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UNIT - 1

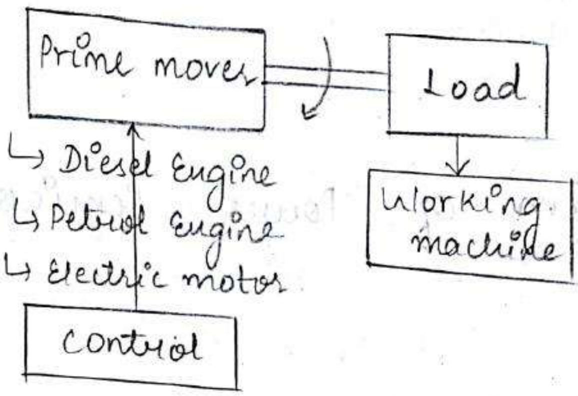
FUNDAMENTALS OF ELECTRIC DRIVES.

↳ Application of power electrons.

↳ P.E + machines.

Introduction :

* Drive : Any system that is employed for a motion control is called as a drive.



* A prime mover can be a diesel engine / petrol engine / electric motor.

* Electric Drives : Drives which employs electrical motors in it are called electrical drives.

Motion control of any motor.

↳ Fan

↳ Mixer

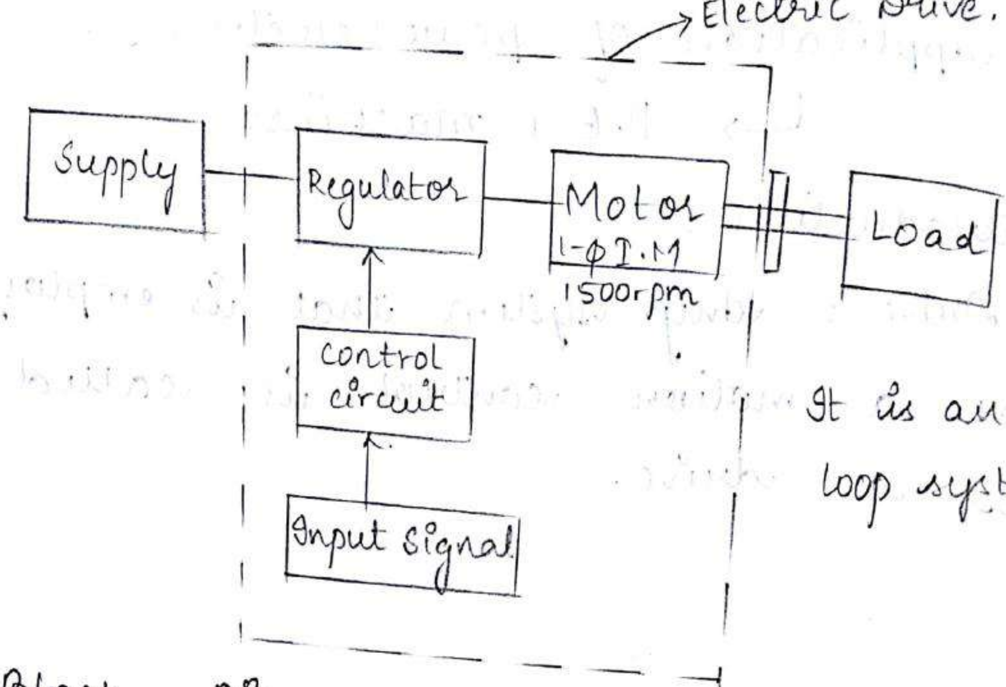
↳ Washing machine

↳ Locomotives

↳ Electric Bike.

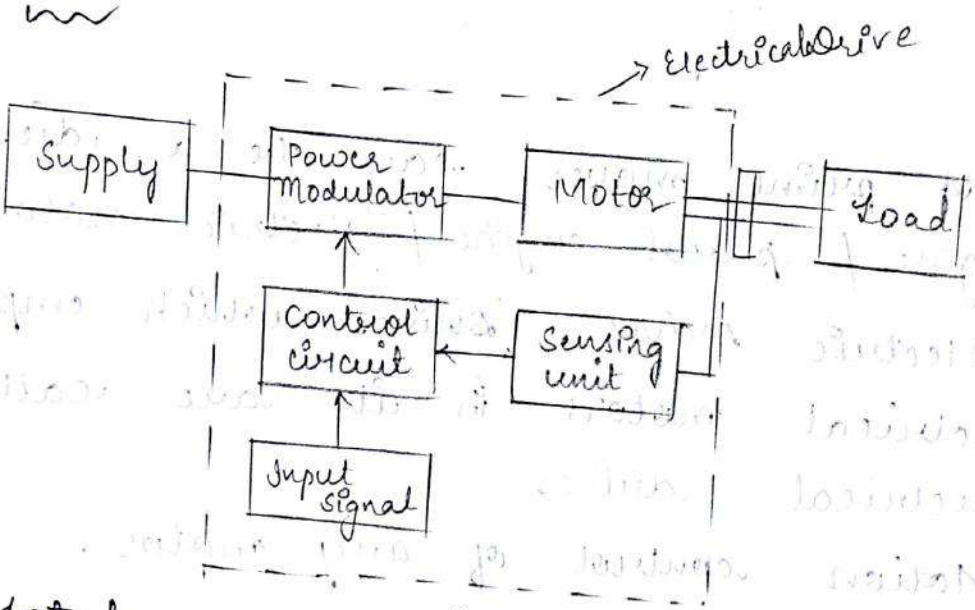
Block Diagram of Electric Drive :-

For Example : Fan.



It is an open loop system

Block Diagram of Power Semiconductor Drive :



Total system is called electrical drive system.

Power modulator is nothing but a power electronic converter.

Input signal → firing angle.

Supply.

- AC (Variable)
  - 1ϕ - 230V, 50Hz
  - 3ϕ - 440V, 50Hz.
- DC (Fixed).

Motors.

- DC Motors
  - Separately excited
  - Series
  - Shunt
  - Compound
    - Long
    - Short.
- AC Motors.
  - 1ϕ
    - Induction motor
    - Synchronous motor
    - Special motors.
      - Stepper
      - Shaded pole
      - Universal motor.
  - 3ϕ.
    - Synchronous motor.
    - I.I

* Load is something which performs the given task.

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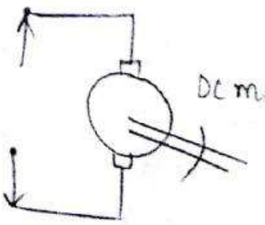
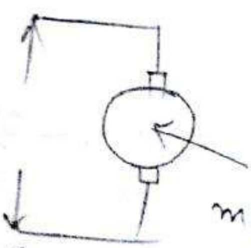
Speed Control.

- DC motor
- AC motor.



Dc motor 1ϕ, 230V, 50Hz.

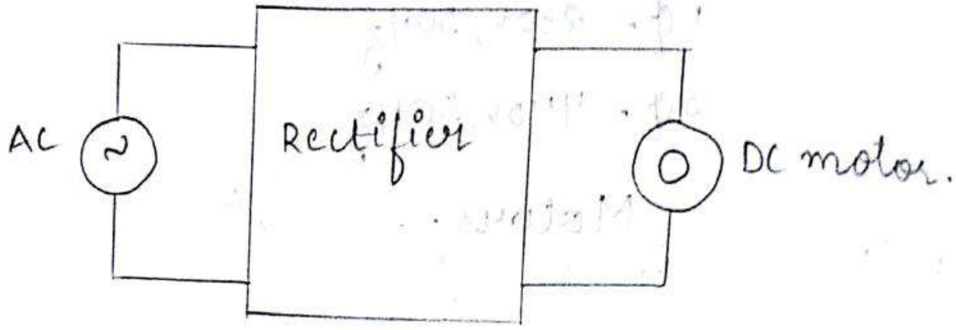


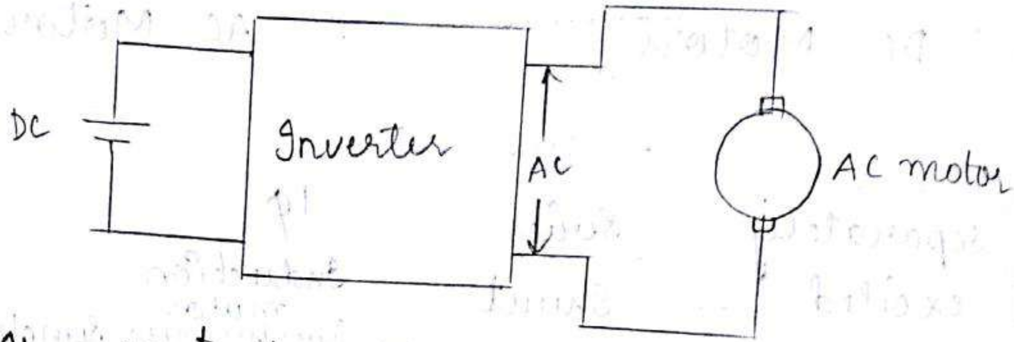
AC motor.

1) changing the voltage keeping frequency constant.
2) changing the voltage along with frequency.

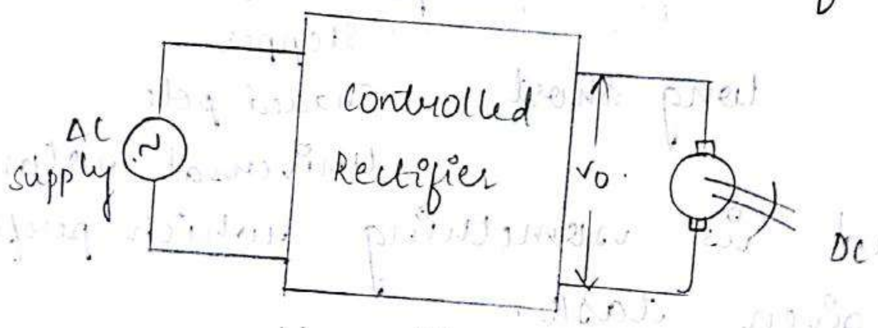
3*'s Power Modulator:

↳ It converts the supply voltage to be suitable to the motor.



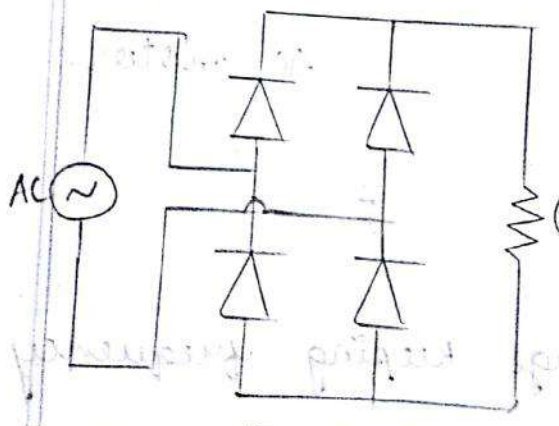


↳ It controls the motion of the motor.

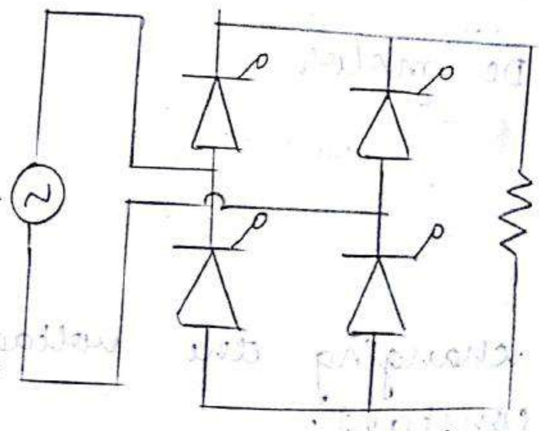


$$V_o = \frac{2V_m}{\pi} \cos\alpha.$$

Rectifier:

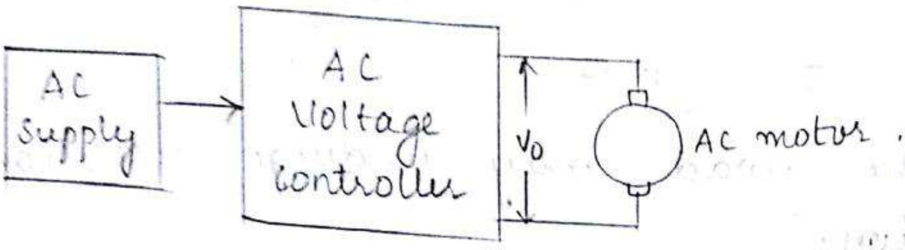


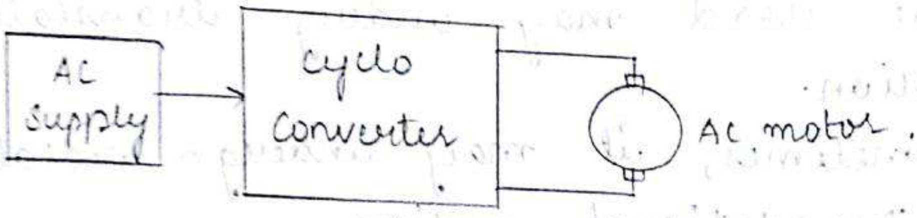
Uncontrolled.

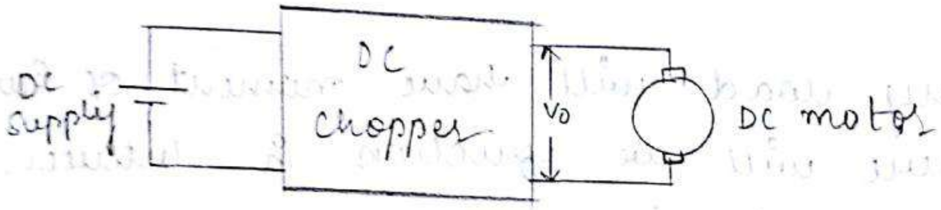


controlled.

It converts constant AC to variable AC supply. so the speed of the motor changes. Hence it is AC voltage controller.

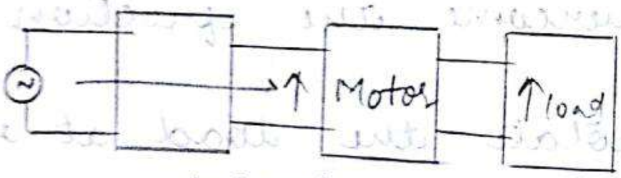






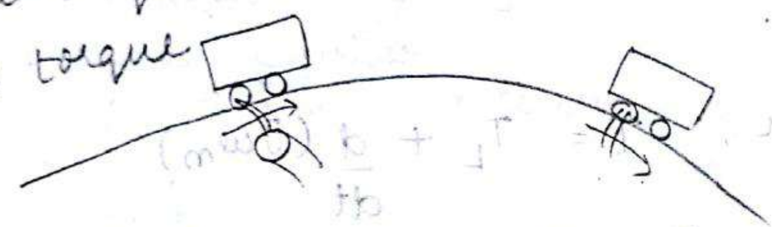
chopper converts constant DC to variable DC.

↳ It modulates the power from source so that the motor will satisfy the torque - speed characteristics of load.



↑ more torque

↓ less torque

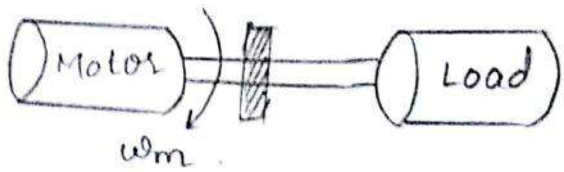


↳ It selects the mode of operation of the motor; → Motoring
→ Braking.

