UNIT II

SELECTION OF MOTORS FOR DRIVE SYSTEM

By

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• RATINGS OF MOTOR

1. Short Time Rating of Motor
2. Continuous Rating of Motor
3. Horse Power Rating of Motor

• Short time rating of motor:

The output which a motor can give for a specified period (1hr, 2hr, 30min etc.) without exceeding the specified temperature rise the motor being assumed to start from cold.

• Continuous rating of motor:

The output which a motor can give continuously without exceeding the temperature rise specified by I.S.(Indian Standard).A continuously rated motor can also give overload of 2.5% for2hours. In this case the motor is loaded for few days. Motor attains it's maximum temperature after certain time and remains constant for remaining period. For example, the motor of water pump, generator , etc.

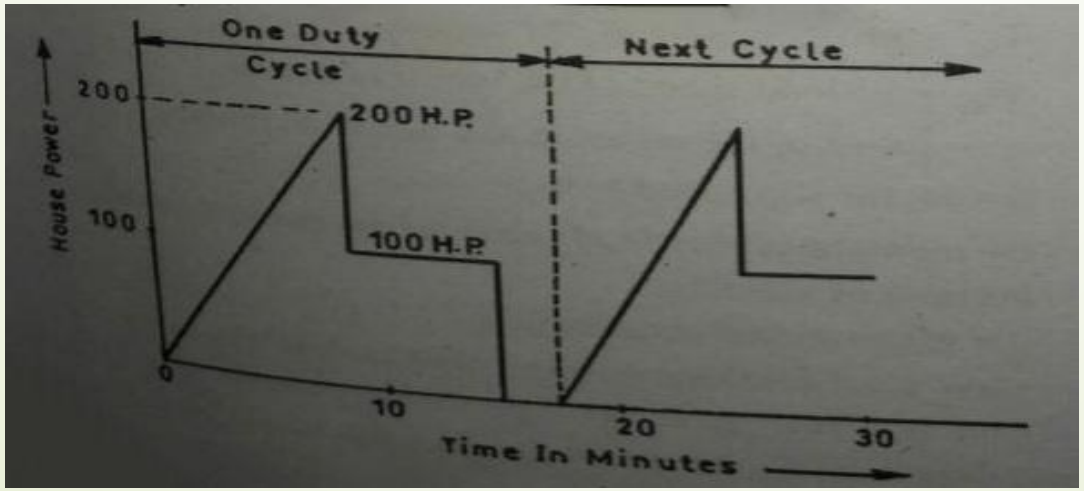
• Horse Power Rating Motor

Horse Power rating of motor is given by-

$$\text{R.M.S. horse power} = \sqrt{\frac{1}{Time\ for\ one\ cycle}\int (hp)^2\ dt}$$

