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CMR Institute of Technology, Bangalore
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
I - INTERNAL ASSESSMENT

Semester: 8-CBCS
Subject: INDUSTRIAL DRIVES AND APPLICATIONS (15EE82)
Faculty: Ms Geethanjali P

Date: 22 May 2021
Time: 09:00 AM - 10:30 AM
Max Marks: 50

Answer any 5 question(s)

Q.No			Marks	CO	PO	BT/CL
1	a	Draw the block diagram of an electric drive and mention the functions of Power Modulator.	4	CO1	PO1	L2
	b	A motor drives two loads. One has rotational motion. It is coupled to the motor through a reduction gear with a=0.1 and efficiency of 90%. The load has a moment of inertia of 10kg-m2 and a torque of 10N-m. Other load has translational motion and consist of 1000 kg weight to be lifted at a m2uniform speed of 1.5 m/s. Coupling between this load and the motor has efficiency of 85%. Motor has an inertia of 0.2 kg-m2 and runs at a constant speed of 1420rpm. Determine equivalent inertia referred to the motor shaft and power developed by the motor.	6	CO1	PO2	L3
2	a	With a neat diagram, explain the four-quadrant operation of a motor driving a hoist load.	6	CO2	PO1	L1
	b	Explain how a current limit control functions in closed loop control of drives.	4	CO2	PO1	L1
3	a	Derive expressions for equivalent values of moment of inertia and torque as referred to motor shaft for loads with rotational motion.	6	CO2	PO1	L2
	b	A motor equipped with a flywheel is to supply a load torque of 1000 N-m for 10 sec followed by a light load period of 200 N-m long enough for the flywheel to regain its steady-state speed. It is desired to limit the motor torque to 700 N-m. What should be the moment of inertia of flywheel? Motor has an inertia of 10 kg-m2. Its no load speed is 500 rpm and the slip at a torque of 500 N-m is 5%. Assume speed-torque characteristics of motor to be a straight line in the region of interest.	4	CO2	PO2	L3
4		Explain clearly different components of load torque with its characteristics. Also give a brief description of classification of load torques.	10	CO2	PO2	L1
5		With usual notations derive expression for the temperature rise of a machine. Sketch temperature rise v/s time curve.	10	CO3	PO1	L1
6	a	A constant speed drive has the following duty cycle: (i) Load rising from 0 to 400 kw: 5 min (ii) Uniform load of 500 kw : 5 min (iii) Regenerative power of 400kw returned to the supply : 4 min (iv) Remains idle for : 2 min Estimate power rating of the motor. Assume losses to be proportional to (power) 2	4	CO3	PO2	L3
	b	A motor operates on a periodic duty cycle in which it is clutched to its load for 10 min and declutched to run on no-load for 20 min. Minimum temperature rise is 40 °C. Heating and cooling time constants are equal and have a value of 60 min. When load is declutched continuously the temperature rise is 15 °C. Determine (i) maximum temperature during the duty cycle, and (ii) temperature when the load is clutched continuously.	6	CO3	PO3	L3