UNIT - 1.

FUNDAMENTAL TORQUE EQUATION:

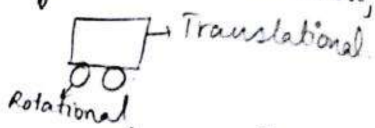
Let us consider a motor which is going to drive a load.



→ The load may undergo rotational motion.

→ The load may undergo translational motion.

→ Sometimes, it may undergo rotational & translational motion.



→ Every load will have moment of inertia(J)

→ There will be friction in between shaft & load.

→ windage friction.

* Torque - Turning effect of force.

→ It has to provide a torque to overcome inertia (For motor to accelerate)

→ Torque to overcome the friction & windage.

→ Torque to rotate the load at rated speed.

→ T_L (Load torque or resisting torque).

Then, $T = T_L + \frac{d}{dt}(J\omega_m)$

$$T = T_L + \omega_m \frac{dJ}{dt} + J\frac{d\omega_m}{dt}$$

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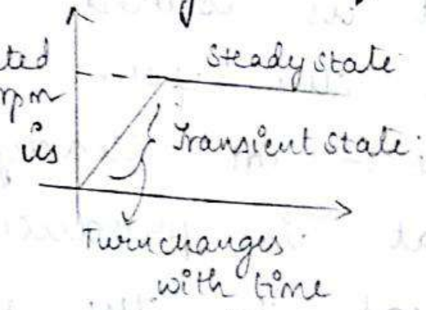
→ Loads having constant inertia.

$$\Rightarrow T = T_L + J.\frac{d\omega_m}{dt}.$$

where, T_L - Torque required to move the load at rated speed.

$J\frac{d\omega_m}{dt}$ - accelerating Torque.

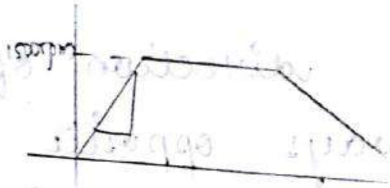
* For constant inertia loads, the equation is



$$T = T_L + J\frac{d\omega_m}{dt}.$$

i) If $T > T_L$:

$$T = T_L + J\frac{d\omega_m}{dt}.$$



$$T - T_L = J\frac{d\omega_m}{dt}.$$

$$\therefore +ve = J\frac{d\omega_m}{dt}.$$

The system is accelerating

ii) If $T < T_L$:

$$T - T_L = J\frac{d\omega_m}{dt}$$

$$-ve = J.\frac{d\omega_m}{dt}$$

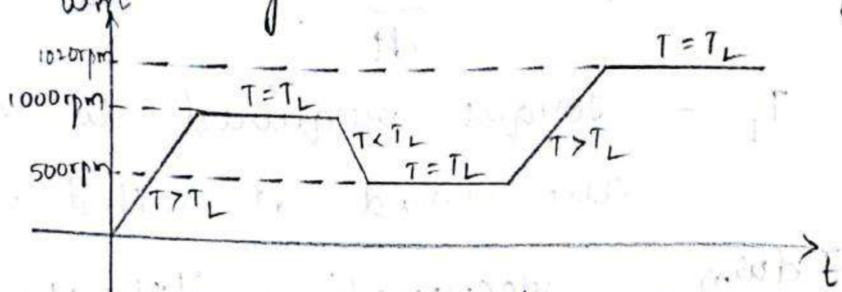
The system is decelerating.

iii) If $T = T_L$:

$$T = T_L + J\frac{d\omega_m}{dt}$$

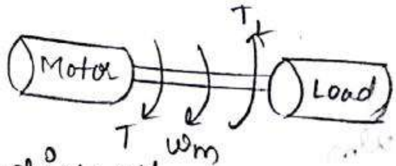
$$\therefore J\frac{d\omega_m}{dt} = 0.$$

→ It is in steady state, neither accelerating nor decelerating.



→ It is stored as kinetic energy (in the form of inertia). $= \frac{1}{2} J\omega^2$.

Note :- At steadystate, the torque that is produced by the motor is equal to the load torque.



The direction of load torque is always opposite to the motor torque because of friction & windage.

* COMPONENTS OF LOAD TORQUE (T_L):

↳ Friction Torque (T_F) : The friction will lie at the motor shaft.

↳ Windage Torque (T_W) : The wind will oppose the motion of load, windage frictional torque.

↳ Torque that is needed to do useful work (T_m).

* Depends on the application we use.

→ constant.

→ Function of Speed.

→ Time Invariant

→ Time variant.

* FRICTION TORQUE :

↳ Coulomb's Friction (T_c).

↳ Viscous Friction (T_v)

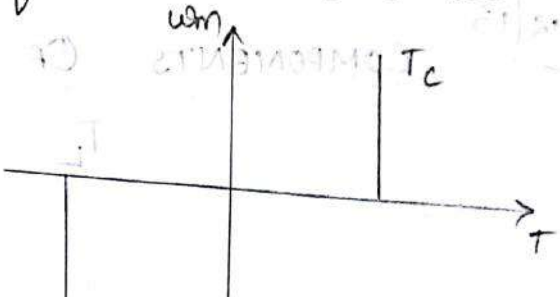
↳ Stiction (T_s).

1. COULOMB'S FRICTION (T_c) :

Coulomb's friction will exist whenever the two dry surfaces are in contact.

→ Torque due to coloumb's friction is constant.

→ It won't depend on speed.

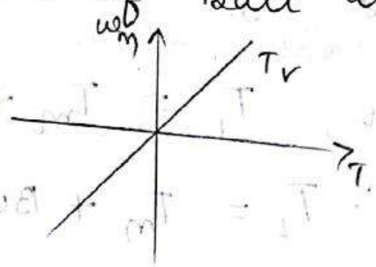


2. VISCOUS FRICTION (T_V) : (Torque).

The torque that comes in picture due to lubrication of Ball bearings.

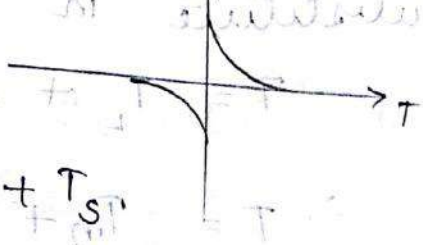
$T_V \propto \omega_m$.

$\therefore T_V = B.\omega_m$.

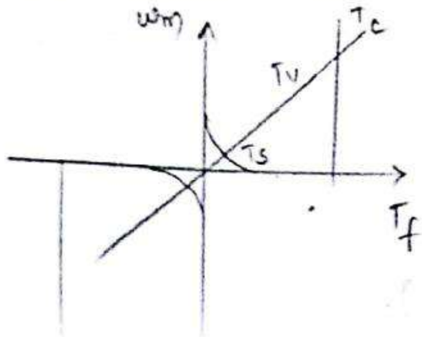


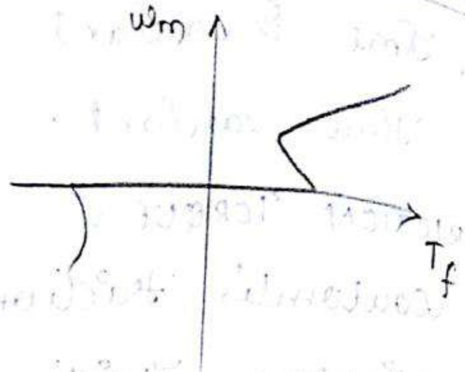
3. Stiction (T_s):

The torque due to sticking nature of the surface is called Stiction.



$T_f = T_c + T_V + T_S$



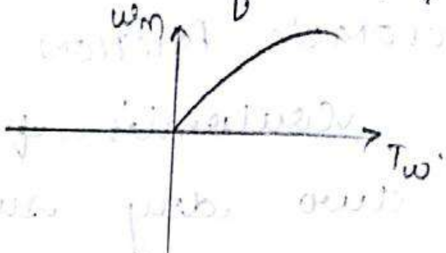


* Windage Torque :

opposing nature of air.

$T_\omega \propto \omega_m^2$.

$\therefore T_\omega = K\omega_m^2$.



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COMPONENTS OF LOAD TORQUE :

T_L

- Friction torque (T_F)
  - T_C
  - T_V ↳ $\propto \omega$.
  - T_S.
- windage torque (T_ω)
  - $\propto \omega^2$
- Torque due to useful work (T_m)

Then, $T_L = T_m + T_c + T_V + T_S + T_\omega$.

$\therefore T_L = T_m + B\omega + T_c + C\omega^2$.

Usually, $(T_c + C\omega^2) << T_\omega + B\omega$.

Then, $T_L = T_m + B\omega$.

Substitute in torque equation.

$$T = T_L + J\frac{d\omega}{dt}.$$

$$\therefore T = \underbrace{T_m + B\omega}_{\text{Components}} + J\frac{d\omega}{dt}.$$

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NATURE OF LOAD TORQUE (T_L):

→ Loads with constant load torques (which are independent of speed).

→ Loads for which $T_L \propto \omega$.

→ Loads for which $T_L \propto \omega^2$.

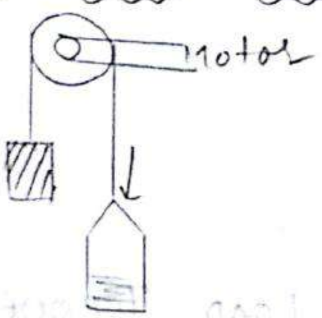
→ Loads for which $T_L \propto \frac{1}{\omega}$.

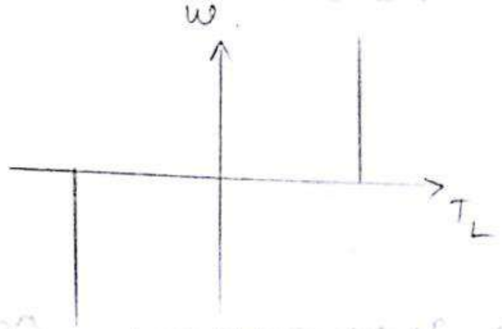
* CONSTANT LOAD TORQUES:

→ The loads in which coloumbs friction is dominant.

$$T_c = \text{constant (independent of speed)}.$$

* Low speed hoist.





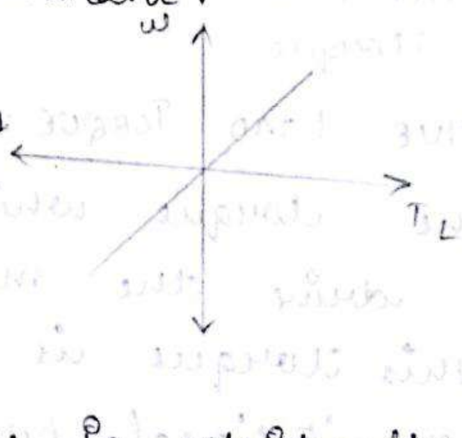
→ $T_L \propto \omega$.

The loads in which viscous friction is dominant.

Ex:

→ Calendaring machines

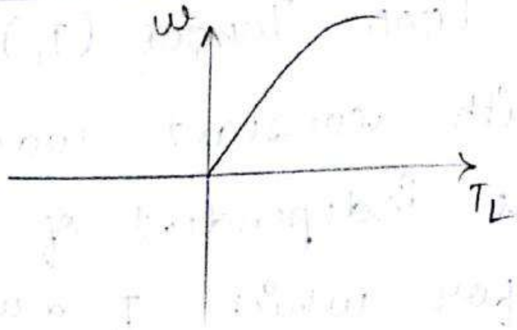
→ Eddy current Brakes



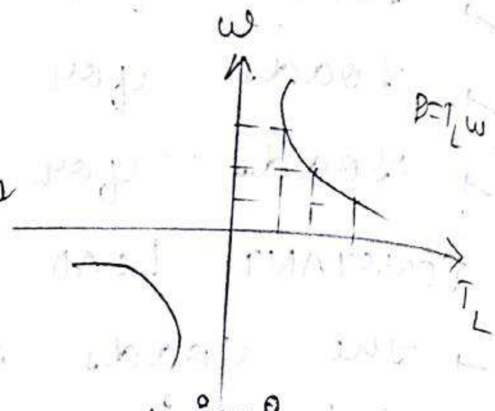
→ $T_L \propto \omega^2$.

A load torque in which the windage friction is dominant.

Eg: Aeroplanes, fans, centrifugal pumps & ship propellers.



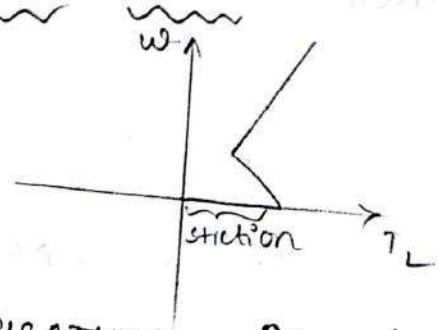
→ $T_L \propto \frac{1}{\omega}$



These type of loads are called constant power loads.

Eg: Boaring machine, drilling machine, lathes.

→ Traction load:



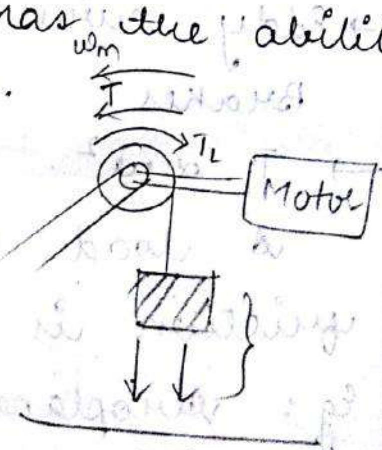
* CLASSIFICATION OF LOAD TORQUE:

- Active load torque
- Passive load torque.

1. ACTIVE LOAD TORQUE:

1) The torque which has the ability to drive the motors.

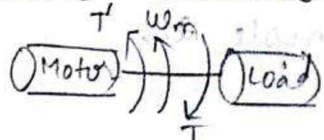
2) This torque is due to gravitational pull or potential energy stored in the load.



3) The direction of this torque remains the same, eventhough the direction of load reverses.

4) The examples for this active load torque are lifts, hoists, accelerators.

2. PASSIVE LOAD TORQUE :



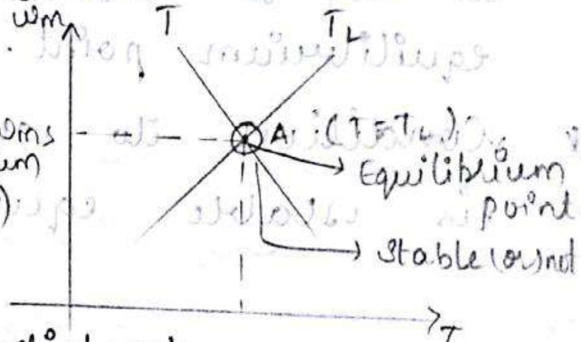
1) The load torque which always opposes the motion.

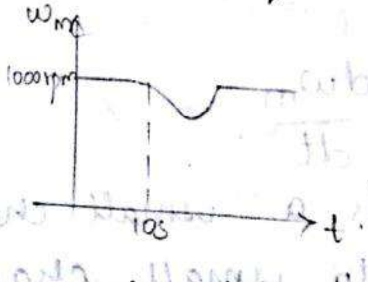
2) This torque changes its direction when the direction of load is changed.

