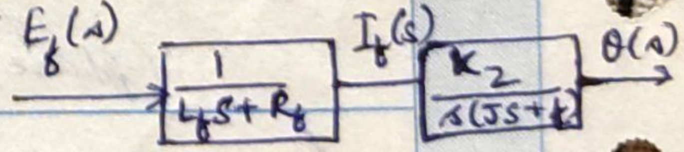



$T = K_1 \psi i_a = K_2 i_f = J\ddot{\theta} + f\dot{\theta}$ [Assuming $e_b$ constant]

$K_m = K_2 / R_f f$

$L_f \frac{di_f}{dt} + R_f i_f = e_f$

$T_f = L_f / R_f$

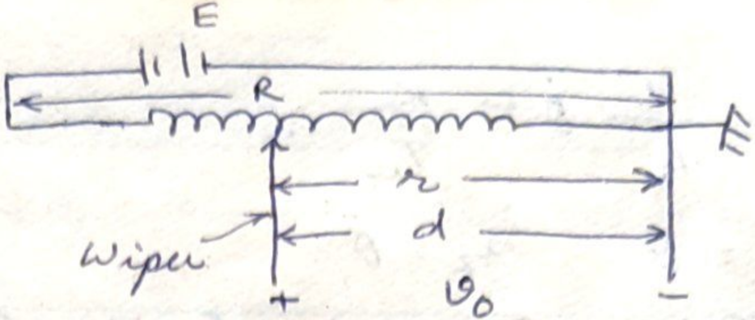
$\frac{\theta(s)}{E_f(s)} = \frac{K_2}{s(L_f s + R_f)(Js + f)} = \frac{K_m}{s(T_f s + 1)(T_m s + 1)}$ $\quad T_m = J/f$.

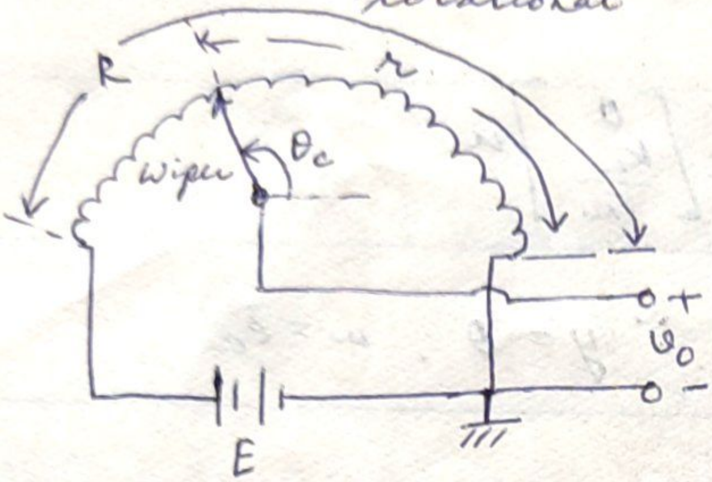
① $L_{fc}$ NOT negligible.

$T \propto i_f$ only ⇐ ② not $i_a$ constant needed but $e_b$ cons.