Solution

Q.1 a

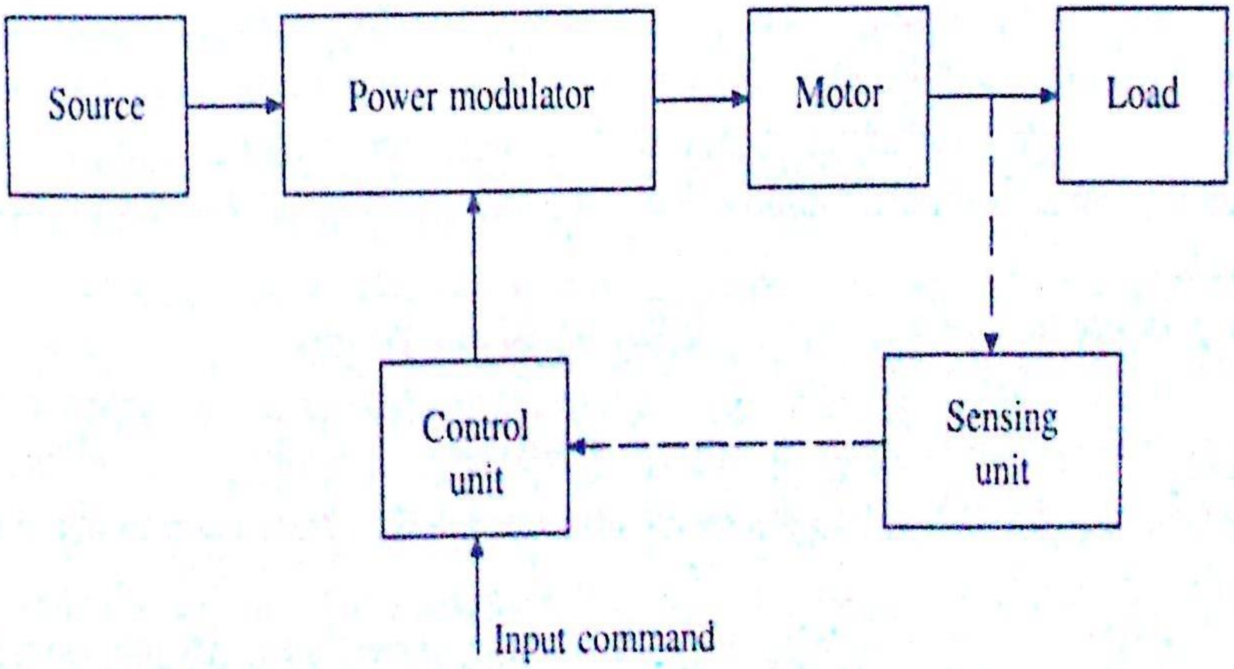
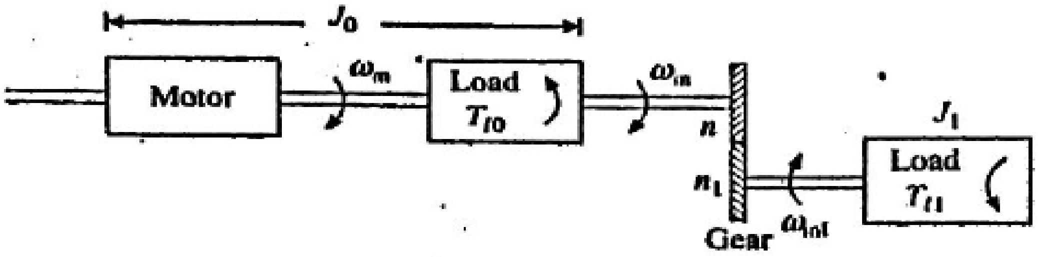


Fig. 1.1 Block diagram of an electrical drive

Functions of Power Modulator:

- Modulates the power flow from source to the motor in such a way that the motor is imparted speed-torque characteristics required by the load.
- During transient operations, such as staring, braking and speed reversal, it restricts source and motor currents within permissible values; excessive current drawn from source may overload it or may cause a voltage dip.
- Converts electrical energy of the source in the form suitable to the motor, e.g. if the source is D.C and the Induction motor is to be driven, then the power modulator is required to convert the DC into a variable frequency AC.
- Selects the mode of operation of the motor i.e. motoring or braking.

Q 1. B)



(a) Loads with rotational motion

$$J = J_0 + a_1^2 J_1 + M_1\left(\frac{v_1}{\omega_m}\right)^2$$

$$J = 0.2 + (0.1)^2 \times 10 + 1000\left(\frac{1.5}{148.7}\right)^2 = 0.4 \text{ kg-m}^2$$

$$T_l = \frac{a_1 T_{l1}}{\eta_1} + \frac{F_1}{\eta_1'}\left(\frac{v_1}{\omega_m}\right)$$

$$T_l = \frac{0.1 \times 10}{0.9} + \frac{1000 \times 9.81}{0.85}\left(\frac{1.5}{148.7}\right) = 117.53 \text{ N-m}$$