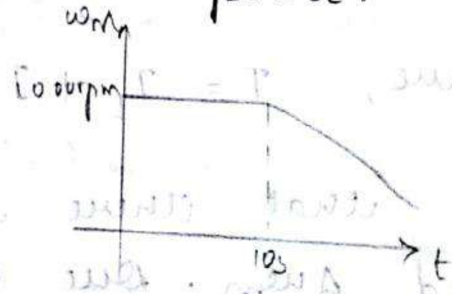
3) Examples for this Passive load torque are friction & tension of the string.

* STEADY STATE STABILITY :

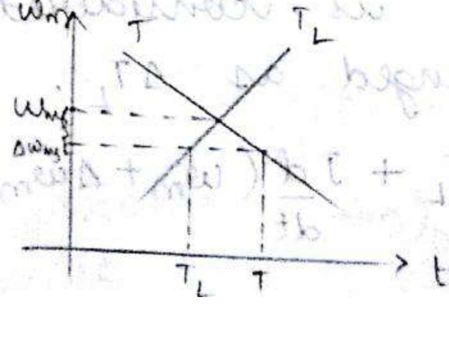
⇒ If the system can be able to retain its equilibrium point (speed) irrespective of any disturbance in load side / motor side. Then this point is stable equilibrium point.





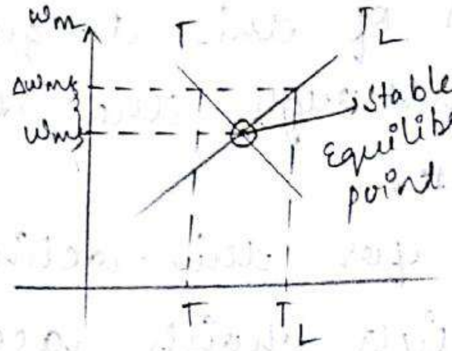


Example 1 :



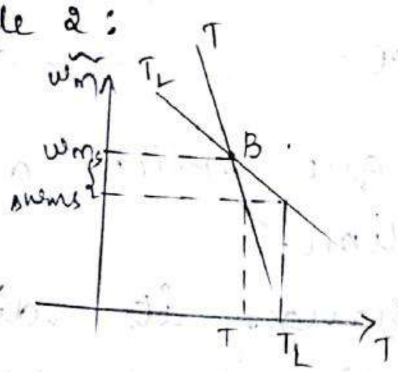
Since, $T > T_L$.

It accelerates & system is stable.



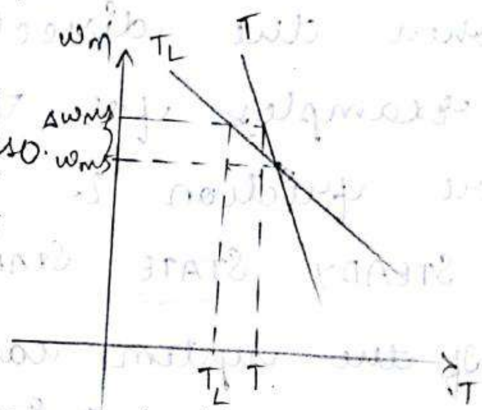
$T_L > T$. It decelerates & it is unstable.

Example 2 :



Here, $T_L > T$

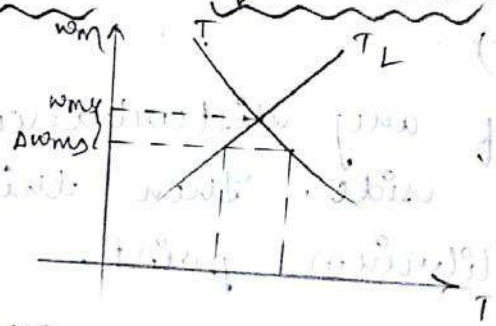
It decelerates. So, B is not stable equilibrium point.



Here, $T > T_L$.

It accelerates and also it move away, so it is not a stable equilibrium point.

* Condition to check whether a point is stable equilibrium point :



we have, $T = T_L + J \frac{d\omega_m}{dt}$ —(1)

Assume that there is a small change in speed $\Delta\omega_m$. Due to small change, the torque changed is considered as ΔT & T_L has changed as ΔT_L.

Then, $T + \Delta T = T_L + \Delta T_L + J \frac{d}{dt}(\omega_m + \Delta\omega_m)$. —(2)

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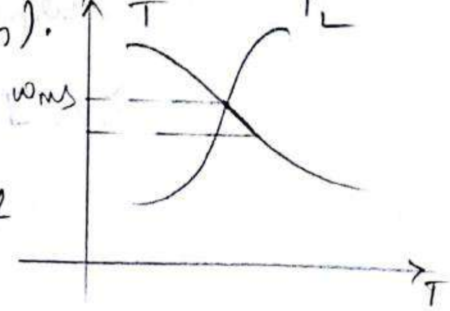
(2) − (1) ⇒ $\Delta T = \Delta T_L + J \frac{d}{dt_{\omega m}} (\Delta \omega_m)$.

$\therefore \Delta T - \Delta T_L = J \frac{d}{dt} (\Delta \omega_m)$.



Here, $\Delta \omega_m$ is very very small. Therefore, small change $\Delta \omega_m$ is taken as the slope of the curve.

$\therefore \frac{\Delta \omega_m}{\Delta T} = \frac{d\omega_m}{dT}$ & $\frac{\Delta \omega_m}{\Delta T_L} = \frac{d\omega_m}{dT_L}$.

$\Rightarrow \frac{\Delta T}{\Delta \omega_m} = \frac{dT}{d\omega_m}$.

$$\therefore \boxed{\Delta T = \frac{dT}{d\omega_m} \cdot \Delta \omega_m}$$

& $\frac{\Delta T_L}{\Delta \omega_m} = \frac{dT_L}{d\omega_m}$.

$$\Rightarrow \boxed{\Delta T_L = \frac{dT_L}{d\omega_m} \cdot \Delta \omega_m}.$$

Substitute these values in above equatio

$$J \cdot \frac{d(\Delta \omega_m)}{dt} = \frac{dT}{d\omega_m} \Delta \omega_m - \frac{dT_L}{d\omega_m} \Delta \omega_m$$

$$J \cdot \frac{d}{dt}(\Delta \omega_m) = \Delta \omega_m \left[\frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m} \right].$$

$$\Rightarrow J \cdot \frac{d}{dt}(\Delta \omega_m) - \Delta \omega_m \left[\frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m} \right] = 0.$$

Let $K = \frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m}$.

$$J \cdot \frac{d}{dt}(\Delta \omega_m) - \Delta \omega_m K = 0.$$

Assume $(\Delta \omega_m)_0$ is initial deviation at $t = 0$.

$$J\left[s\,\Delta\omega_m(s) - (\Delta\omega_m)_0\right] - K\,\Delta\omega_m(s) = 0.$$

$$\Delta\omega_m(s)\left[sJ - K\right] - J(\Delta\omega_m)_0 = 0$$

$$\Rightarrow J(\Delta\omega_m)_0 = (sJ - K)\,\Delta\omega_m(s).$$

$$\Delta\omega_m(s) = \frac{J(\Delta\omega_m)_0}{sJ - K}$$

$$\Rightarrow \Delta\omega_m(s) = (\Delta\omega_m)_0\left[\frac{1}{s - K/J}\right].$$

$$\Rightarrow \Delta\omega_m(t) = (\Delta\omega_m)_0\, e^{+(K/J)t}.$$

$$\Delta\omega_m(t) = (\Delta\omega_m)_0 \cdot e^{\frac{1}{J}\left[\frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m}\right]\cdot t}.$$

As $t \to \infty$, then if $\frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m}$ is +ve, then $\Delta\omega_m(t) \neq 0$.

If $\frac{dT}{d\omega_m} - \frac{dT_L}{d\omega_m} < 0$ Then we get steady state. $\Rightarrow$ If $\frac{dT}{d\omega_m} < \frac{dT_L}{d\omega_m}$ then point is steady state equilibrium point.

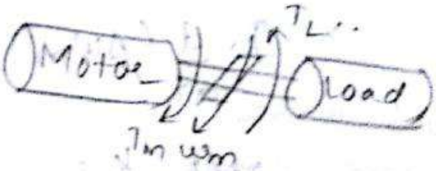
* MODES OF OPERATION OF MOTOR :

↳ Motoring

↳ Braking.

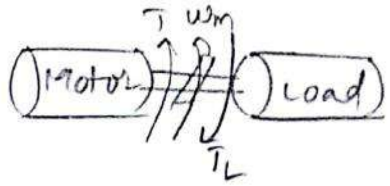
MOTORING :

A motor should provide a torque which produces the speed.



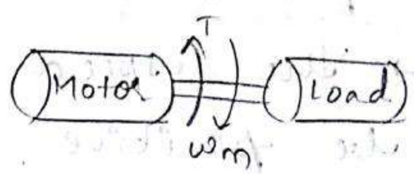
→ when T & ω_m are in same direction, then it is in forward motoring mode.

→ when T & ω_m are in same direction but in anticlockwise direction, then it is in motoring Backward / reverse mode.



2. BRAKING:

It will move because of inertia, the motor has to provide torque in opposite direction, this phenomenon is "Braking mode."



If we want to stop load, then we should provide torque in opposite direction i.e., [Reverse Braking]

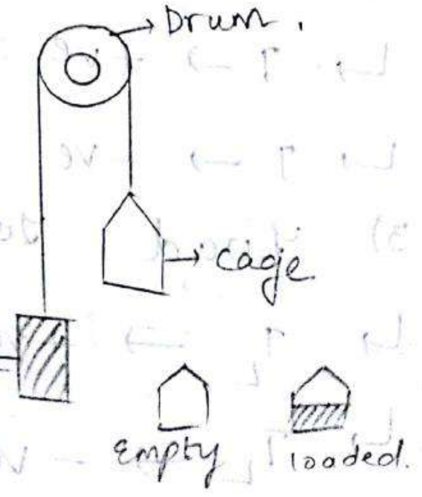
Eg: Hoist.

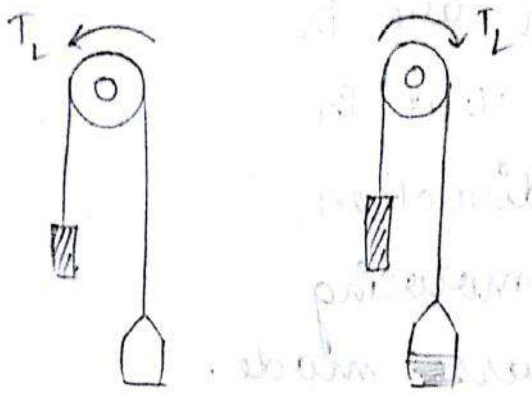
11/12/15

FOUR QUADRANT OPERATION OF A DRIVE: (Hoist load):

Assumptions:

1. The counter weight is heavier than the empty cage.
2. The loaded cage is heavier than the counter weight.





Sign conventions:

1) Speed (ω_m):

↳ The speed (ω_m) is considered to be positive, if the cage is moving upwards or in forward direction. [i.e., Drum is in counter clockwise direction].

↳ ω_m is considered to be negative, if the cage is moving downwards direction in Reverse direction [i.e., Drum is in clockwise direction]

2) Motor Torque (T):

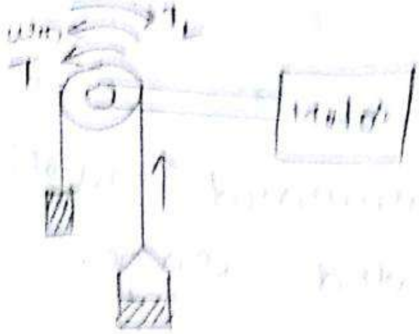
↳ $T \rightarrow +ve$ if it is in ccw direction

↳ $T \rightarrow -ve$ if it is in cw direction

3) Load Torque (T_L).

↳ $T_L \rightarrow +ve$ if it is in cw direction

↳ $T_L \rightarrow -ve$ if it is in ccw direction case i) : Upward motion of the loaded cage.



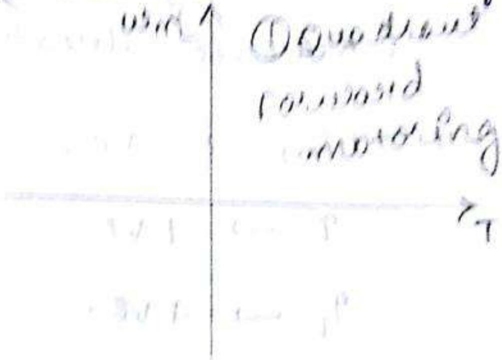
→ Motoring Mode (Forward motoring).

→ $\omega_m \rightarrow +ve$

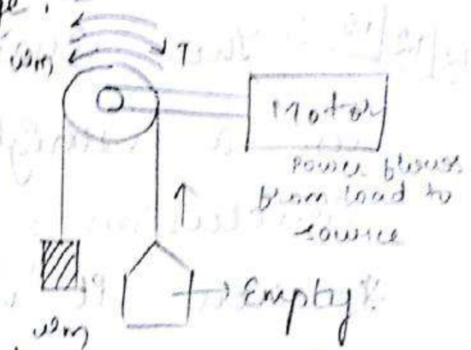
$T_m \rightarrow +ve$

$T_L \rightarrow +ve$.

→ power = $T \times \omega$.



case ii) : Upward motion of an empty cage.

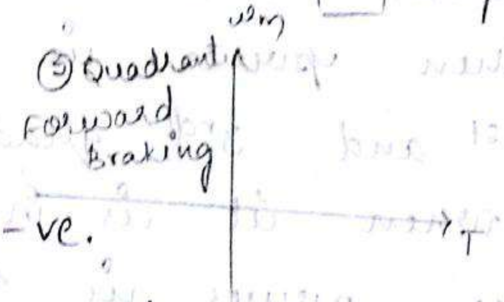


→ Braking mode. (Forward Braking)

→ $\omega_m \rightarrow +ve$.

$T \rightarrow -ve$.

$T_L \rightarrow -ve$.



→ power = $T \times \omega$ = $-ve$.

case iii) : Downward motion of an empty cage.

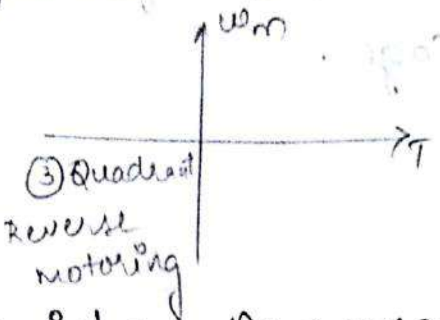
→ Motoring mode (Reverse motoring)

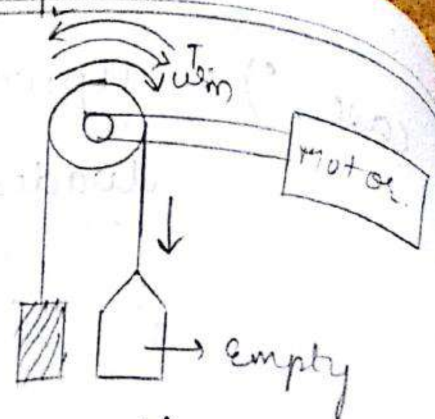
→ $\omega_m \rightarrow -ve$

$T \rightarrow -ve$

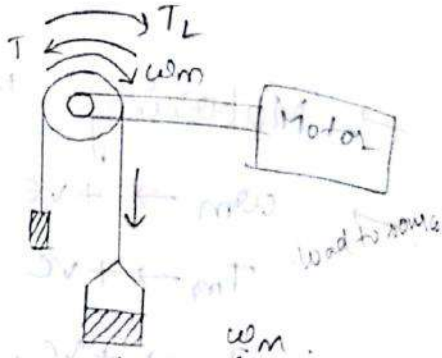
$T_L \rightarrow -ve$.