## Sensors

1. Potentiometers { linear / rotational

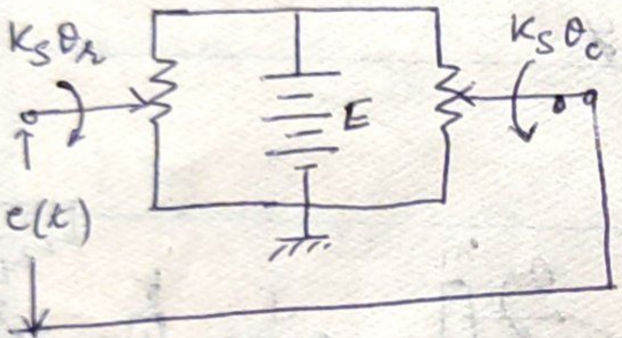



$v_0 = K_S \theta_c(t)$  or $= K \theta_c \cdot E$

where $K_S = \frac{E}{2\pi N}$ V/rad ; $K = \frac{1}{2\pi N}$ rad$^{-1}$

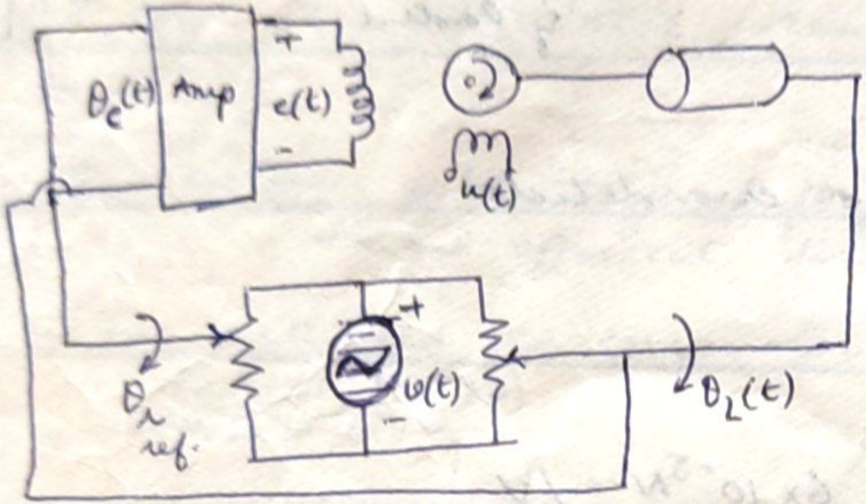
when it is a N turn rotary pot.