Q. 2 a)

Four quadrant operation of a motor driving a hoist load

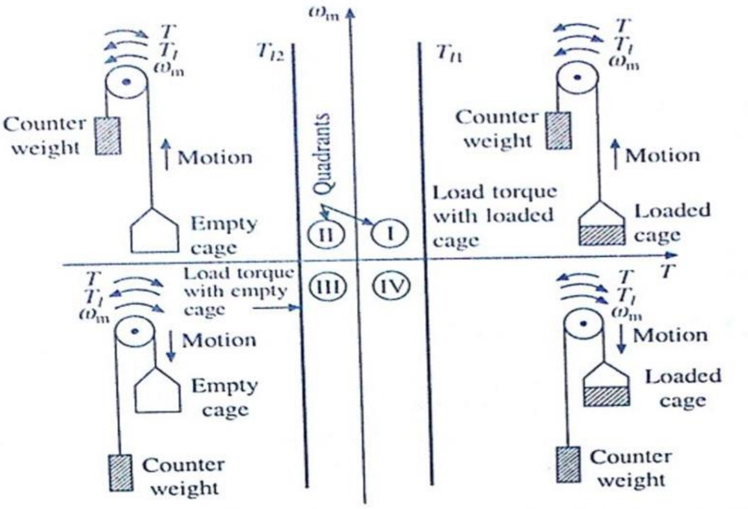
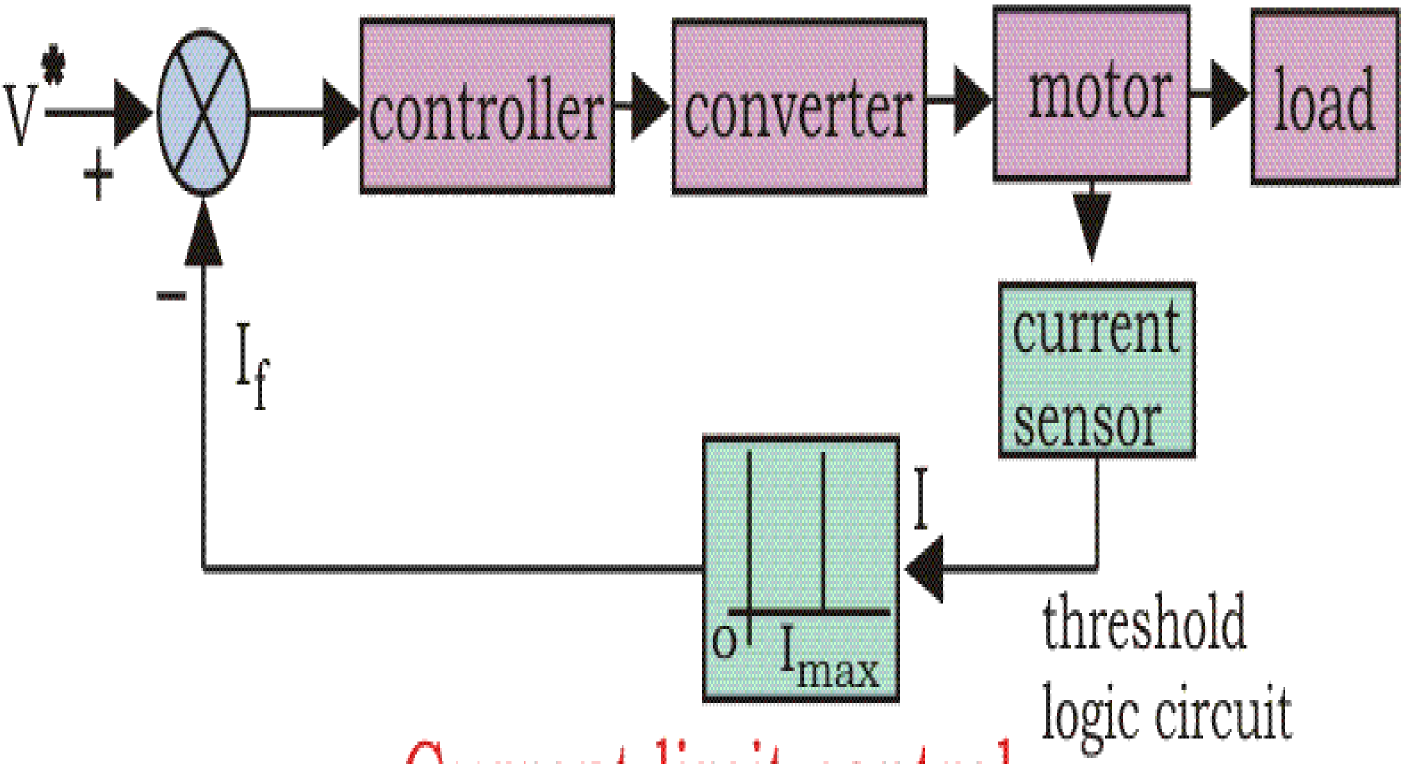


Fig. 2.3 Four quadrant operation of a motor driving a hoist load

Q.2 b)

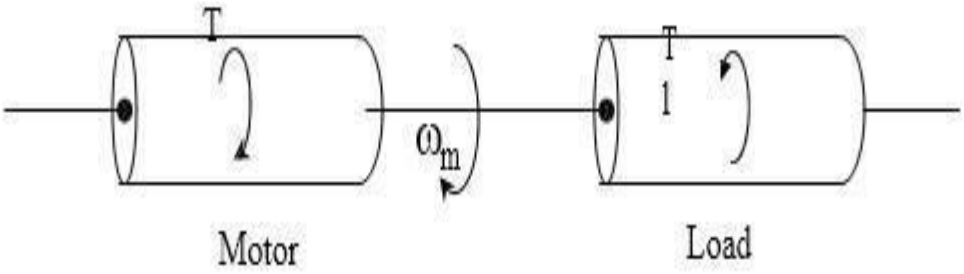
- During the starting, we know if precautionary measures are not taken there is a chance of huge current flow through the motor circuit.
- Current Limit Control scheme is employed to limit the converter and motor current below a safe limit during transient operations.
- It has a current feedback loop with a threshold logic circuit.
- To limit the current and sense the current fed to the motor, current limit controller is installed.