→ power = $T \times \omega$ = +ve.





Case iv) : Downward motion of loaded cage.



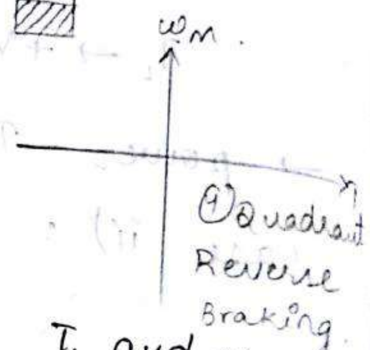
→ Braking mode
(Reverse braking)

→ ω_m → −ve.

T → +ve

T_L → +ve.

→ power = $T \times \omega$ = −ve



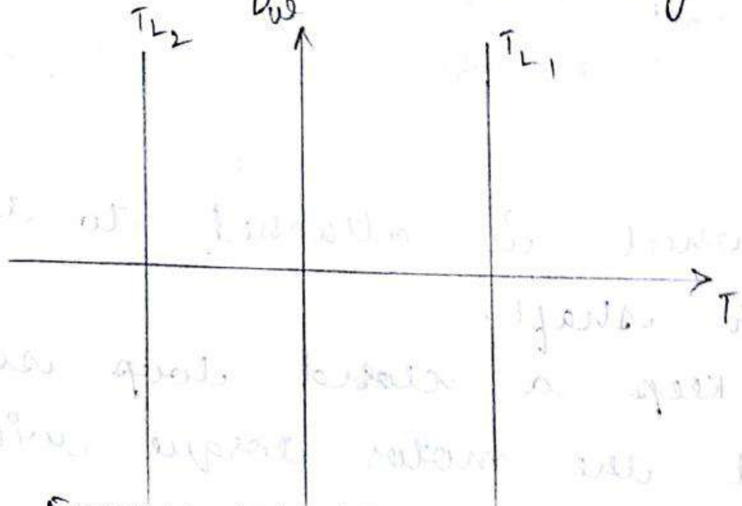
12/12/15. The characteristics of T_L and ω is a straight line.

Conclusion :

* when it is in motoring mode, then power is positive in both 1st and 3rd quadrant.
* when it is in Braking mode, then power is negative in both 2nd and 4th Quadrant, & the load drives the motor from the source.

Let, T_{L_1} = The equivalent load torque of a loaded cage.

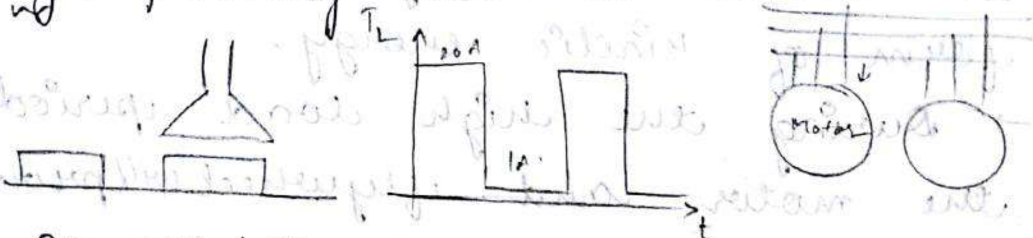
T_{L_2} = The equivalent load torque of unloaded cage.



* LOAD EQUALISATION:

→ Load varies with time.

E.g: pressing machines.



For Motor:

→ The rating of the motor is very high.

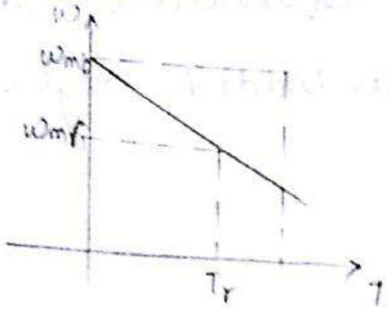
→ It will take pulsating currents.

→ Voltage fluctuation, other equipment that is connected undergo voltage fluctuation.

⇒ **Load equilisation:**

The main agenda is to reduce the rating of the motor and also pulsating current by equalising the load.

→ They select a motor which will have drooping speed - torque characteristics.

→ 

$(0, \omega_{m0})$ (T_r, ω_{mr})

$$\frac{x - x_1}{x_2 - x_1} = \frac{y - y_1}{y_2 - y_1}$$

$$\frac{T - 0}{T_r - 0} = \frac{\omega_m - \omega_{m0}}{\omega_{mr} - \omega_{m0}}$$

$$\omega_m - \omega_{m0} = \frac{T}{T_r}(\omega_{mr} - \omega_{m0}).$$

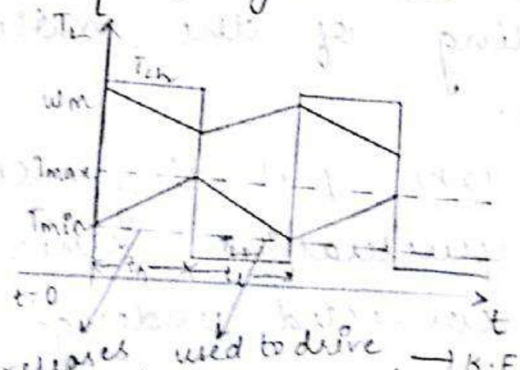
$$\Rightarrow \omega_m = \omega_{m0} - \frac{T}{T_r}(\omega_{mr} - \omega_{m0}).$$

→ Flywheel is attached to the motor shaft.

→ They keep a closed loop system to restrict the motor torque within the limits. ($T_{min} - T_{max}$).

→ During low load period, energy is stored in flywheel in the form of kinetic energy.

→ During the high load period, the motor and flywheel will provide the T_{Lh}. (High load torque).



where, T_{Lh} = High load torque

T_{LL} = Low load torque

T_{min} = Minimum motor torque

T_{max} = Maximum motor torque.

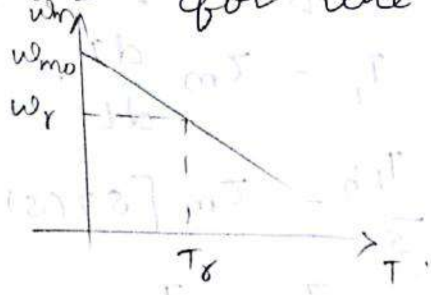
$t_h \rightarrow$ time direction of High load.

$t_l \rightarrow$ time direction of low load.

15/12/15

Calculation of Moment of Inertia of the Flywheel (J):

$\rightarrow$ Equation for the drooping characteristic



$(0, \omega_{mo})$ (T_r, ω_{mr}).

$$\Rightarrow \frac{y-y_1}{y_2-y_1} = \frac{x-x_1}{x_2-x_1}.$$

$$\Rightarrow \frac{\omega_m - \omega_{mo}}{\omega_{mr} - \omega_{mo}} = \frac{T-0}{T_r-0}.$$

$$\Rightarrow \omega_m = \omega_{mo} - \frac{(\omega_{mo} - \omega_{mr})}{T_r} \cdot T \quad \text{---(1)}$$

Then, $$J \cdot \frac{d\omega_m}{dt} = 0 - J\left[\frac{\omega_{mo} - \omega_{mr}}{T_r}\right] \cdot \frac{dT}{dt}.$$

$$\Rightarrow \tau_m \text{ (Mechanical time constant)} = \frac{J(\omega_{mo} - \omega_{mr})}{T_r} \quad \text{---(2)}$$

$$\Rightarrow \boxed{J\frac{d\omega_m}{dt} = -\tau_m \cdot \frac{dT}{dt}}$$

$$T = T_L + J\frac{d\omega_m}{dt}.$$

$$\Rightarrow T = T_L - \tau_m \cdot \frac{dT}{dt} \quad \begin{cases} (T_{Lh}) & 0 < t < t_h \; (T_{Lh}) \\ (T_{Ll}) & t_h < t < (t_h + t_l) \end{cases}$$

→ For High load period :

$$0 < t < t_h .$$

conditions : At $t = 0$, $T = T_{min}$

At $t = t_h$, $T = T_{max}$.

Here, Load Torque, $T_L = T_{Lh}$ (constant)

Then, $T = T_L - \tau_m \dfrac{dT}{dt}$.

$$\Rightarrow T(s) = \frac{T_{Lh}}{s} - \tau_m \left[s T(s) - T_{min} \right]$$

$$\Rightarrow T(s)\left[1 + s\tau_m\right] = \frac{T_{Lh}}{s} + \tau_m \cdot T_{min}$$

$$\Rightarrow T(s) = \frac{T_{Lh}}{s(1+s\tau_m)} + \frac{\tau_m \cdot T_{min}}{1+s\tau_m}$$

By using partial fractions,

$$\frac{1}{s(1+s\tau_m)} = \frac{A}{s} + \frac{B}{s\tau_m+1}$$

$$1 = A(s\tau_m + 1) + B(s)$$

$$\Rightarrow 1 = (A\tau_m + B)s + A.$$

$$\Rightarrow A = 1.$$

$$\tau_m + B = 0.$$

$$\Rightarrow B = -\tau_m.$$

$$\Rightarrow \frac{1}{s} - \frac{\tau_m}{s\tau_m + 1} = \frac{1}{s} - \frac{\cancel{\tau_m}}{\cancel{\tau_m}\left[s + \frac{1}{\tau_m}\right]} = \frac{1}{s} - \frac{1}{(s+1/\tau_m)}$$

$$\therefore \frac{1}{s(1+s\tau_m)} = \frac{1}{s} - \frac{\tau_m}{(s\tau_m+1)}.$$

$$\& \quad \frac{\tau_m}{s\tau_m + 1} = \frac{\cancel{\tau_m}}{\cancel{\tau_m}\left[s + \frac{1}{\tau_m}\right]}$$

$$= \frac{1}{(s + 1/\tau_m)}.$$

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$$\Rightarrow T(s) = T_{Lh}\left[\frac{1}{s} - \frac{\tau_m}{1+s\tau_m}\right] + T_{min}\left[\frac{1}{s+1/\tau_m}\right]$$

$$= T_{Lh}\left[\frac{1}{s} - \frac{1}{s+1/\tau_m}\right] + T_{min}\left[\frac{1}{s+1/\tau_m}\right]$$

$$\therefore T(t) = T_{Lh}\left[1 - e^{-t/\tau_m}\right] + T_{min}\left[e^{-t/\tau_m}\right].$$

$\Rightarrow$ At $t = t_h$, $T = T_{max}$.

$$\Rightarrow T_{max} = T_{Lh}\left[1 - e^{-t_h/\tau_m}\right] + T_{min}\left[e^{-t_h/\tau_m}\right]$$

$$\Rightarrow T_{max} = e^{-t_h/\tau_m}\left[T_{min} - T_{Lh}\right] + T_{Lh}.$$

$$\frac{T_{max} - T_{Lh}}{T_{min} - T_{Lh}} = e^{-t_h/\tau_m}.$$

$$\frac{-t_h}{\tau_m} = \ln\left[\frac{T_{max} - T_{Lh}}{T_{min} - T_{Lh}}\right].$$

$$\boxed{\tau_m = \frac{t_h}{\ln\left[\frac{T_{min} - T_{Lh}}{T_{max} - T_{Lh}}\right]}} \quad -(3)$$

Substitute (3) in (2)

$$\frac{t_h}{\ln\left[\frac{T_{min} - T_{Lh}}{T_{max} - T_{Lh}}\right]} = \frac{J(\omega_{m0} - \omega_{mr})}{T_r}.$$

$$\Rightarrow \boxed{J = \frac{t_h \cdot T_r}{\ln\left[\frac{T_{min} - T_{Lh}}{T_{max} - T_{Lh}}\right](\omega_{m0} - \omega_{mr})}}.$$

$\rightarrow$ For low load period:

$$t_h < t < (t_h + t_l).$$

Conditions: At $t = 0$, $T = T_{max}$.

At $t = (t_h + t_l)$, $T = T_{min}$.

Then, load torque $T_L = T_{LL}$ (constant)

$$\Rightarrow T = T_L - \tau_m \cdot \frac{dT}{dt}.$$

$$t_n < t < t_n + t_l.$$

$$t_n - t_n < t - t_n < t_n + t_l - t_n.$$

$$0 < t - t_n < t_l.$$

Assume, $t' = t - t_n$.

$\Rightarrow 0 < t' < t_l. \Rightarrow T_L = T_{LL}$ (constant)

Then, at $t' = 0$, $T = T_{max}$

at $t' = t_l$, $T = T_{min}$.

$$\Rightarrow \quad T = T_L - \tau_m \frac{dT}{dt}.$$

$$T(s) = \frac{T_{LL}}{s} - \tau_m \left[s T(s) - T_{max} \right].$$

$$T(s)\left[1 + s\tau_m\right] = \frac{T_{LL}}{s} + T_{max} \cdot \tau_m.$$

$$T(s) = \frac{T_{LL}}{s(1+s\tau_m)} + \frac{\tau_m}{1+s\tau_m} \cdot T_{max}$$

Using partial fractions,

$$T(s) = T_{LL}\left[\frac{1}{s} - \frac{1}{s + 1/\tau_m}\right] + T_{max} \cdot \left[\frac{1}{s+1/\tau_m}\right]$$

$$\Rightarrow T(t') = T_{LL}\left[1 - e^{-t'/\tau_m}\right] + T_{max}\left[e^{-t'/\tau_m}\right]$$

when, $t = t'$, $T = T_{min}$.

$$T_{min} = T_{LL}\left[1 - e^{-t_l/\tau_m}\right] + T_{max}\left[\cancel{1}\, e^{-t_l/\tau_m}\right]$$

$$\therefore T_{min} = T_{LL}\left[1 - e^{-t_l/\tau_m}\right] + T_{max}\left[e^{-t_l/\tau_m}\right].$$

$$\Rightarrow T_{min} = e^{-t_e/\tau_m}\left[T_{max} - T_{LL}\right] + T_{LL}.$$

$$\frac{T_{min} - T_{LL}}{T_{max} - T_{LL}} = e^{-t_e/\tau_m}.$$

$$\Rightarrow -\frac{t_e}{\tau_m} = \ln\left[\frac{T_{min} - T_{LL}}{T_{max} - T_{LL}}\right].$$

$$\boxed{\tau_m = \frac{t_e}{\ln\left[\frac{T_{max} - T_{LL}}{T_{min} - T_{LL}}\right]}}$$

Substitute the above in eq (2).

$$\frac{t_e}{\ln\left[\frac{T_{max} - T_{LL}}{T_{min} - T_{LL}}\right]} = \frac{J(\omega_{m0} - \omega_{mr})}{T_r}.$$

$$\therefore \boxed{J = \frac{t_e \cdot T_r}{\ln\left[\frac{T_{max} - T_{LL}}{T_{min} - T_{LL}}\right]\cdot(\omega_{m0} - \omega_{mr})}}$$

17/12/15.

A drive has the following parameters Motor torque $T = 150 - 0.1N$ (N-m) [N = Speed in rpm] Load torque $T_L = 100$ N-m. Initially, the drive is operating in steady state. The characteristics of load torque are changed to $T_L = -100$ N-m. Calculate the initial and final equilibrium speeds.

