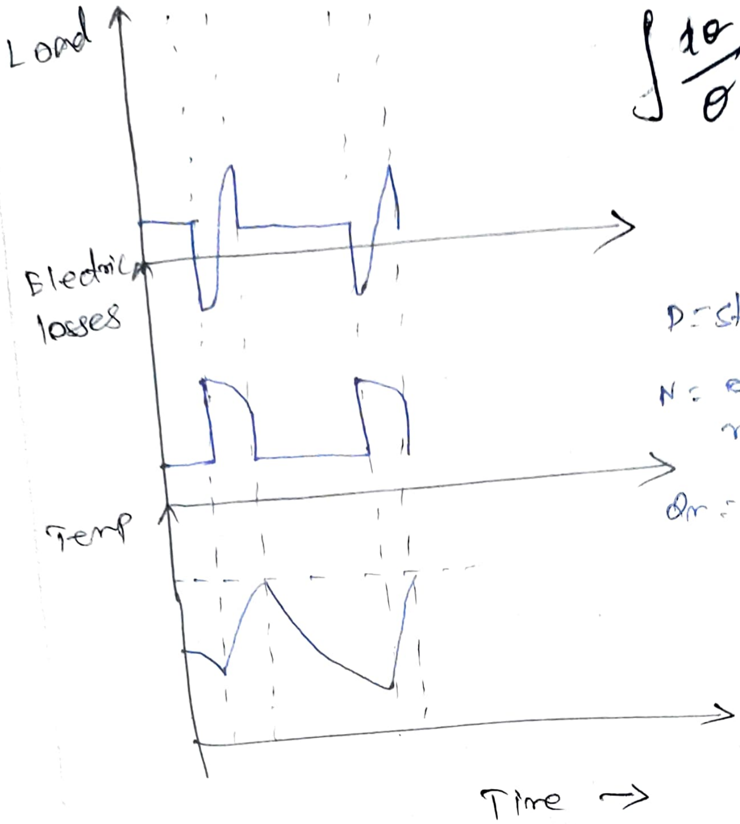
$\int \frac{d\theta}{\theta} = \log \theta$ (25)



D = Starting period

N = operation under rated condition

θ_m = max Temp.

$\log_e$ $\log_e$

(viii) continuous with periodic speed changes:-

* Duty consists of period of operation at constant load corresponding to a determined speed and followed immediately by a period of operation at another load corresponding to a different speed of operation.
* The operating period is too short to attain thermal equilibrium.
* There is No rest and de-energised period.

⇒ Selection of Power Rating for Drive Motors:-

* Drive Motor which is driving a constant load for sufficiently longer period, till it reaches thermal equilibrium.
* It's rating must be sufficient to drive it without exceeding the specified temperature.
* The Rating of the Motor selected for such type of duty is called continuous or design Rating.

* The continuous rating specifies the Max. load that the motor can take over a period of time without exceeding the temperature rise.
* It's also expected that, the motor should carry momentary over loads.
* Hence some times the selected motor ratings slightly more than the power required by load.

let

F = Force in kg

v = velocity in m/s

T = Torque in kg-m

η = Efficiency of motor

N = speed in r.p.m

∴ The rating of the Motor required in case of linear motion is

$$P = \frac{F.V}{75\eta} \text{ HP} \Rightarrow \frac{F.V}{102\eta} \text{ kW}$$

In case of rotary motion, the rating of the Motor is

$$P = \frac{T.N}{716\eta} \text{ H.P} \Rightarrow \frac{TN}{975\eta} \text{ kW}$$

* should check whether the motor is able to provide enough starting torque or not. ~~if the~~

usually in case of loads where the torque and speed known, the output power of load is

$$P_{out} = \frac{2\pi}{60} TN \text{ in W}$$

If the efficiency of load and transmission is η known, then power input to the load is

$$P = \frac{2\pi}{60} \cdot \frac{TN}{\eta} \text{ in W}$$

The rating of motor in case of elevator is

$$P = \frac{F \cdot V}{(2)(0.102)\eta} \text{ in W}$$

[∵ 2 indicates counter weight i.e one half of the useful load is always present].

In case of pump application, the rating of motor is

$$P = \frac{HQ\rho}{0.102\eta} \text{ in W}$$

where
H = Head consisting suction, delivery, friction and velocity.
Q = Delivery of pump
ρ = Density of liquid being pumped
η = combined efficiency of pump and transmission.