- The feedback loop does not effect the normal operation of the drive but if the current exceeds the predetermined safe limit, the feedback loop activates and the current is brought down below the safe limit.
- Once the current is brought down below the safe limit the feedback loop again deactivates and in this way the control of current takes place.



Current limit control

Q. 3 a)



J = Moment of inertia of motor load system referred to the motor sha

ω_m = Instantaneous angular velocity of motor shaft, rad/sec.

T = Instantaneous value of developed motor torque, N-m

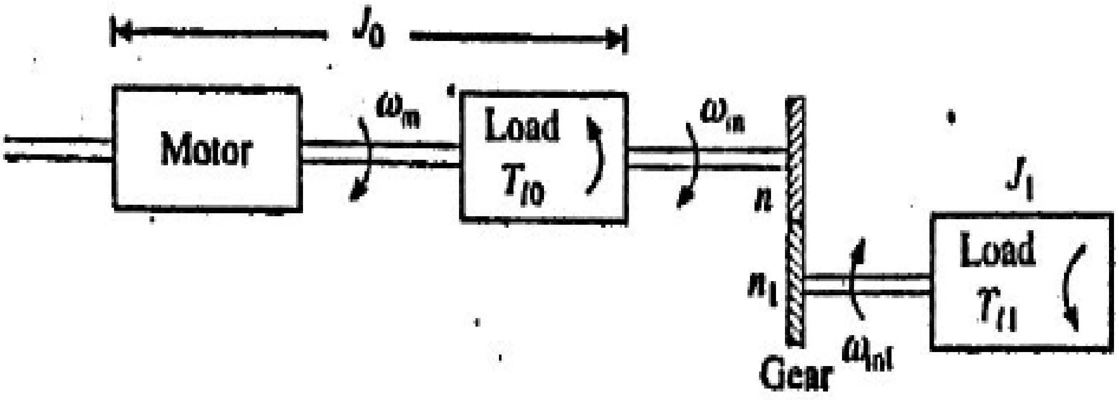
Tl = Instantaneous value of load torque, referred to the motor shaft

$$T-T_1 = d/dt\,(J\,\omega_m) = J\,d/dt\,(\omega_m) + \omega_m\,dJ/dt \qquad \ldots\ldots\ldots\ldots\ (1)$$

$$\frac{dJ}{dt} = 0$$

$$T = T_1 + J\,d/dt\,(\omega_m) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Equivalent Values of Drive Parameters Loads with Rotational Motion



(a) Loads with rotational motion

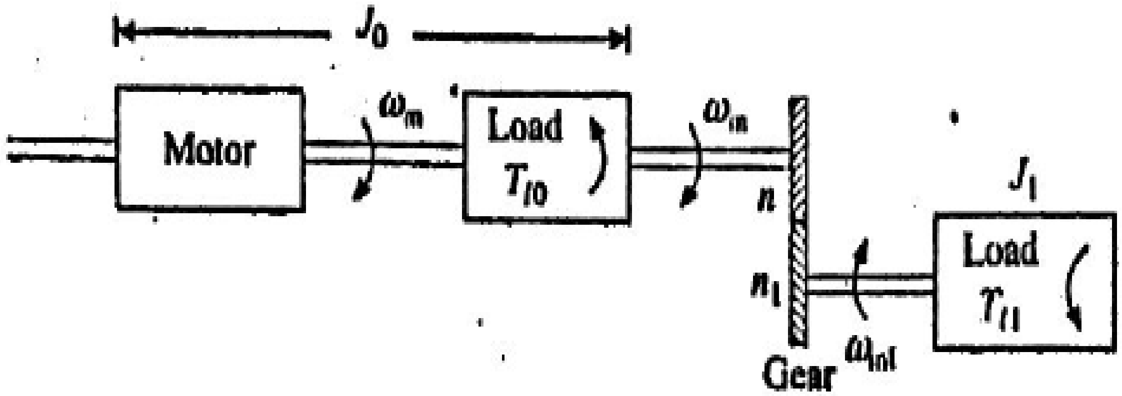
$$\frac{\omega_{m1}}{\omega_m} = \frac{n}{n_1} = a_1$$