$$= \left[\frac{\sum (hp)^2 \times time}{Time\ for\ one\ cycle}\right]$$

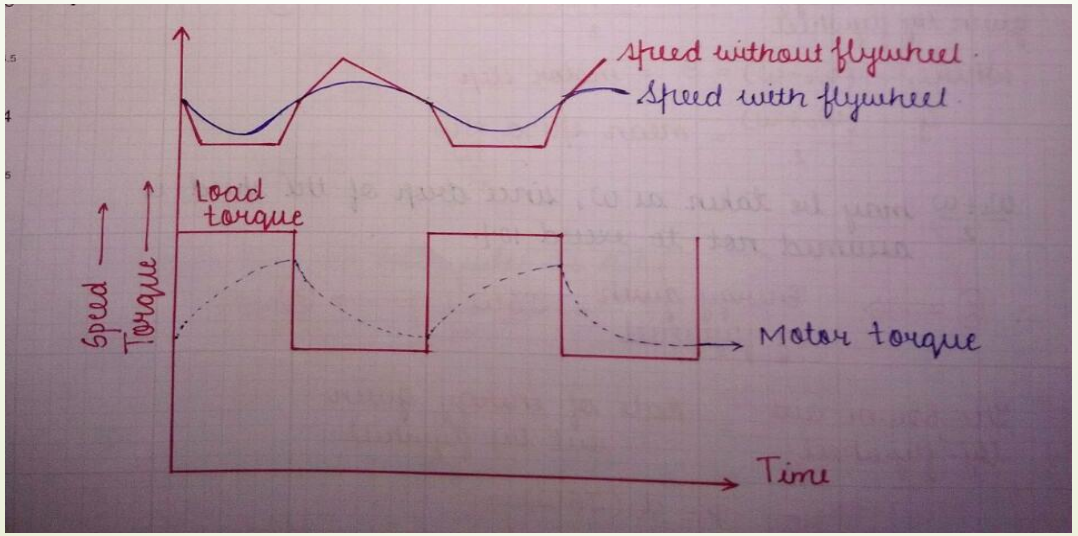
Duty cycle is as shown in below



LOAD EQUALIZATION-

In individual drives such as rolling mills, electric hammer, reciprocity forms load fluctuate over a wide range during short time of period. For eg- In rolling mill it is necessary to smooth out the peak demand, otherwise would result in heavy current bring drawn from the supply & produce large voltage drop in the system.

The process of smoothing out the fluctuating load is called load equalization. The most common method for equalization is to the flywheel. During light load period, flywheel accelerate is stores the energy drawn from the supply and during peak load period flywheel deaccelerates is supplies some of the store energy to the load in addition to the energy supplied from the supply.



Let,

Tm = motor torque at any instant (N-m)

Tf = Flywheel torque (N-m)

TL = load torque(N-m)

To = no load torque(N-m)

Wo = motor speed at no load (rad/sec)

W = motor speed at any instant (rad/sec)

S = Slip(Wo-W)

t = time

Case I- Load Increasing:-

During this period flywheel deaccelerates it gives some part of energy stored in it the torque supplied by the motor is given by,

$$Tm = TL - Tf \quad \text{----------(1)}$$

energy given out by flywheel when its energy reduces from Wo to W

$$\text{Energy} = \tfrac{1}{2} J (Wo^2 - W^2)$$

$$\text{Energy} = \tfrac{1}{2} J (Wo+W) (Wo-W)$$

Energy = $\frac{J(Wo+W)(Wo-W)}{2}$ ---------(2)

where, (Wo-W0) = S= motor slip

(Wo+W)/2 = mean speed = w

(Wo+W)/2 may be taken as w, since drop of the speed is assumed not to exceed 10%.

eq.(2) becomes

energy given by flywheel = JSW ---------(3)

the power out by flywheel = rate of energy given out by flywheel

i.e. P = d/dt (JSW)

P = JW d/dt (S) ----------(4)

Flywheel torque = $\frac{power\ given\ out\ by\ flywheel}{w}$

Tf = $\frac{JW\ ds/dt}{w}$

Tf = J ds/dt ----------(5)

eq.(1) becomes, Tm = TL – J ds/dt -------(6)

since, the value of slip is 10% and slip is proportional to the torque.

$$S = KTm$$

$$Tm = TL - JK\ d/dt\ Tm$$

$$\frac{d\ Tm}{TL - Tm} = dt/Jk$$

Integrating on both side we get,

$$-\log (TL - Tm) = t/Jk + C1 \text{ ---------(7)}$$

for initial condition, t=0 & Tm= To

$$-\log (TL - To) = C1 \text{ ----------(8)}$$

eq.(7) becomes, $-\log [TL-To] = t/Jk - \log [TL- Tm]$

$$t/Jk = \log \left[\frac{TL-To}{TL-Tm}\right]$$

$$Tm = TL\left(1 - e^{\frac{-t}{JK}}\right) + To\ e^{\frac{-t}{JK}}$$

Case II- Load Decreasing:

when load decreases, motor accelerates flywheel to its normal speed, slip ‘S’ decreases & ds/dt is negative.

$$Tf = -J\ ds/dt$$

$$Tm = To - J\ ds/dt$$

$$Tm = To - J\ dk/dt\ \ Tm$$

$$JK\ dTm/dt = To - Tm$$

$$dTm/To\text{-}Tm = dt/JK$$

Integrating on both side we get,

$$-\log (To - Tm) = t/Jk\ + C2 \text{ ---------(9)}$$

for initial condition, t=0 & Tm= Tm’