For fan motor, the power rating is

$$P = \frac{QH}{0.102\eta} \text{ in W}$$

where
Q = Volume of air in m^3/sec
H = Pressure of air in mm water or kg/m^2

* It's all are related to continuous duty constant load applications.
* It may be possible that the duty is continuous but the load is variable having several steps in one cycle.
* if avg. losses with slight variations in load, motor at highest load and continuous rating from the available is selected.

* But if the variations in the load are large, the machine undergoes continuous change in temperature.
* If the motor selected is based on lowest load then motor will be unable to drive the load. The motor takes more current at higher load and hence it's temperature rises.
* If the motor selected is based on highest load then motor will be over rated and may have poor efficiency.

⇒ Selection of Motor capacity for continuous Rating:-

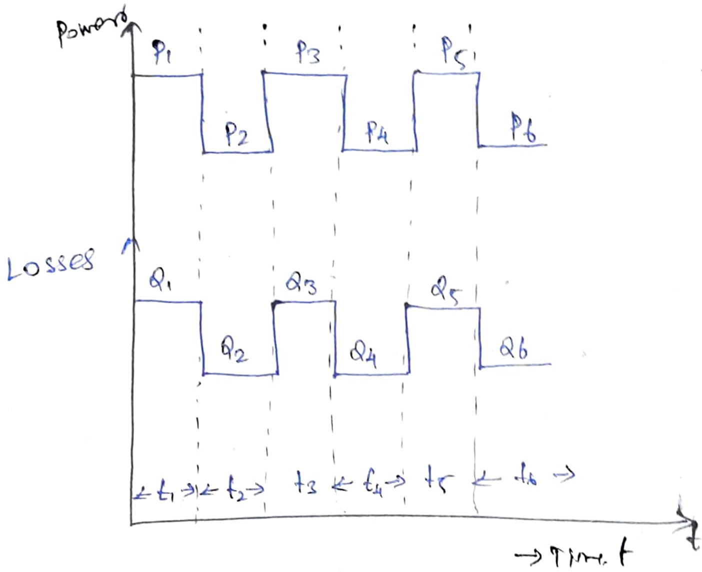
* In most of the Industrial and domestic applications, continuous duty (load) will be given to the drive.
* Hence Max. continuous power demand of the load is ascertained.
* The load requirement (Rating) is found out and motor is selected slightly more than ~~a~~ load rating. ~~in~~ ~~a~~
* The motor speed should be same as the load's speed requirements.
* The Motor should capable of provide a starting Torque required by the load.
* The Motor Should drive the load continuously without any over rise in temperature.

⑩ Methods for Determination of Motor Rating for Fluctuating and Variable Loads:-

For calculating the proper rating of drive motor for fluctuating and variable loads are

(i) Method of Average loss
(ii) Equivalent current method
(iii) Equivalent torque Method
(iv) Equivalent power method

(i) Method of Average losses:-



* It's based on a assumption that, $Q_{av} = Q_{norm}$ i.e the Average losses produced in a cycle of operation is equal to the normal (max) losses permitted for the machine.
* The rating of electric motor can be found from the method of successive approximation

$$\therefore \quad Q_{av} = \frac{Q_1 t_1 + Q_2 t_2 + Q_3 t_3 + \dots + Q_n t_n}{t_1 + t_2 + t_3 + \dots t_n} \longrightarrow (1)$$

* First motor is selected corresponding to the load requirement. It's calculated by product of Avg. power load and safety factor (1.1 to 1.3).

* when the Qar is compared with Qnorm. if both are equal or differ by a small value, the motor will be selected.
* If the value of differ is more, another motor is selected by same calculation. (repeated)
* To check, the motor selected has a sufficient overload capacity and starting torque.