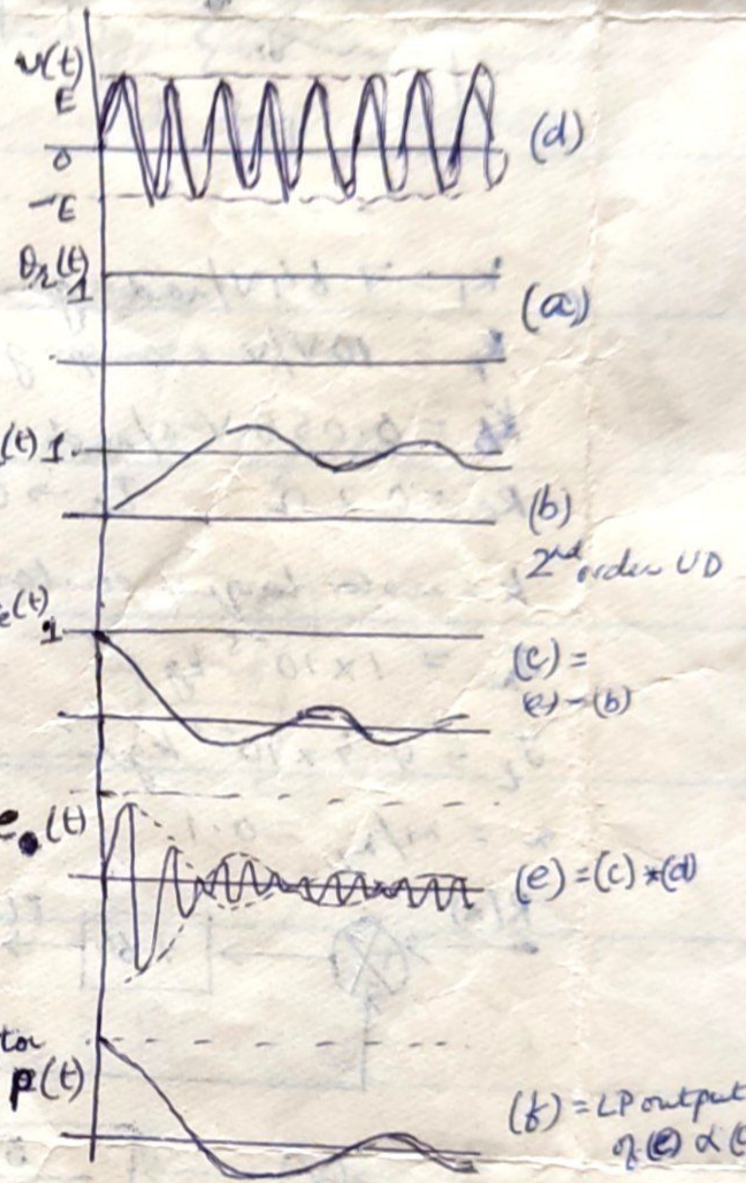



$e(t) = K_S[\theta_r - \theta_c]$ for error detector

$= K[\theta_r - \theta_c]E$

AC position servo:




CARRIER $v = E \sin \omega_c t$  **AMP. MODULATION**

$e = K_s \theta_e v$  Let $\theta_e = \sin \omega_s t$  $\omega_s \ll \omega_c$

$= \frac{1}{2} K_s E [\cos(\omega_c - \omega_s)t$  $= \theta_r - \theta_L$

$- \cos(\omega_c + \omega_s)t]$  (where $K = \frac{1}{2\pi N}$)

$= \frac{1}{2} K_s [\cos(\omega_c - \omega_s)t - \cos(\omega_c + \omega_s)t]$

Motor acts as integrator

ac — used in aerospace applications for noise suppression (signal drifts - LF!)

f < 50Hz Normal
400Hz Military
1000Hz Aerospace

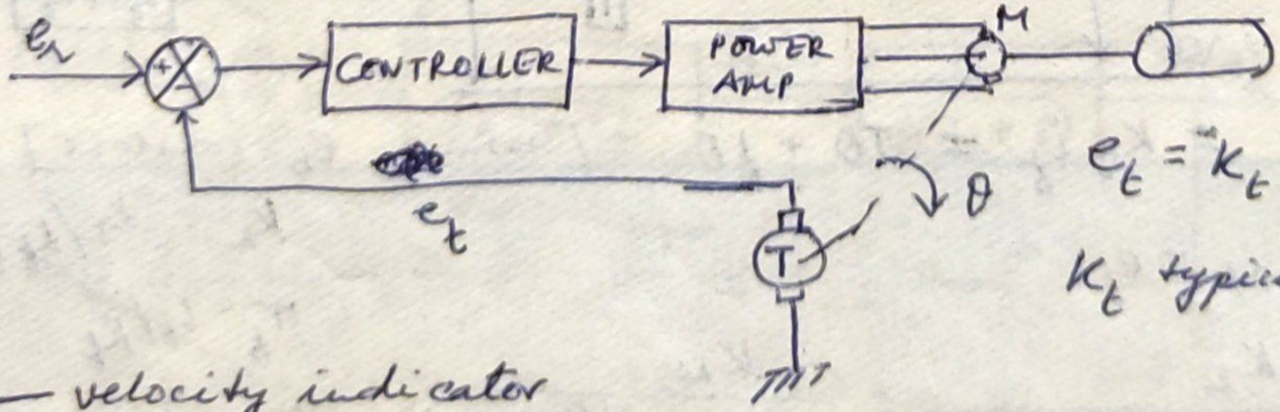
• Tachometer: To [illegible]

2. Tachometers : Tachogenerators — Mech energy to electrical energy

DC tachometer : a) Iron core rotor , field from PM, no external supply voltage   b) moving coil tacho : ironless rotor + armature cantilevered bet. PM poles

AC tacho : Quad-arrangement, rotor shaft rotation $\propto$ o/p voltage speed

(phase) $\phi = f$ (direction of rotation)




$e_t = K_t \omega$

$K_t$ typically 6V/krpm

— velocity indicator

— velocity fb. for speed control [need accuracy as in fb loop]

— velocity fb for improving stability or damping — inner fb loop

∴ NON CRITICAL.