$$\frac{1}{2} J\omega_m^2 = \frac{1}{2} J_0\omega_m^2 + \frac{1}{2} J_1\omega_{m1}^2$$

$$J = J_0 + a_1^2 J_1$$

$$T_l \omega_m = T_{l0} \omega_m + \frac{T_{l1} \omega_{m1}}{\eta_1}$$

$$T_l = T_{l0} + \frac{a_1 T_{l1}}{\eta_1}$$



(a) Loads with rotational motion

$$J = J_0 + a_1^2 J_1 + a_2^2 J_2 + \ldots + a_m^2 J_m$$

$$T_l = T_{l0} + \frac{a_1 T_{l1}}{\eta_1} + \frac{a_2 T_{l2}}{\eta_2} + \ldots + \frac{a_m T_{lm}}{\eta_m}$$

Q. 3b)

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

$$\text{no load speed} = \frac{500 \times 2\pi}{60} = 52.36 \text{ rad/sec}$$

$$\text{Speed at 500 N-m} = (1 - 0.05)\, 52.36 = 49.74 \text{ rad/sec}$$

$$\frac{T_r}{(\omega_{m0} - \omega_{mr})} = \frac{500}{52.36 - 49.74} = 190.84$$

Q.4

Components of Load Torque

- Friction Torque, TF
- Windage Torque,TW
- Torque required to do the useful mechanical work,TL
- Tl can be divided into the following components;
- i) Friction torque TF – Friction will be present at the motor shaft and also in various parts of the load. TF is equivalent value of various friction torques referred to the motor shaft.
- ii) Windage Torque Tw – It is a torque generated when a motor runs, which opposes the motion.
- iii) Torque required to do the useful mechanical work TL Nature of this torque depends on particular application.
- It may be constant and independent of the speed;
- It may be some function of speed;
- It may depend on the position or path followed by the load;
- It may be time invariant or time variant;
- It may vary cyclically and its nature may also change with the load's mode of operation