(ii) Equivalent current Method:-

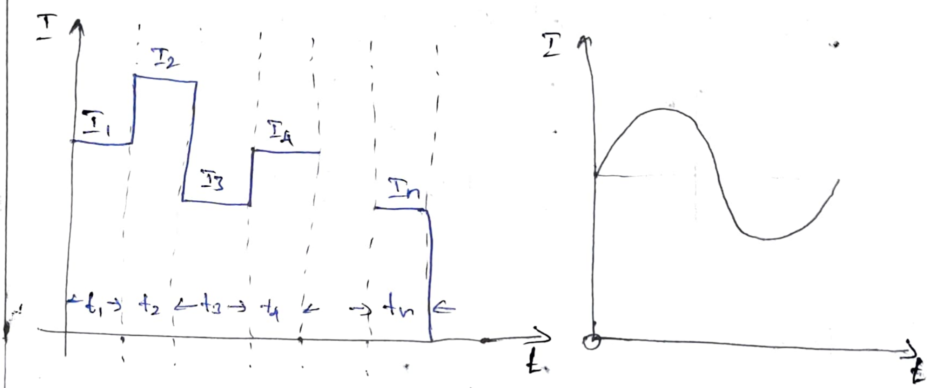


Fig: Fluctuating load

* It's used on approximation that the actual variable motor current can be replaced by an equivalent current (I_{eq}), which produces same losses in the motor as actual current.
* This equivalent current is have to determine.

Two types of losses in Motor are.

(a) constant loss, which is independent of load. (∵ const for all opr. point)

* This is depends on voltage and Not the load current.
* This loss consists of core loss and friction loss. It is also called as No-load loss (P_c).

(b) copper loss: which is dependent on load i.e load current. Represented by $P_{cu} = I^2R$.

For a fluctuating load consisting of n value of motor current $I_1, I_2, \dots I_n$ for durations $t_1, t_2 \dots t_n$. The equivalent current (I_{eq}) is

∴ The Total losses are

$$P_c + I_{eq}^2 R = \frac{(P_c + I_1^2 R_o)t_1 + (P_c + I_1^2 R)t_2 + \dots + (P_c + I_n^2 R)t_n}{t_1 + t_2 + \dots + t_n}$$

(or)

$$P_c + I_{eq}^2 R = \frac{P_c(t_1 + t_2 + \dots t_n)}{(t_1 + t_2 + \dots + t_n)} + \frac{(I_1^2 t_1 + I_2^2 t_2 + \dots I_n^2 t_n) R}{(t_1 + t_2 + \dots + t_n)}$$

(or)

$$I_{eq} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + \dots + I_n^2 t_n}{t_1 + t_2 + \dots + t_n}} \longrightarrow (2)$$

If the current varies smoothly over a period T,

$$I_{eq} = \sqrt{\frac{1}{T}\int_0^T i^2 \, dt} \longrightarrow (3)$$

* After calculation I_{eq}, the next higher rating of the motor is selected.

(iii) Equivalent torque method:

when torque is directly proportional to current, then T_{eq}.

$$T_{eq} = \sqrt{\frac{T_1^2 t_1 + T_2^2 t_2 + \dots + T_n^2 t_n}{t_1 + t_2 + \dots + t_n}} \longrightarrow (4)$$

(iv) Equivalent Power Method:

when motor operates at nearly fixed speed, it's power will be directly proportional to torque.

$$P_{eq} = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + \dots P_n^2 t_n}{t_1 + t_2 + \dots + t_n}}$$

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③ Selection of Motor Rating for Short time Duty:

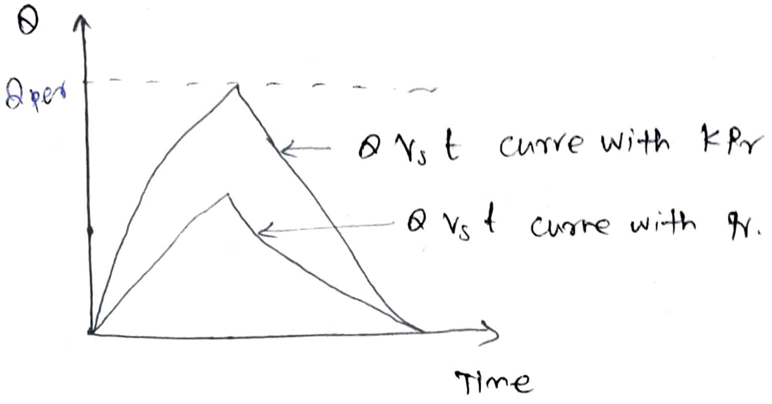


Fig: Load dgm of Fluctuating load

* consider, the motor's operating time period is less than the heating time constant.
* It's allowed to cool down to the ambient temperature, before it's required to operate again.
* If a motor of continuous duty is subjected to a load (P_r) for short time, then the Temp rise will be below of permissible value(θ_{per}) and the motor is highly under utilised.
* If the motor is is over loaded for a short time by a factor k (k>1) then it's reaches the θ_{per} value.