Sol. Given that,

$$T = (150 - 0.1N) \text{ N-m}.$$

$T_L = 100\ N\text{-}m$. (initially)

$T_L = -100\ N\text{-}m$ (Finally).

At equilibrium or steady state

$T = T_L$.

i) $T_L = 100\ N\text{-}m$.

$\Rightarrow T = T_L$.

$150 - 0.1N = 100$.

$\Rightarrow N = 500$ rpm.

ii) $T_L = -100\ N\text{-}m$.

$\therefore T = T_L$

$\Rightarrow 150 - 0.1N = -100$.

$N = 2500$ rpm.

2. A motor load system has the following details:

In Quadrant. I & II $\rightarrow T = 400 - 0.4N$. (N = speed)

In Quadrant III & IV $\rightarrow T = -400 - 0.4N$.

& Active load torque is given by $T_L = \pm 200\ N\text{-}m$. Calculate the equilibrium speeds in all the four quadrants.

Sol) Given that,

At Equilibrium or Steady State,

$T = T_L$.

II	I
$T = 400 - 0.4N$	$T = 400 - 0.4N$
$T_L = -200$	$T_L = 200$
III	IV
$T = -400 - 0.4N$	$T = -400 - 0.4N$
$T_L = -200$	$T_L = 200$

i) $T_L = 200$ N-m

$\Rightarrow \quad T = T_L.$

$400 - 0.4N = 200.$

$N = 500$ rpm.

ii) $T_L = -200$ N-m.

$T = T_L.$

$400 - 0.4N = -200.$

$\Rightarrow N = 1500$ rpm

iii) $T_L = -200$ N-m

$T = T_L$

$\Rightarrow -400 - 0.4N = -200.$

$-0.4N = 200.$

$N = -500$ rpm.

iv) $T_L = 200$ N-m

$T = T_L.$

$-400 - 0.4N = 200.$

$\Rightarrow N = -1500$ rpm.

3. A drive have the following equations for motor and a load torque: $T = 1 + 2\omega_m$ & $T_L = 3\sqrt{\omega_m}$. Obtain the equilibrium points and determine their steady state stability.

Sol) At equilibrium, $T = T_L$.

$1 + 2\omega_m = 3\sqrt{\omega_m}.$

$(1 + 2\omega_m)^2 = (\sqrt{\omega_m}\,3)^2.$

$\Rightarrow 1 + 4\omega_m^2 + 4\omega_m - 9\omega_m = 0.$

$\Rightarrow 4\omega_m^2 - 5\omega_m + 1 = 0.$

$1 + 4\omega_m^2 + 4\omega_m - 9\omega_m = 0$

$4\omega_m^2 - 5\omega_m + 1 = 0$

$\omega_m = 1, 0.25.$

Then, $\omega_m = 1$, & $\omega_m = 0.25$.

For $\omega_m = 1$: $\frac{dT}{d\omega_m} = 2$.

$$\frac{dT_L}{d\omega_m} = \frac{3}{2\sqrt{\omega_m}} = \frac{3}{2} = 1.5$$

$$\Rightarrow \frac{dT}{d\omega_m} > \frac{dT_L}{d\omega_m}$$

It does not satisfied the condition $\frac{dT}{d\omega_m} < \frac{dT_L}{d\omega_m}$. Hence, it is unstable.

For $\omega_m = 0.25$:

$$\frac{dT}{d\omega_m} = 2.$$

$$\left.\frac{dT_L}{d\omega_m}\right|_{0.25} = \frac{3}{2\sqrt{0.25}} = \frac{3}{1}.$$

$$\therefore \frac{dT}{d\omega_m} < \frac{dT_L}{d\omega_m}.$$

It satisfies the condition. Therefore, this point is a stable equilibrium point.

4. Obtain the equilibrium points and find the steady state stability when $T = -1 - 2\omega_m$, $T_L = -3\sqrt{\omega_m}$

Sol: At Equilibrium, $T = T_L$

$$-1 - 2\omega_m = -3\sqrt{\omega_m}.$$

Squaring on both sides.

$$(-1-2\omega_m)^2 = (-3\sqrt{\omega_m})^2.$$

$$1 + 4\omega_m^2 + 4\omega_m = 9\omega_m.$$

$$4\omega_m^2 - 5\omega_m + 1 = 0.$$

$$\therefore \omega_m = 1 \ ; \quad \omega_m = 0.25.$$

For $\omega_m = 1$:

$$\frac{dT}{d\omega_m} = -2.$$

$$\left.\frac{dT_L}{d\omega_m}\right|_{\omega_m=1} = \frac{-3}{2(1)} = -1.5.$$

$$\therefore \frac{dT}{d\omega_m} < \frac{dT_L}{d\omega_m}.$$

It satisfies the condition & this point is stable equilibrium point.

For $\omega_m = 0.25$:

$$\frac{dT}{d\omega_m} = -2 \ ; \quad \left.\frac{dT_L}{d\omega_m}\right|_{0.25} = \frac{-3}{2\sqrt{0.25}} = -3.$$

$$\Rightarrow \frac{dT}{d\omega_m} > \frac{dT_L}{d\omega_m}$$

It doesnot satisfies the condition & Hence it is unstable point.

17/12/15.

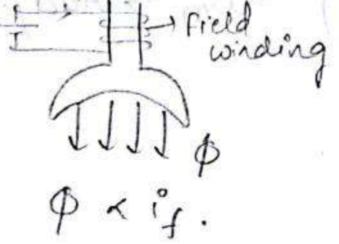
UNIT-2.

THREE PHASE CONVERTER CONTROLLED DC MOTORS.

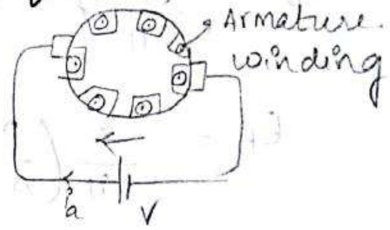
REVIEW OF DC MOTORS:

→ **Motor**: whenever a current carrying conductor is placed in a magnetic field it experiences a force.

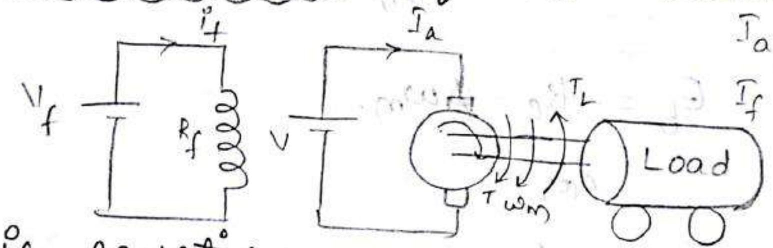
→ **Generator**: whenever a conductor cuts the flux, emf is induced.



$\phi \propto i_f$.

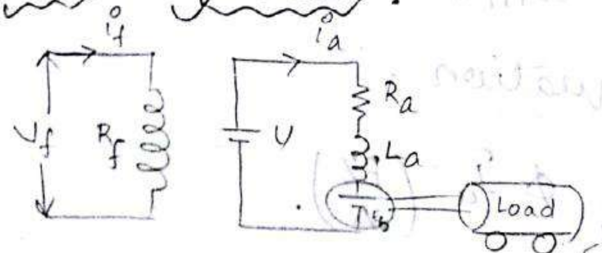


→ **Representation of DC motor:**



I_a = Armature current
I_f = Field current.

* **Basic equation:**



[under stable state $\frac{di_a}{dt} = 0$]

→ $V = I_a R_a + \cancel{L_a \frac{di_a}{dt}} + E_b$.

$\therefore \boxed{V = E_b + I_a R_a} \longrightarrow (1)$

→ $\boxed{E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right)}$.

⇒ ϕ = Flux/pole.

Z = No. of conductors.

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N = Speed in rpm.

P = No. of poles.

A = No. of parallel paths.

→ $E_b = \phi Z N \left(\frac{P}{A}\right)$ where N is in rps.

$E_b = \frac{\phi Z (2\pi N)(P/A)}{2\pi}$.

$$\boxed{E_b = \frac{1}{2\pi} \phi Z \omega_m \left(\frac{P}{A}\right)}$$ ω_m → rad/sec.

$E_b = \frac{Z}{2\pi}\left(\frac{P}{A}\right) \phi \omega_m$.

Let, $K_e = \frac{Z}{2\pi}\left(\frac{P}{A}\right)$.

$\Rightarrow \boxed{E_b = K_e \cdot \phi \omega_m.}$ → (2)

(or)

$\boxed{E_b \propto \phi \omega_m}$.

→ Torque Equation :

$T = \frac{1}{2\pi} \phi I_a \left(\frac{PZ}{A}\right)$.

$T = \frac{1}{2\pi}\left(\frac{PZ}{A}\right) \phi I_a$.

Let, $K_e = \frac{1}{2\pi}\left(\frac{PZ}{A}\right)$

$\Rightarrow \boxed{T = K_e \cdot \phi I_a}$ — (3)

(or)

$\Rightarrow \boxed{T \propto \phi \cdot I_a}$

→ Relationship between speed (ω_m) & Torque (τ) :

$$V = I_a R_a + E_b .$$

we have, $E_b = K_e \phi \omega_m$.

$$\therefore V = I_a R_a + K_e \phi \omega_m .$$

$$K_e \phi \omega_m = V - I_a R_a .$$

$$\omega_m = \frac{V - I_a R_a}{K_e \phi} .$$

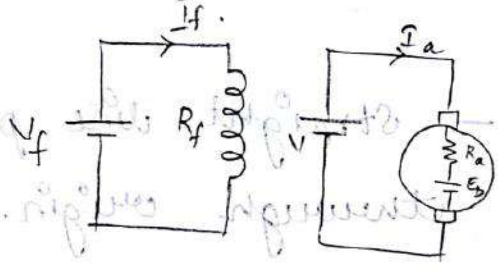
from (3), we have, $\tau = K_e \phi . I_a$.

$$I_a = \frac{\tau}{K_e . \phi} .$$

$$\Rightarrow \omega_m = \frac{V}{K_e \phi} - \frac{I_a R_a}{K_e \phi} .$$

$$\boxed{\omega_m = \frac{V}{K_e \phi} - \frac{\tau R_a}{(K_e \phi)^2}} .$$

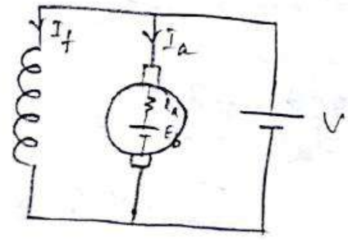
1) SEPERATELY EXCITED MOTOR :



$V_f = I_f$ = constant

$\therefore \phi$ = constant.

2) SHUNT MOTOR :



$V = I_f$ = constant

ϕ = constant.

For Separately excited motor (OR) SHUNT MOTOR:

1) $V = I_a R_a + E_b$.

2) $E_b = K_e \phi \omega_m$

$E_b = K \cdot \omega_m \quad [\because K = K_e \cdot \phi]$.

$\therefore \boxed{E_b \propto \omega_m}$

3) $T = K_e \cdot \phi I_a$.

$T = K \cdot I_a. \quad [\because K = K_e \cdot \phi]$

$\therefore \boxed{T \propto I_a}$.

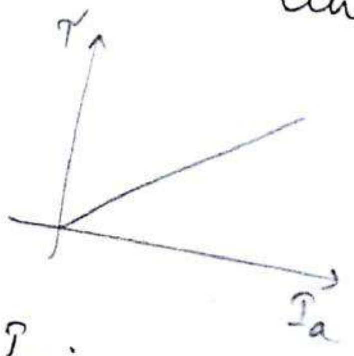
4) $\omega_m = \dfrac{V}{K_e \cdot \phi} - \dfrac{T \cdot R_a}{(K_e \cdot \phi)^2}$.

$\Rightarrow \boxed{\omega_m = \dfrac{V}{K} - \dfrac{T \cdot R_a}{K^2}}. \quad [\because K = K_e \cdot \phi]$.

* CHARACTERISTICS OF DC SEPERATELY EXCITED (OR) SHUNT MOTOR:

1) T Vs I_a:

Since $T \propto I_a$ — Straight line passing through origin.



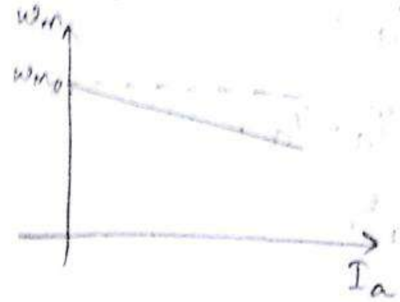
2) ω_m Vs I_a:

$V = E_b + I_a R_a$.

$V = K \omega_m + I_a R_a$.

$$\Rightarrow \frac{V - I_a R_a}{K} = \omega_m.$$

$$\therefore \omega_m \propto (V - I_a R_a) \quad \because R_a \text{ is very less}$$

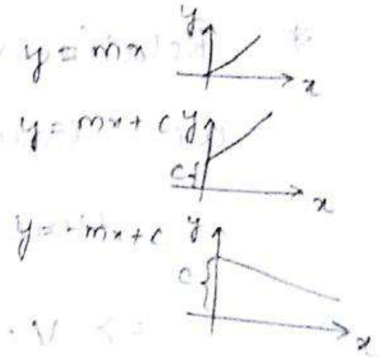


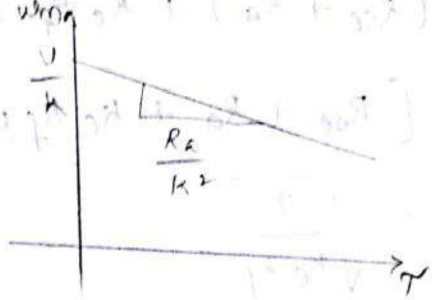
3) T Vs ω_m :

$$\omega_m = \frac{V}{K} - \frac{T R_a}{K^2}.$$

$$\Rightarrow \omega_m = -\frac{R_a}{K^2}(T) + \frac{V}{K}.$$

$$y = -mx + c$$





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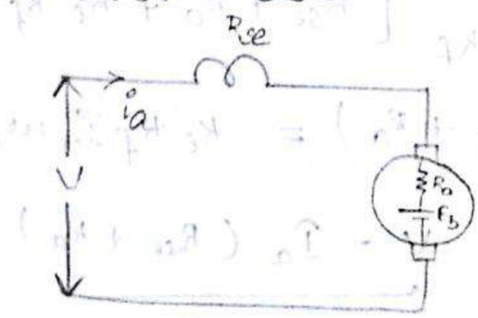
FOR SERIES MOTOR :

R_{se} — less to limit losses.
R_f — High. to limit current



$$\phi \propto i_a.$$

$$\Rightarrow \phi = k_f \cdot i_a$$

$\rightarrow$ $V = I_a R_{se} + I_a R_a + E_b.$

$$\boxed{V = I_a (R_{se} + R_a) + E_b} \text{ —— (1)}$$

$\rightarrow$ $E \propto \phi \omega_m.$

$$E = k_e \phi \omega_m.$$

$$E = k_e k_f i_a \omega_m. \text{ —— (2)}$$

$E \propto i_a \omega_m$.

$\rightarrow$ $T \propto \phi I_a$.

$T = k_e \phi I_a$.

$\Rightarrow T = k_e k_f I_a \cdot I_a$.

$\therefore T = k_e k_f I_a^2$ —— (3)

$\Rightarrow \boxed{T \propto I_a^2}$

* Relationship between T and (ω_m):

we have, $V = I_a (R_{se} + R_a) + E_b$.