Variation of friction torque with speed is shown in the following figure

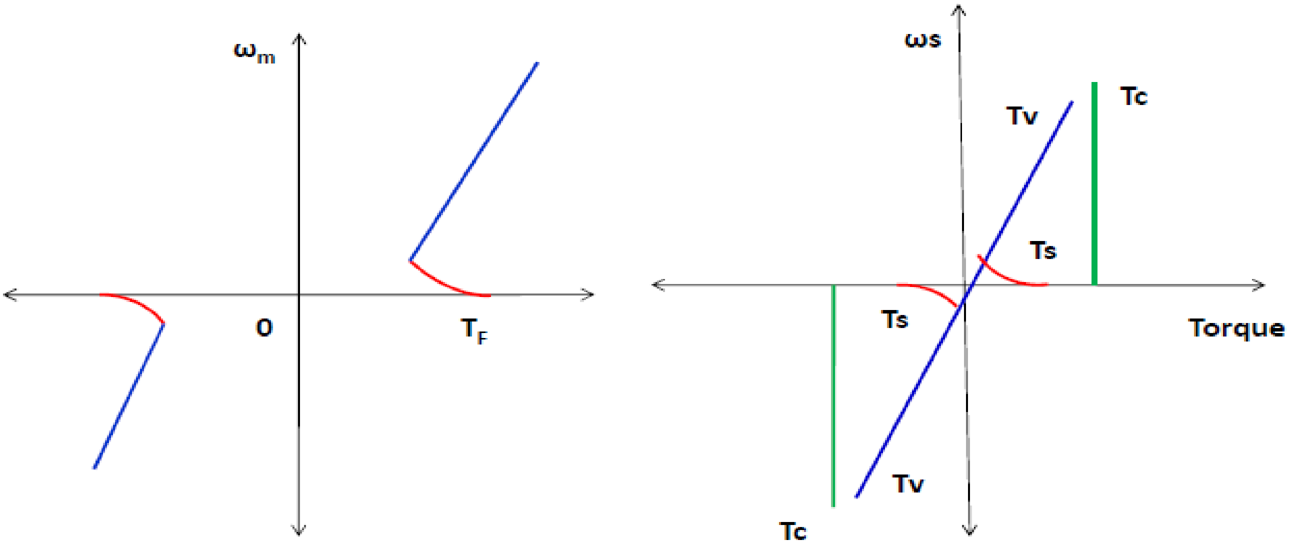


Fig. 3.5. Variation of Friction torque and its components

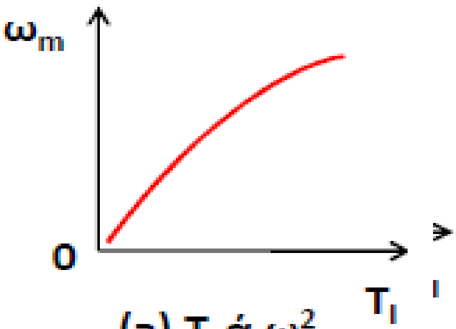
As can be seen from the figure, the Friction torque value at stand still is much higher than its value slightly above zero speed.

- Friction at zero speed is called Stiction or static friction. In order for a drive to start, the motor torque should at least exceed Stiction.
- Friction torque can be resolved into three components (see the fig.)
    - Viscous friction torque (Tv) : - component which varies linearly with speed.
    - Tv = Bωm; where B is viscous friction coefficient.
    - Coulomb friction (Tc) which is independent of speed. Additional friction torque at standstill (Ts):
    - Ts is present only at stand still and is not taken into account in the dynamic analysis.
    - Windage friction torque (Tw): - which is proportional to the speed squared.
    - Tw = Cω2 m; where C is a constant
    - \- From the above discussion, for finite speeds;
    - Tl = TL + Bωm + Tc + Cω2 m
    - where,
    - Tl – instantaneous value of load torque referred to motor shaft.
    - TL – torque required to do the useful mechanical work. . In many applications,
    - (Tc + Cω2 m) is very small and can be neglected. Then the fundamental torque equation becomes;

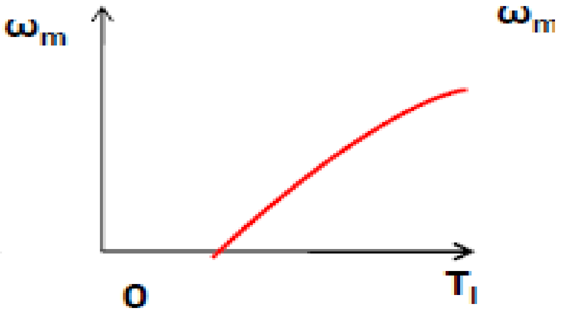
Nature and Classification of Load Torque

As stated earlier, the nature of load torque depends on particular application.

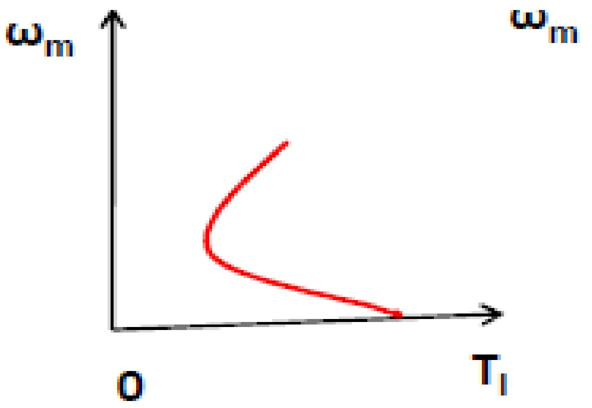
- Fans, compressors, centrifugal pumps, ship-propellors, coilers, high speed hoists, traction, etc… are example of the case where load torque is proportional to speed squared. fig. (a) and (b)
- In a high speed hoist, viscous friction and windage also have appreciable magnitude, in addition to gravity.



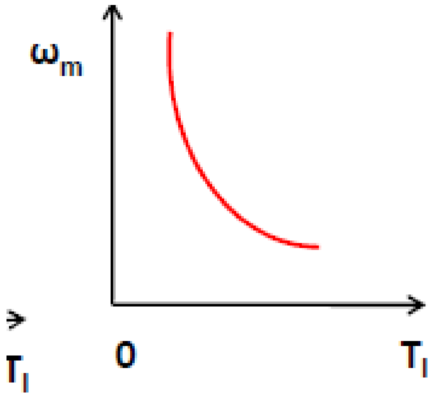
(a) T_l ά ω^2_m



(b) High speed hoist



ist (c) Traction load



oad (d) Const. power load
(coiler machine)

Figure (c) shows the traction load to be function of only speed, assuming a leveled ground. In actual practice the train has to negotiate upward and downward slopes. Consequently, a torque due to gravity, which varies with position is also present. Furthermore, when a train takes a turn, the friction force on wheels changes substantially. Thus traction is an example where the load torque also depends on position or path followed

Q.5

Thermal Model of Motor for heating and Cooling.