The time period of over load (kP_r) is t_r.

$$\theta_{per} = \theta_{ss}(1-e^{-t_r/\tau}) \rightarrow ① \quad [\because \text{From Heating curve eq}(9)]$$

$$\boxed{\frac{\theta_{ss}}{\theta_{per}} = \frac{1}{1-e^{-t_r/\tau}}} \rightarrow ②$$

where

θ_{ss} - steady state Temp rise when over loaded on continuous basis (It's above ambient value)

θ_{per} - " " Temp reached when rated load on continuous basics.

P_{1r} - losses in rated load (P_r)

P_{1s} - " " Increased load (kP_r).

$$\frac{\theta_{ss}}{\theta_{per}} = \frac{P_{1s}}{P_{1r}} = \frac{1}{1-e^{-t_r/\tau}} \longrightarrow (3)$$

let

$$\boxed{P_{1r} = P_c + P_{cu} \Rightarrow P_{cu}(\alpha+1)}, \longrightarrow (4)$$

where

$$\alpha = \frac{P_c}{P_{cu}}$$

Also

$$P_{1s} = P_c + P_{cu}\left(\frac{KP_r}{P_r}\right)^2$$

$$= P_c + K^2 P_{cu}$$

$$\boxed{P_{1s} = P_{cu}(\alpha + K^2)} \longrightarrow (5)$$

sub (4) and (5) in (3)

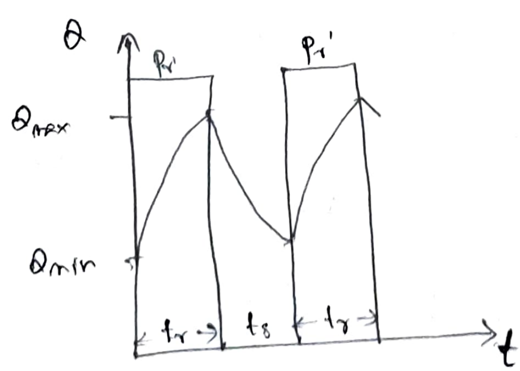
$$\frac{\cancel{P_{cu}}(\alpha+K^2)}{(\alpha+1)\cancel{P_{cu}}} = \frac{1}{1-e^{-t_r/\tau}}$$

$$(\alpha + K^2) = \frac{\alpha+1}{1-e^{-t_r/\tau}} \Rightarrow K^2 = \frac{1+\alpha}{1-e^{-t_r/\tau}} - \alpha$$

$$\boxed{K = \sqrt{\frac{1+\alpha}{1-e^{-t_r/\tau}} - \alpha}} \longrightarrow (6)$$

∴ K, overloading factor can be calculated when constant and copper losses are separately known.

⇒ <u>selection of motor Rating for intermitted Periodic duty:-</u>



* Here the Motor, alternatively subjected to a fixed magnitude load (P_r') for time t_r and stand still condition for t_s.

(34)

* For this type of load, the temperature will be fluctuating between max. value (θ_{max}) and min value (θ_{min}).

* Here, the selected motor should be,
$\theta_{max} < \theta_{per}$,
where θ_{per} - max. permissible temp rise value

Temperature rise at the end of loading (running) is

$$\boxed{\theta_{max} = \theta_{ss}(1 - e^{-t_r/\tau_r}) + \theta_{min}\, e^{-t_r/\tau_r}} \rightarrow (1)$$

Temp fall after the end of stand still (cooling)

$$\boxed{\theta_{min} = \theta_{max}\, e^{-t_s/\tau_s}} \rightarrow (2)$$

where
τ_r - heating time constants
τ_s - cooling time constants

$\therefore \frac{\cancel{\theta_{ss}}}{\cancel{\theta_{max}}}$

sub (2) in (1)

$$\theta_{max} = \theta_{ss}(1 - e^{-t_r/\tau_r}) + \theta_{max}\, e^{-t_s/\tau_s} \cdot e^{-t_r/\tau_r}$$

$$\theta_{max}\left(1 - e^{-\left(\frac{t_r}{\tau_r} + \frac{t_s}{\tau_s}\right)}\right) = \theta_{ss}\left(1 - e^{-t_r/\tau_r}\right)$$

$$\boxed{\frac{\theta_{ss}}{\theta_{max}} = \frac{\left(1 - e^{-\left(\frac{t_r}{\tau_r} + \frac{t_s}{\tau_s}\right)}\right)}{1 - e^{-(t_r/\tau_r)}}} \rightarrow (3)$$

when the motor is fully utilised upto it's full capacity then $\theta_{max} = \theta_{per}$.