Here, $E_b = k_e k_f I_a \omega_m$.

$\Rightarrow V = I_a (R_{se} + R_a) + k_e k_f I_a \omega_m$.

$\times \left[V = \cancel{I_a} \left[R_{se} + R_a \cancel{+ k_e} k_f \omega_m \right]. \right.$

Then $I_a = \sqrt{\dfrac{T}{k_e k_f}}$.

$\cancel{V =} \sqrt{\cancel{\dfrac{T}{k_e k_f}}} \left[R_{se} + R_a \cancel{+} k_e k_f \omega_m \right] \Big] \times$

$\Rightarrow V - I_a (R_{se} + R_a) = k_e k_f I_a \omega_m$

$$\omega_m = \frac{V - I_a (R_{se} + R_a)}{k_e k_f I_a}$$

$$\omega_m = \frac{V}{k_e k_f I_a} - \frac{I_a (R_a + R_{se})}{k_e k_f I_a}$$

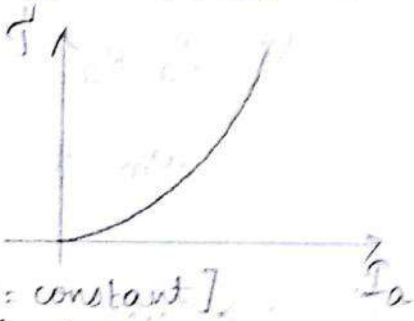
from (3), $I_a = \dfrac{\sqrt{T}}{\sqrt{k_e k_f}}$.

$$\omega_m = \frac{V\sqrt{k_e k_f}}{k_e k_f \sqrt{T}} - \frac{(R_{se} + R_a)}{k_e k_f}$$

$$\Rightarrow \boxed{\omega_m = \frac{V}{\sqrt{k_e k_f T}} - \frac{(R_{se} + R_a)}{k_e k_f}} \quad (4)$$

* CHARACTERISTICS OF DC SERIES MOTOR :

i) T Vs I_a :-



$$T \propto I_a^2.$$

Before saturation : $T \propto I_a^2$

After saturation : $T \propto I_a$ [ϕ = constant].

ii) ω_m Vs I_a :-

$\rightarrow$ $V = I_a(R_{se} + R_a) + E_b.$

$$V = I_a(R_{se} + R_a) + k_e k_f I_a \omega_m.$$

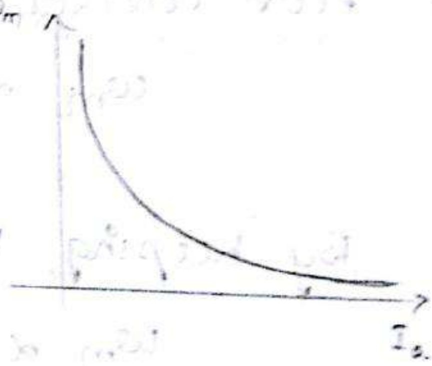
$$\Rightarrow \omega_m = \frac{V - I_a(R_{se} + R_a)}{k_e k_f I_a}$$

Thus

$$\therefore \omega_m \propto \frac{V - \cancel{I_a(R_{se} + R_a)}}{I_a}$$

$$\omega_m \propto \frac{V \rightarrow \text{constant}}{I_a}.$$

$$\therefore \omega_m \propto \frac{1}{I_a}.$$



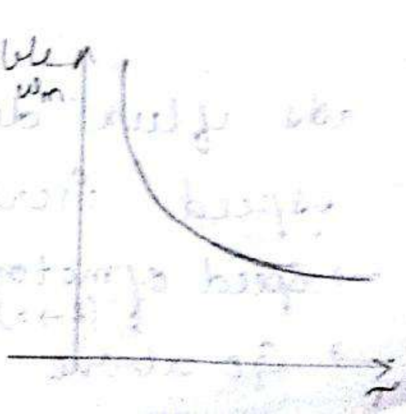
iii) T Vs ω_m :

negligible

$$\omega_m = \frac{V}{\sqrt{k_e k_f}\sqrt{T}} - \cancel{\frac{(R_a + R_{se})}{k_e k_f}}.$$

$$\omega_m = V / \sqrt{k_e k_f}\sqrt{T}$$

$$\therefore \omega_m \propto 1/\sqrt{T}.$$



Speed Control of DC Machines:

We know that,

$$V = I_a R_a + E_b.$$

& $E_b = K_e \phi \omega_m$.

$$\Rightarrow V = I_a R_a + K_e \phi \omega_m.$$

$$V - I_a R_a = K_e \phi \omega_m.$$

$$\therefore \omega_m = \frac{V - I_a R_a}{K_e \phi}.$$

$$\Rightarrow \boxed{\omega_m \propto \frac{V - I_a R_a}{\phi}}$$

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Speed can be changed by changing

i) Flux (ϕ).

ii) Armature Resistance (R_a).

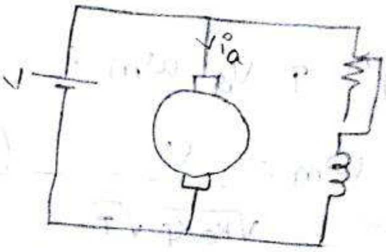
iii) Voltage to the armature.

1) Flux Control Method:

$$\omega_m \propto \frac{V - I_a R_a}{\phi}$$

By keeping, V & R_a constant

$$\omega_m \propto \frac{1}{\phi}.$$



As flux decreases, speed increases.

→ Speed of motor $(R \to 0)$ - Base speed $R\uparrow \to I_f \downarrow \to \phi\downarrow \to \omega_m\uparrow$.

→ Go above base speed.

Analysis :

$E_b \propto \phi \omega_m$.

$T \propto \phi I_a$.

→ The load connected will have constant load torque characteristics.

→ $T = T_L$ = constant.

ϕI_a = constant.

→ As resistance increase, I_f decreases, so flux decreases.

As flux decreases, E_b decreases.

$\downarrow E_b \propto \phi \omega_m \downarrow$

→ As E_b decreases, current I_a increases.

→ $T \propto \phi I_a$:

Due to increase in I_a, motor torque increases than the load torque. therefore, it accelerates and speed increases.

→ Assume, $I_{a_1} \rightarrow \omega_{m_1} \rightarrow \phi_1$.

$I_{a_2} \rightarrow \omega_{m_2} \rightarrow \phi_2$.

$$\omega_{m_1} \propto \frac{V - I_{a_1} R_1}{\phi_1} \; ; \; \omega_{m_2} = \frac{V - I_{a_2} R_2}{\phi_2}.$$

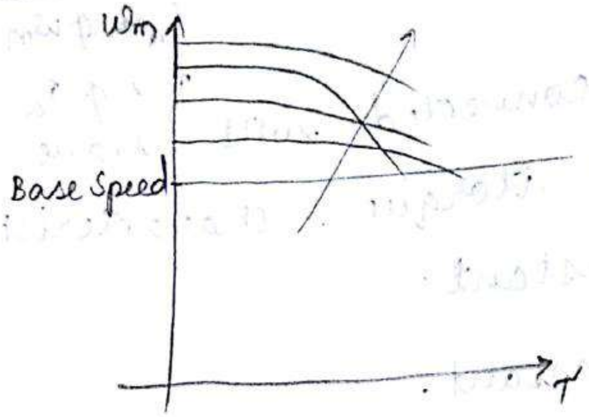
$\therefore \omega_{m_2} > \omega_{m_1}$.

* Torque - Speed characteristics :-

we know that,

$$\omega_m = \frac{V}{K_e \phi} - \frac{R_a}{(K_e \phi)^2} T.$$

$y = -mx + c$.



Advantages:

1. In this method, we can increase the speed i.e., above speed.
2. Since the field current is very less, the losses are less and is more efficient.

Disadvantage:

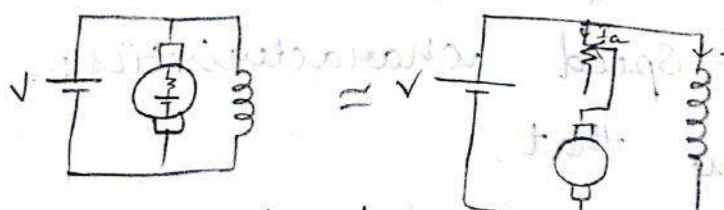
*. In this method, we cannot go below base (rated) speed.

2. ARMATURE RESISTANCE CONTROL:

$$\omega_m \propto \frac{V - I_a R_a}{\phi}$$

$$\therefore \omega_m \propto V - I_a R_a.$$

$R_a \uparrow$, $V - I_a R_a \downarrow \rightarrow \omega_m \downarrow$.



→ when rheostat is at min. position the machine runs at base speed.

→ As $R \uparrow \rightarrow \omega \downarrow$.

$E_b \propto \omega_m$
$T \propto I_a$.

Analysis :

→ The load connected will have constant load torque characteristics.

→ $T = T_L$ = constant.

$\Rightarrow I_a$ = constant.

→ Assume, initially → R_a.

$$\Rightarrow I_{a_1} = \frac{V - E_b}{R_a} = \frac{V - K\omega_m}{R_a}$$

→ Insert → $R_a + R_e$.

$$\Rightarrow I_{a_2} = \frac{V - E_b}{R_a + R_e} = \frac{V - K\omega_m}{R_a + R_e}$$

$\Rightarrow I_{a_1} > I_{a_2}$. [$I_{a_2}$ is less because of insertion of R_e].

→ Since, $T \propto I_a$.

As $I_a \downarrow$, T also decreases.

As $T < T_L$, motor decelerates, $\omega_m \downarrow$

→ $E_b \propto \omega_m$. As $\omega_m \downarrow$, E_b also $\downarrow$.

As E_b gets decreases, I_a is increased untill the initial current.

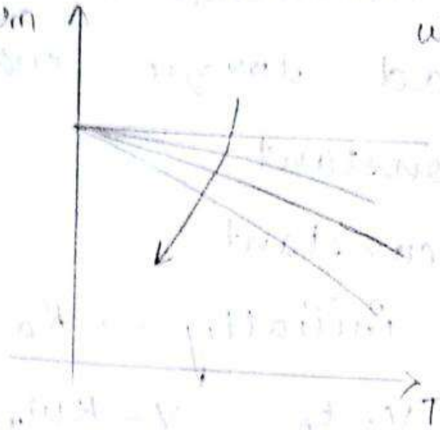
→. I_{a_2} increases to I_{a_1}

→ $\omega_{m_1} \propto V - I_{a_1} R_a$

→ $\omega_{m_2} \propto V - I_{a_1} (R_a + R_e)$

$\Rightarrow \omega_{m_2} < \omega_{m_1}$.

Torque - Speed characteristics:



$$\omega_m = \frac{V}{K} - \frac{R_a}{K^2} T$$

R ↑ slope ↓

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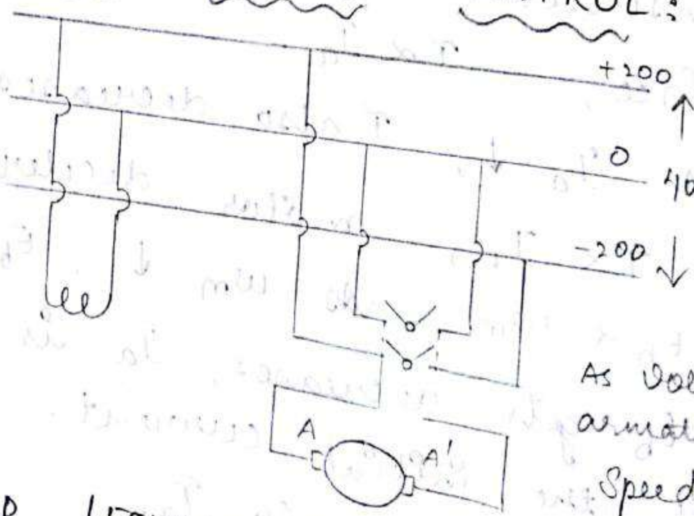
Third Strategy :-

$$\omega_m \propto \frac{V - I_a R_a}{\phi}.$$

changing V, keeping remaining things constant, $\omega_m \propto (V - I_a R_a)$.

As voltage ↑, ω_m ↑.

1) MULTIPLE VOLTAGE CONTROL:



As voltage across armature changes, Speed changes.

2) WARD LEONARD SPEED CONTROL:

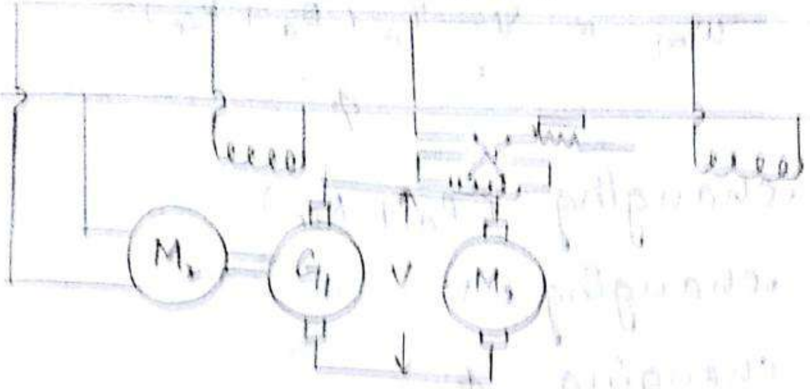
Voltage generated by generator

$$E = \frac{\phi Z N}{60}\left(\frac{P}{A}\right).$$

M_2 rotates with constant speed.

As flux of generator decreases,

the input voltage given to the motor M_1 decreases.

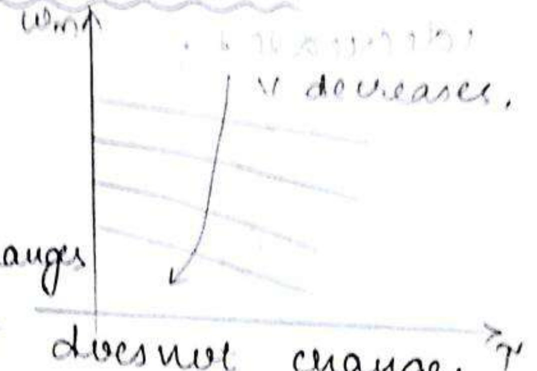


In this method, we can control the speed of the motor in both forward & backward motion

Torque - Speed characteristics:

$$\omega_m = \frac{V}{K_e\phi} - \frac{R_a \cdot T}{(K_e\phi)^2}$$

$$\Rightarrow \omega_m = \frac{V}{K} - \frac{R_a}{K^2} \cdot T$$



The constant V/K changes but slope $(R_a/K^2)T$ doesnot change. So, they are parallel.

Modified Ward Leonard Speed control:

Here, a flywheel has been placed between motor M_2 and generator to reduce the power fluctuations.

The amount of load required (extra) is been provided by flywheel.

Advantages: 1. In this method, speed control is possible in both directions.

2. Speed is controlled very smoothly.

Disadvantages: 1. It is complex and needs an extra generator - motor set.