Assume m/c to be homogeneous body and cooling medium has the following parameters at time t.

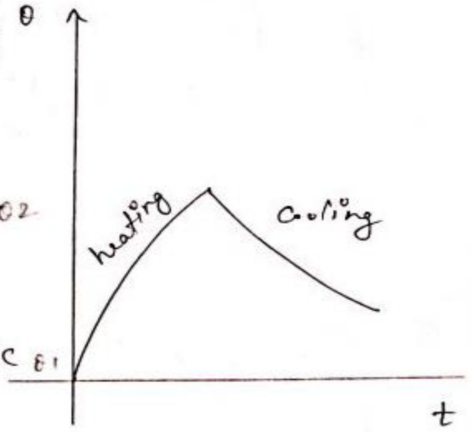
p_1 - heat developed watts / joules/sec.
p_2 - heat dissipated to the cooling medium (watts
W - weight of the active parts of machine kg.
h = Specific heat, Joules per kg per °c.
A = Cooling surface, m^2
d_1 - co-efficient of heat transfer or specific heat dissipation, joules/sec/m^2/°c
θ - mean temp rise, °c.

Heat absorbed = Heat developed - Heat dissipated.

Heat developed = heat absorbed + heat dissipated.

$$p_1\,dt = Wh\,d\theta + p_2\,dt \quad - ①$$

$$\boxed{p_2 = \theta d_1 A}$$



Sub P_2 in ①

$$p_1\,dt = Wh\,d\theta + \theta\,d_1A\,dt$$

assume $Wh = C$ → thermal capacity of m/c in watts/°c.

$d_1A = D$ heat dissipation const.

$$\therefore \quad p_1\,dt = Wh\,d\theta + \theta D\,dt$$

$$p_1\,dt = c\,d\theta + \theta D\,dt .$$

$$c\,d\theta = p_1\,dt - \theta D\,dt \Rightarrow \boxed{c\frac{d\theta}{dt} = P_1 \cancel{dt} - D\theta} \quad - \text{①} .$$

$$c\,d\theta = dt\,(p_1 - \theta D)$$

$$\frac{dt}{c} = \frac{d\theta}{p_1 - \theta D} \quad — \quad ②$$

$$② \times \frac{\cancel{\ }}{D} \qquad \frac{dt}{c/D} = \frac{d\theta}{\frac{p_1}{D} - \theta}$$

$$\boxed{\frac{dt}{\tau} = \frac{d\theta}{\frac{p_1}{D} - \theta}} \quad - \quad ③ .$$

when steady state is reached, Let

heat gen = heat dissipated

$$p_1 \cancel{dt} = \theta_{ss}\,dA \cancel{dt}$$

$$\theta_{ss} = \frac{p_1}{dA} = \frac{p_1}{D}$$

$$\boxed{\theta_{ss} = \frac{p_1}{D}} \quad - \quad ④ .$$

④ in ③, $\dfrac{dt}{\tau} = \dfrac{d\theta}{\theta_{ss} - \theta}$

where $\tau - \dfrac{c}{D}$; $\theta_{ss} = \dfrac{p_1}{D}$

$$\frac{1}{\tau}\int dt = \int \frac{d\theta}{\theta_{ss} - \theta}$$

$$\boxed{\frac{t}{\tau} = -\log(\theta_{ss} - \theta) + K} \quad - \quad ⑤$$

$$\theta_{ss} - \theta = \frac{\theta_{ss} - \theta_1}{e^{t/\tau}}$$

$$\theta_{ss} - \theta = (\theta_{ss} - \theta_1)\, e^{-t/\tau}$$

$$\theta_{ss} - \theta = \theta_{ss}\, e^{-t/\tau} - \theta_1 e^{-t/\tau}$$

$$\theta = \theta_{ss} - \theta_{ss} e^{-t/\tau} + \theta_1 e^{-t/\tau}$$

$$\boxed{\theta_h = \theta_{ss}(1 - e^{-t/\tau}) + \theta_1 e^{-t/\tau}} \quad - ④.$$

where τ = heating or thermal time const.

at $t \to \infty$, $\theta = \theta_{ss}$

i.e θ_{ss} - steady state temp of the m/c when it is continuously heated by power p1.

i.e at this temp, all the heat produced in m/c is dissipated to the surrounding medium.

Now if the load is thrown off after its temp rise θ_2, heat loss will reduce to a small value. Let it be p_1' and cooling operation of the motor will begin.