$$\frac{\theta_{ss}}{} = \frac{P_{ls}}{} \rightarrow (4) \quad [\because \text{losses } P_{ls}, P_{lr}]$$

and $K = P_r'/P_r$ [∵ Losses]

$$\boxed{\frac{\theta_{ss}}{\theta_{per}} = \frac{P_{is}}{P_{ir}} = \frac{1-e^{-\left(\frac{t_r}{\tau_r}+\frac{t_s}{\tau_s}\right)}}{1-e^{-(t_r/\tau_r)}}} \longrightarrow (5)$$

W.K.T

$$P_{ir} = P_c + P_{cu} = P_{cu}(\alpha+1)$$

$$P_{is} = P_c + P_{cu}\left(\frac{KP_r}{P_r}\right)^2 \Rightarrow P_c + K^2 P_{cu} \Rightarrow P_{cu}(\alpha+K^2)$$

Now

$$\left(\frac{\alpha+K^2}{\alpha+1}\right) = \frac{1-e^{-\left(\frac{t_r}{\tau_r}+\frac{t_s}{\tau_s}\right)}}{1-e^{-(t_r/\tau_r)}} \longrightarrow (6)$$

$$\therefore \boxed{K = \sqrt{\frac{(1+\alpha)\left(1-e^{-\left(\frac{t_r}{\tau_r}+\frac{t_s}{\tau_s}\right)}\right)}{\left(1-e^{-(t_r/\tau_r)}\right)} - \alpha}} \longrightarrow (7)$$

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1. The temperature rise of motor after operating for 30 minutes on full load is 20°c and after another 30 minutes it becomes 30°c on the same load. Find the final temperature rise and time constant.

given:-

$t_1 = 30\,min$, $\theta_1 = 20°c$

$t_2 = 30+30 = \frac{60\,min}{60}$, $\theta_2 = 30°c$

To find:-

Final temperature Rise = ?

Time constant = ?

solution:

$$\theta_1 = \theta_F(1-e^{-t_1/\tau}) \text{ and}$$

$$\theta_2 = \theta_F(1-e^{-t_2/\tau})$$

$$\therefore \frac{\theta_1}{\theta_2} = \frac{\cancel{\theta_F}(1-e^{-t_1/\tau})}{\cancel{\theta_F}(1-e^{-t_2/\tau})} \Rightarrow \frac{20}{30} = \frac{1-e^{-0.5/\tau}}{1-e^{-1/\tau}}$$

let $e^{-0.5/\tau} = u$ and $e^{-1/\tau} = u^2$

$\frac{20}{30} = \frac{1-u}{1-u^2}$; $\frac{20}{30} = \frac{(1-u)}{(1+u)(1-u)}$

$\frac{2}{3} = \frac{1}{1+u}$; $1+u = \frac{3}{2}$; $u = 1.5 - 1$

$\therefore$ $\boxed{u = 0.5}$

$\therefore$ $e^{-0.5/\tau} = u$; $\frac{-0.5}{\tau} = \ln(u)$

$\frac{-0.5}{\tau} = \ln(0.5) = -0.6931$

$\boxed{\tau = 0.7214 \text{ hrs}}$

$\therefore$ $20 = \theta_F(1 - e^{-0.5/0.7214})$

$= \theta_F(1 - 0.5)$

$\boxed{\theta_F = 40^\circ C}$

Ans:-

(i) The Final Temp. Rise $(\theta_F) = 40^\circ c$

(ii) Time constant $(\tau) = 0.7214$ hrs.

2. The temperature rise of a motor when operating for 25 min on full load is 25°c and becomes 40°c when the motor operates for another 25 min on the same load. Determine heating time constant and steady state temperature rise.

Ans:- $\tau = 0.8157$ hrs, $\theta_F = 62.49^\circ c$

3. At full load of a 10 H.P the temperature rise of a motor is 25°c after one hour and 40°c after two hours. Find (i) The Final temperature rise on full load (ii) Heating time constant of motor.