2. It is of high cost.

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Speed Control of DC Series Motor:

$$\omega_m \propto \frac{V - I_a(R_a + R_{se})}{\phi}$$

→ changing $(R_a + R_{se})$

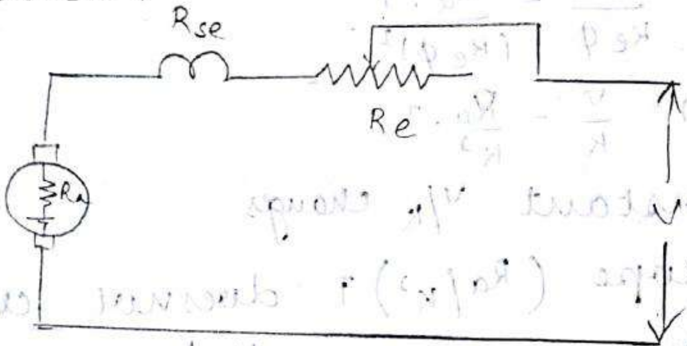
→ changing V

→ changing ϕ.

1) changing Armature Resistance Control:

$$\omega_m \propto V - I_a(R_a + R_{se}).$$

As resistance increases, speed (ω_m) decreases.



→ Intially $I_{a_1} \rightarrow \omega_{m_1}$ (Before inserting resistance).

$$V = I_{a_1}(R_a + R_{se}) + E_b.$$

$$V = I_{a_1}(R_a + R_{se}) + K_e K_f I_{a_1} \omega_m.$$

$$\Rightarrow \omega_{m_1} \propto \frac{V - I_{a_1}(R_a + R_{se})}{I_{a_1}}$$

→ After insertion of resistance,

$$R_e \Rightarrow I_{a_2} \rightarrow \omega_{m_2}.$$

$$\Rightarrow \omega_{m_2} \propto \frac{V - I_{a_2}(R_a + R_{se} + R_e)}{I_{a_2}}$$

constant load Torque :

$$T = \text{Constant}.$$

$$K_e \, K_f \, I_a^2 = \text{constant}.$$

$$\Rightarrow \quad I_a = \text{constant}.$$

At equilibrium, I_a = constant.

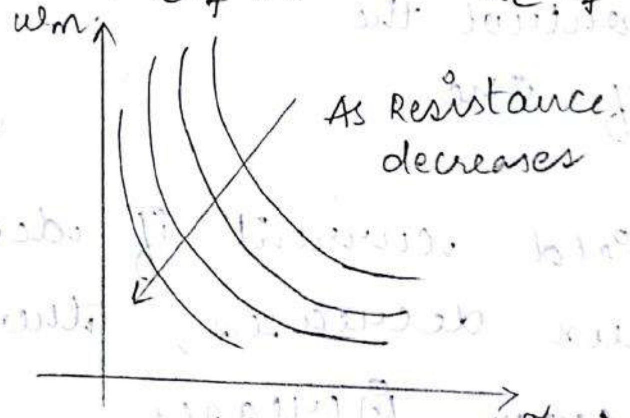
$$\therefore I_{a_1} = I_{a_2}.$$

$$\Rightarrow \omega_{m_2} \propto \frac{V - I_{a_1}(R_a + R_{se} + R_e)}{I_{a_1}}.$$

$$\Rightarrow \omega_{m_2} < \omega_{m_1}.$$

Torque - Speed characteristics :-

$$\omega_m = \frac{V}{\sqrt{K_e K_f}\,\sqrt{T}} - \frac{R_a + R_{se}}{K_e \cdot K_f}$$



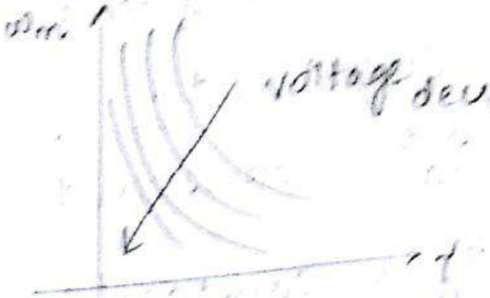
2) Armature Voltage control :

$$\omega_m \propto \frac{V - I_a(R_a)}{\phi}.$$

$V \rightarrow$ change (constant)

As $V \uparrow$, $\omega_m \uparrow$.

Also as $V \downarrow$, $\omega_m \downarrow$.



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3) Flux control of DC Series Motor:

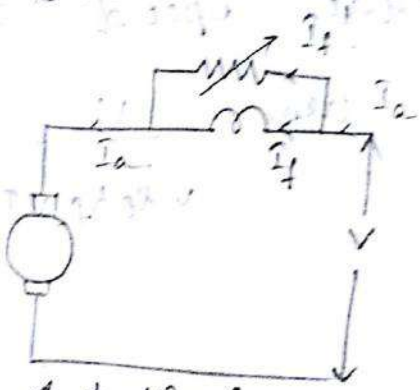
$$\omega_m \propto \frac{V - I_a R_a}{\phi}$$

$$\omega_m \propto \frac{1}{\phi}.$$

As flux decreases, speed increases.

1) Field diverter control:

By controlling the flux, we can control the speed of the motor.

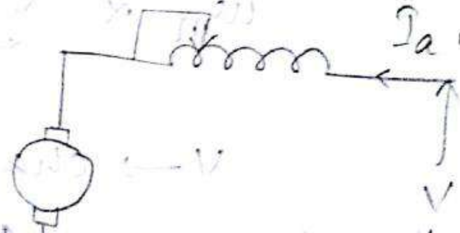


$I_f \downarrow, \phi \downarrow, \omega_m \uparrow$

As field current I_f decreases, (ϕ) flux decreases, thereby speed ~~decre~~ increases.

2) Tapped field control:

This can be obtained by varying the no. of turns (N) (field changes)



As $N \downarrow$, $\phi \downarrow$, $\omega_m \uparrow$. $\phi = NI$

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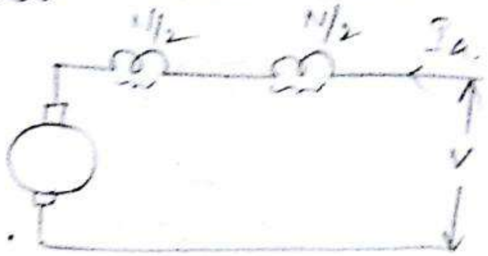
3) Series - Parallel field control :

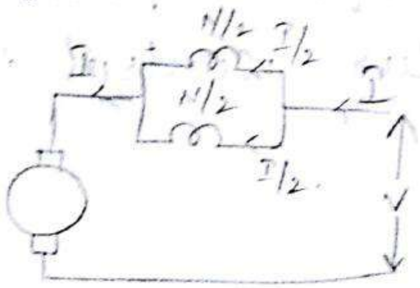
→ Connected in Series :



$$\phi \propto I_a \cdot \frac{N}{2} + I_a \cdot \frac{N}{2}.$$

$$\phi \propto I_a \cdot N.$$

→ Field winding connected in Parallel:



$$\phi \propto \frac{I}{2} \cdot \frac{N}{2} + \frac{I}{2} \cdot \frac{N}{2}.$$

$$\phi \propto \frac{IN}{2}.$$

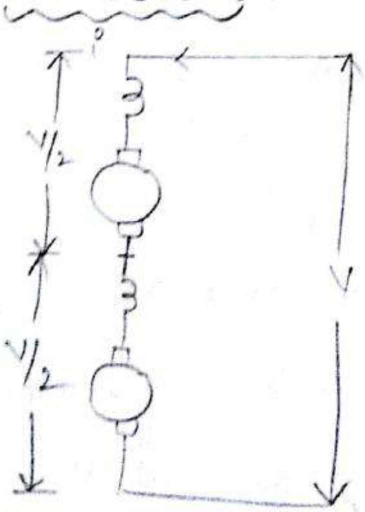
4) Series - Parallel Control :

→ This type of speed control is implemented where two or more series machines are employed.

→ If we want less speed, we connect the motors in series

→ If we want high speed, we connect the motors in parallel.

* Series connection :



negligible

$$\omega_m \propto \frac{V - I_a (R_a)}{\phi}$$

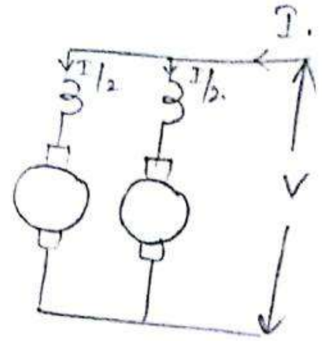
$$\{\because \phi \propto I_a\}$$

$$\omega_m \propto \frac{V - I_a (R_a)}{I_a}.$$

$$\omega_m \propto \frac{V}{I}.$$

$$\Rightarrow \omega_m \propto \frac{V}{2I}.$$

* Parallel Connection :



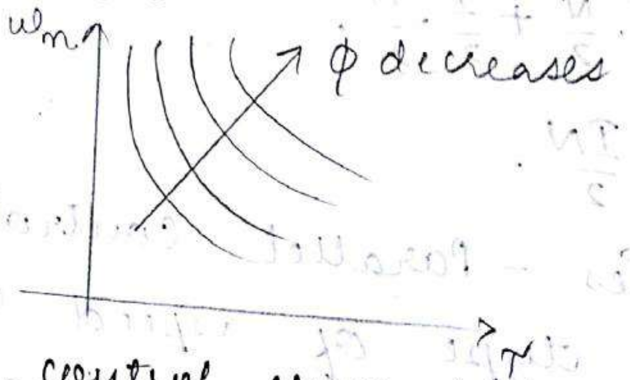
$\omega_m \propto \frac{V}{I}$.

$\omega_m \propto \frac{V}{I/2}$.

$\Rightarrow \omega_m \propto \frac{2V}{I}$.

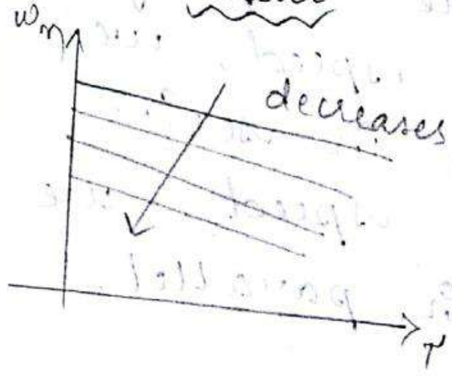
Speed is multiplied by 4 times.

Torque - Speed characteristics of flux control :

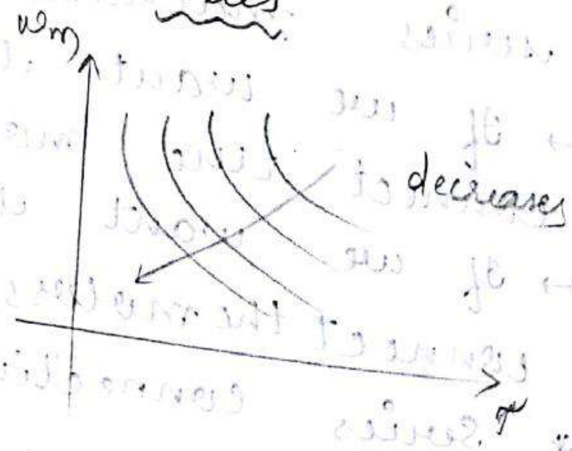


Voltage control characteristics:

Shunt



Series

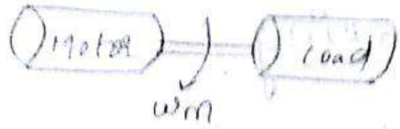


2/12/15 UNIT 1.

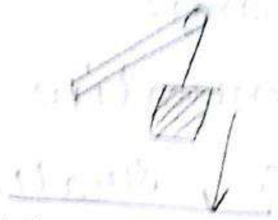
BRAKING METHODS :

↳ A Brake is a equipment which is used to stop or slow down any moving equipment or any rotating part.

* Need of Braking :



Applying brake to stop the load.



To bring it to safer limits we apply brake

* There are 2 types of Braking.
→ Mechanical Braking
→ Electrical Braking.

↳ MECHANICAL BRAKING :
→ A brake shoe is used to apply a brake the system.
→ All the stored energy is wasted/ dissipated in the form of heat.
→ It requires regular maintenance and change of pole shoe.
→ It is used along with electrical braking for reliability.

↳ ELECTRICAL BRAKING :
→ The braking which uses the electrical power for stoping or slow down any equipment.

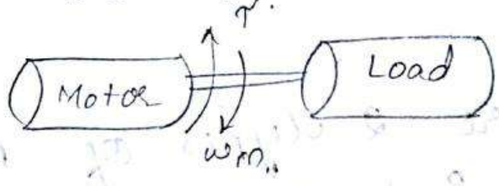
↳ It [K.E]. is dissipated in the form of heat

↳ The power is transferred from load to source.

Types of Electrical Braking:

1. Plugging
2. Dynamic
3. Regenerative Braking.

* Basic Strategy:



It should produce a torque in the opposite direction

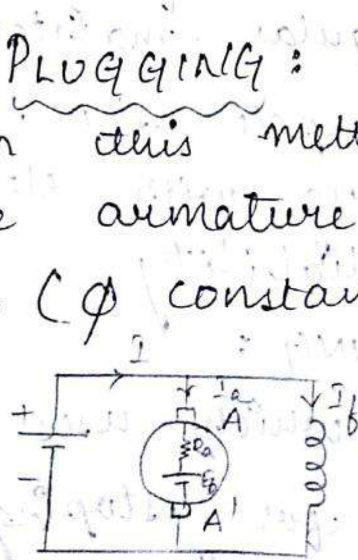
$T \propto \phi I_a$

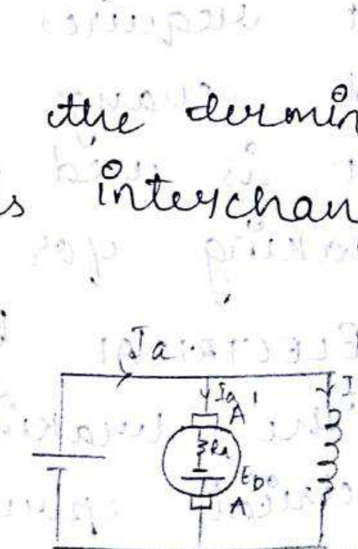
$\therefore T \rightarrow$ reversed by changing the direction of either ϕ or I_a.

[If we change both, then it will remains same].

*1) PLUGGING:

→ In this method, the terminals of the armature is interchanged i.e., (ϕ constant).



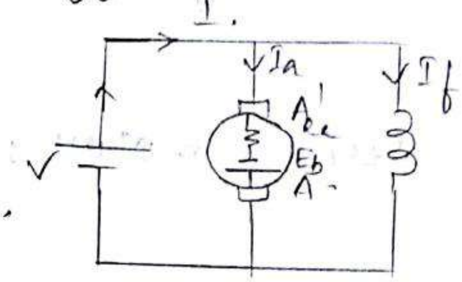


In Armature, current direction gets reversed

$T \propto \phi I_a$

opposite torque is applied.

→ Expression of T_B :



$V = I_a(R_a) - E_b$.

$\Rightarrow V + E_b = I_a R_a$.

$\therefore I_a = \dfrac{V + E_b}{R_a}$

we have, $E_b \propto \phi \omega_m$.

$E_b = K_e \phi \omega_m$.

$\Rightarrow T_b = K_e \phi I_a$ [Backward Torque T_b]

$\Rightarrow T_b = K_e \phi \left[\dfrac{V + E_b}{R_a}\right]$.