To find K, at $t=0$, $\theta = \theta_1$

$$0\ \cancel{\frac{t}{\tau}} = -\log(\theta_{ss} - \theta_1) + K$$

$$\boxed{K = \log(\theta_{ss} - \theta_1)} \quad - ⑥.$$

⑥ in ⑤,

$$\frac{t}{\tau} = -\log(\theta_{ss} - \theta) + \log(\theta_{ss} - \theta_1)$$

$$\frac{t}{\tau} = \log\frac{(\theta_{ss} - \theta_1)}{(\theta_{ss} - \theta)}$$

$$e^{t/\tau} = \frac{\theta_{ss} - \theta_1}{\theta_{ss} - \theta}.$$

∴ Using ⑦,

$$c\frac{d\theta}{dt} = p_1' - D'\theta \quad - ⑧$$

solving ⑧,

$$\boxed{\theta_c = \theta_{ss}'\left(1 - e^{-t/\tau'}\right) + \theta_2 e^{-t/\tau'}} \quad - ⑨$$

where $\theta_{ss}' = \frac{p_1'}{D'}$; $\tau' = \frac{C}{D'}$

τ' - cooling time const, θ_{ss}' steady state operation for new cond of operation

If motor is disconnected from supply

then $p_1' = 0 = \theta_{ss}'$

$$\therefore \boxed{\theta = \theta_2 e^{-t/\tau'}}$$

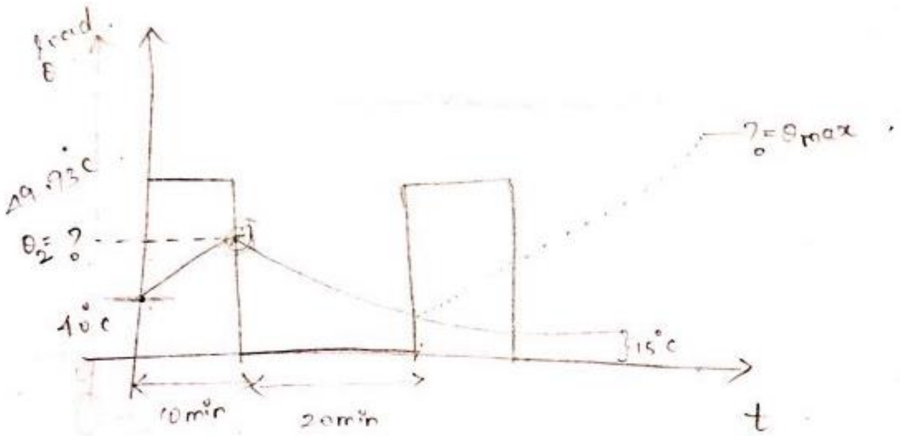
Q.6 a)

$$P_1 = \sqrt{\frac{1}{5}\int_0^5 \left(\frac{400}{5}x\right)^2 dx} = \frac{400}{\sqrt{3}\,\text{kW}}$$

$$P_{rms} = \sqrt{\frac{\left(\frac{400}{\sqrt{3}}\right)^2 \times 5 + 500^2 \times 5 + 400^2 \times 4}{16}}$$

Since $P_{max} = 500$ kW is less than two times P_{rms}, motor rating = 367 kW.

Q.6 b)



$\tau = \tau' = 60$

heating

$\theta = \theta_{ss_1}(1 - e^{-t/\tau}) + \theta_1 e^{-t/\tau}$

θ_1 - initial temp rise.

$\theta_{ss_1} \to \theta_{max}$

$\theta = \theta_{ss_1}(1 - e^{-10/60}) + 40\, e^{-10/60}$.

$\theta = \theta_{max}(0.1535) + 33.86$.

$\boxed{\theta = 0.15\, \theta_{max} + 33.86}$. — ①.

④

$\theta = \theta_{ss}(1 - e^{-t/\tau'}) + \theta_2\, e^{-t/\tau'}$

θ - mean temp rise at partic time

$\theta = 15\left(1 - e^{-20/60}\right) + \theta_2\, e^{-20/60}$.

$\theta = 40°$ during coolin

$40 = 4.25 + \theta_2(0.716)$

$0.716\, \theta_2 = 35.75$

$\boxed{\theta_2 = 49.93°C}$

Take ①

$\theta = \theta_2$ b'coz mean temp during heating

$49.93 = \theta_{max}(0.1535) + 33.86$.

$0.1535\, \theta_{max} = 16.07$.

$\boxed{\theta_{max} = 104.69}$.