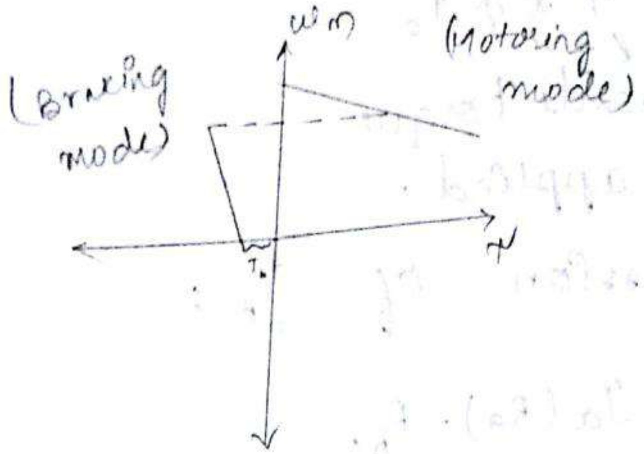
$T_b = K_e \phi \left[\dfrac{V + K_e \phi \omega_m}{R_a}\right]$.

$\Rightarrow T_b = \dfrac{V K_e \cdot \phi}{R_a} + \dfrac{(K_e \phi)^2 \omega_m}{R_a}$.

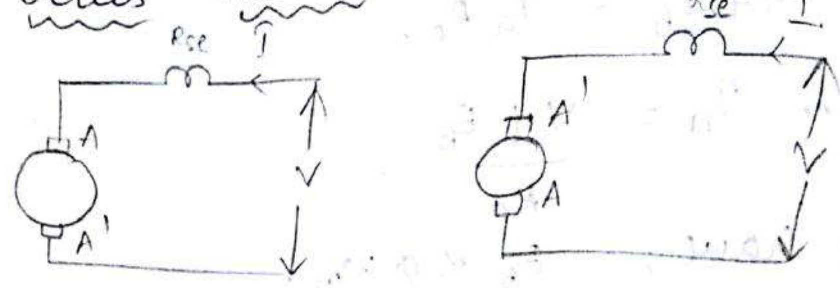
→ Assuming shunt motor :-

$T_b = \dfrac{V \cdot K}{R_a} + \dfrac{K^2 \omega_m}{R_a}$ [$\because \phi$ = constant] $(K_e \phi = K)$

$$\boxed{T_b = K_1 + K_2 \cdot \omega_m}$$



→ Series motor :

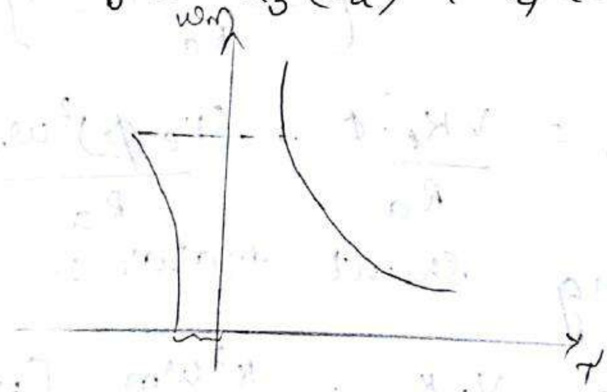


* T_B for series motor :

→ $\phi \propto I_a \Rightarrow \phi = K_f I_a$.

Then, $T_b = \dfrac{V \cdot K_e K_f I_a}{R_a + R_{se}} + \dfrac{(K_e K_f I_a)^2 \omega_m}{R_a + R_{se}}$

$T_b = K_3 (I_a) + K_4 (I_a)^2 \omega_m$.



Advantages :-

1) This method is very simple to implement and this is used in the applications where we need a quick reversal or quick braking

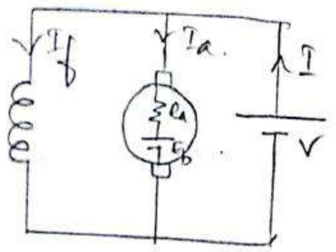
Disadvantages :

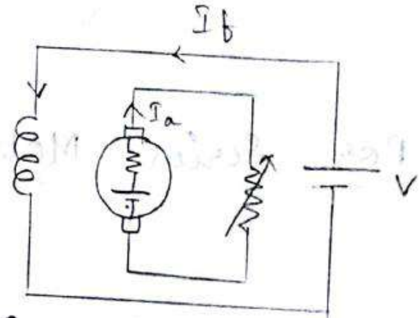
1) In this type of braking, if the supply is taken away, the motor will accelerate in reverse direction

2) During the changing of terminals there will be a huge inrush current

* 2) DYNAMIC BRAKING OR RHEOSTATIC BRAKING :

↳ In this type of braking, the armature is taken out and connected across a rheostat.





when I_a flows in opposite direction, a reverse torque is produced such that, the motor slowly comes to rest.

$\downarrow E_b \propto \phi \omega_m \downarrow$

$\tau \propto \phi\ I_a$ → varies
constant

→ Expression for T_b :

$$E_b = I_a (R_a + R_{ex}).$$

$$I_a = \frac{E_b}{(R_a + R_{ex})}$$

$$E_b = K_e \phi \omega_m.$$

$$T_b = K_e \phi I_a.$$

$$T_b = K_e \phi \left[\frac{E_b}{R_a + R_{se}} \right]$$

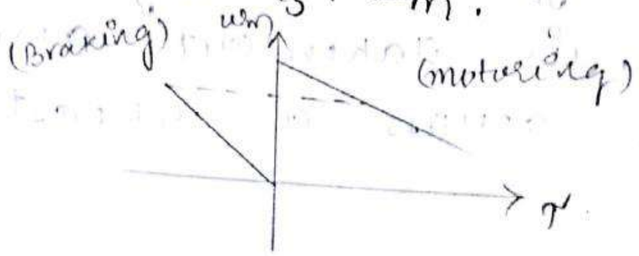
$$T_b = K_e \phi \left[\frac{K_e \phi \, \omega_m}{R_a + R_{se}} \right].$$

$$\Rightarrow T_b = \frac{(K_e \phi)^2 \omega_m}{R_a + R_{se}}$$

* For shunt machine : [ϕ constant]

$$T_b = \frac{K^2 \omega_m}{R_a + R_{se}}$$

$$T_b = K_5 \cdot \omega_m .$$



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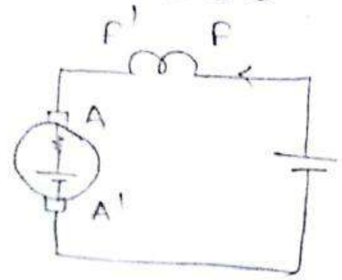
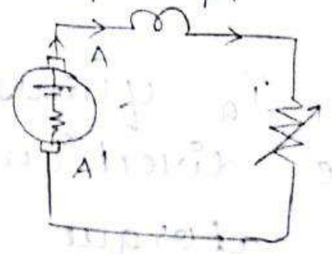
For Series Motor :



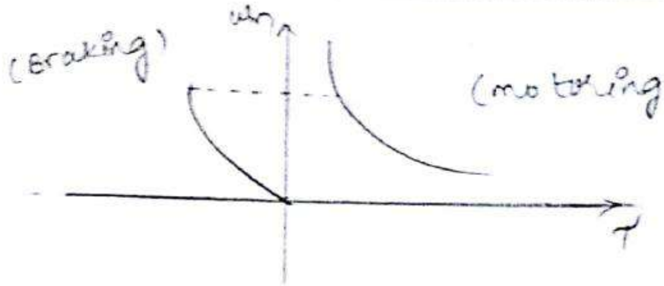
During Braking.



During Braking, interchange the terminals of field winding in a series motor.

Here $\phi \propto I_a$ $\qquad \phi = K_f \cdot I_a$

Then , $$T_b = \frac{(K_e K_f I_a)^2 \omega_m}{R_a + R_{se} + R_{ext}}.$$

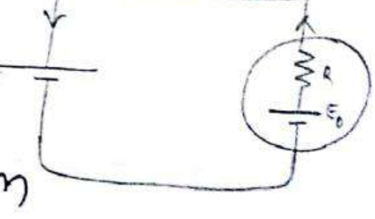


Advantages :
1. In this method, the motor won't accelerate in the opposite direction

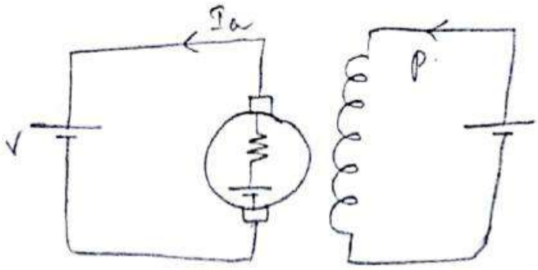
Disadvantages :
All the energy i.e., stored in the motor is dissipated in the resistance

* 3) REGENERATIVE BRAKING :
The main agenda of regenerative braking is
↳ Applying a brake to the system. (i.e., I_a reverses).
↳ Transfering the energy stored in the motor to the source.
[This is the main phenomena i.e., happening in all locomotives].

* when $E_b > V$, then current flows in opposite direction



From fig, it is clear that, current flows from (motor) load to the source (i.e., in opposite direction.



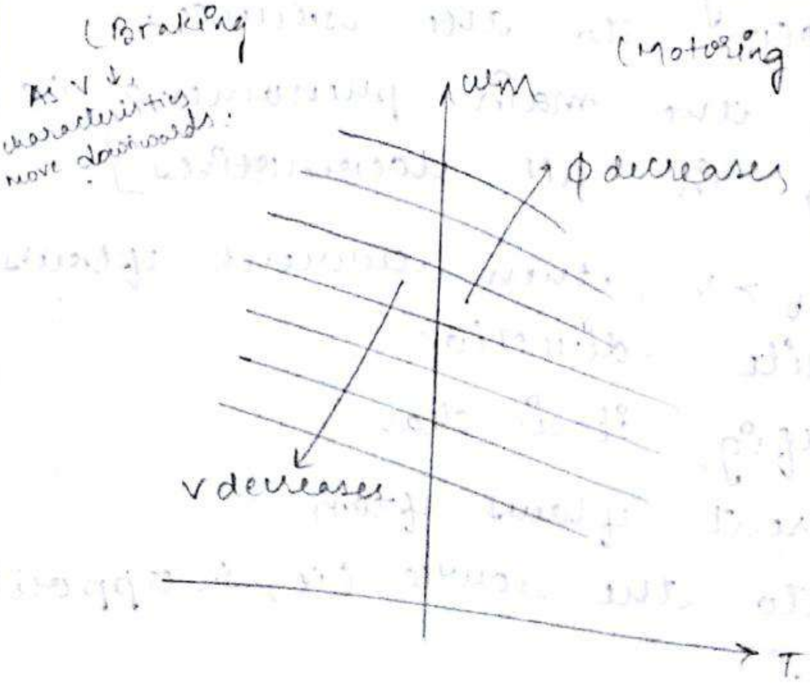
$E_b \propto \phi \omega_m$.

* i) when ϕ increases, E_b increases more than V, so I_a flows in opposite direction. As a result, speed decreases gradually & E_b also decreases untill $E = V$. (i) To increase field current untill $E > V$.)

ii) For $E < V$, by decreasing the supply voltage.

iii) This happens when motor speed becomes more than the no load speed.

* Torque - speed characteristics :-



Advantages :

In this method, along with braking the energy is fed to the supply. So it is more efficient.

Disadvantages :

It needs complex equipment to control the regeneration. So, it is more costly and more maintenance is required.

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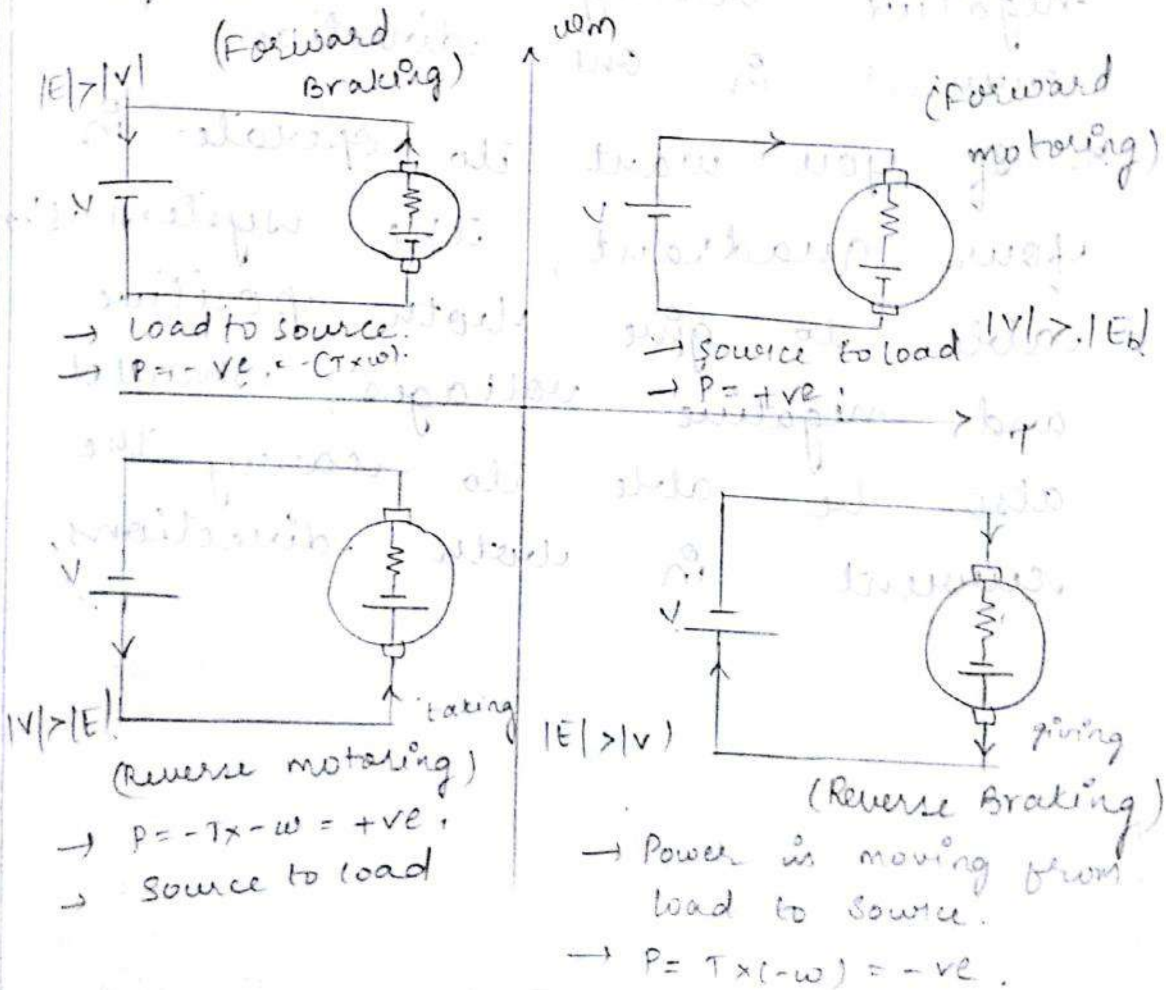
* MULTI - QUADRANT SEPERATELY EXCITED DC MOTOR :

$T \propto \phi I_a \; ; \; E \propto \phi \omega_m$.



Conclusions :-

1. If you want to operate the motor in 1 & 2 quadrants. The system should able to give a positive voltage and able to carry currents in both direction

2. If you want to operate in 1 & 4 quadrants, the system should able to give both positive & negative voltage but can carry the current in one direction.

3. If you want to operate in four quadrant, the system sho able to give both positive and negative voltages, should also be able to carry the current in both directions.

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3-ϕ FULL CONVERTER FED SEPERATELY EXCITED MOTOR (CONTINIOUS CONDUCTION):