$$-\log (To - Tm') = t/JK - \log (To\text{-}Tm')$$

$$\log \left[\frac{To-Tm'}{To-Tm}\right] = \frac{t}{JK}$$

$$(To - Tm) = e^{\frac{-t}{Jk}} (To - Tm')$$

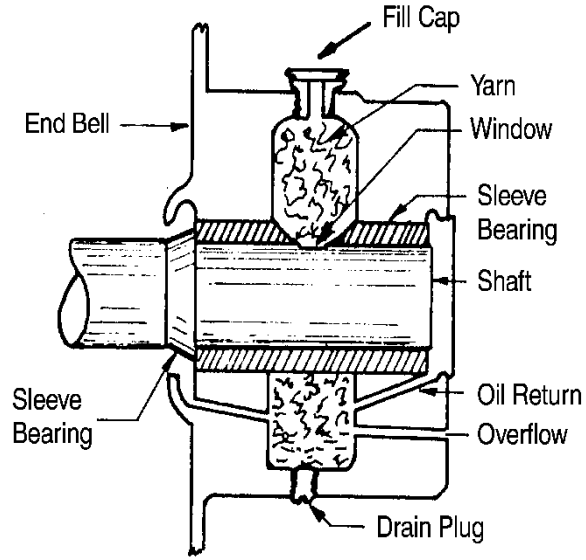
$$Tm = To - e^{\frac{-t}{Jk}} (To - Tm')$$

$$\boxed{Tm = To\,(1 - e^{\frac{-t}{Jk}}) + Tm'\, e^{\frac{-t}{Jk}}}$$

Types of Bearings Used in Electric Motors

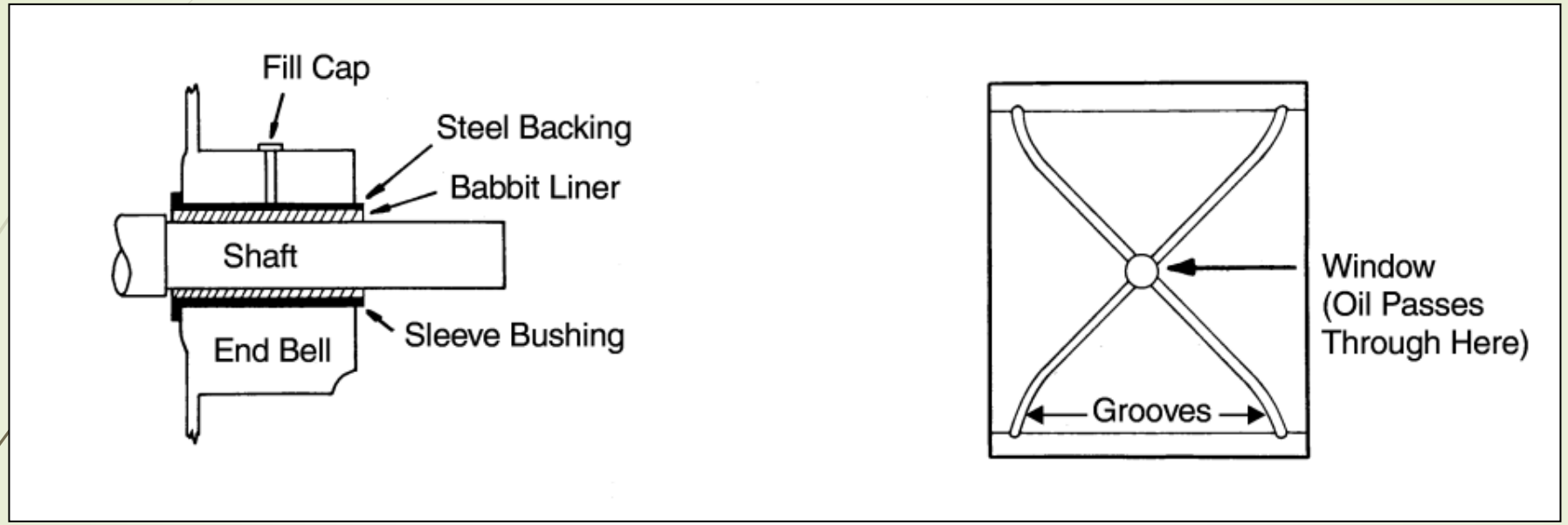
Sleeve Bearings

- A bushing that must be pressed into the motor housing
- Diameter of motor shaft is 0.001” smaller than sleeve bearing
- Adequate to hold a film of oil between the shaft and bearing
- Designed for axial loads



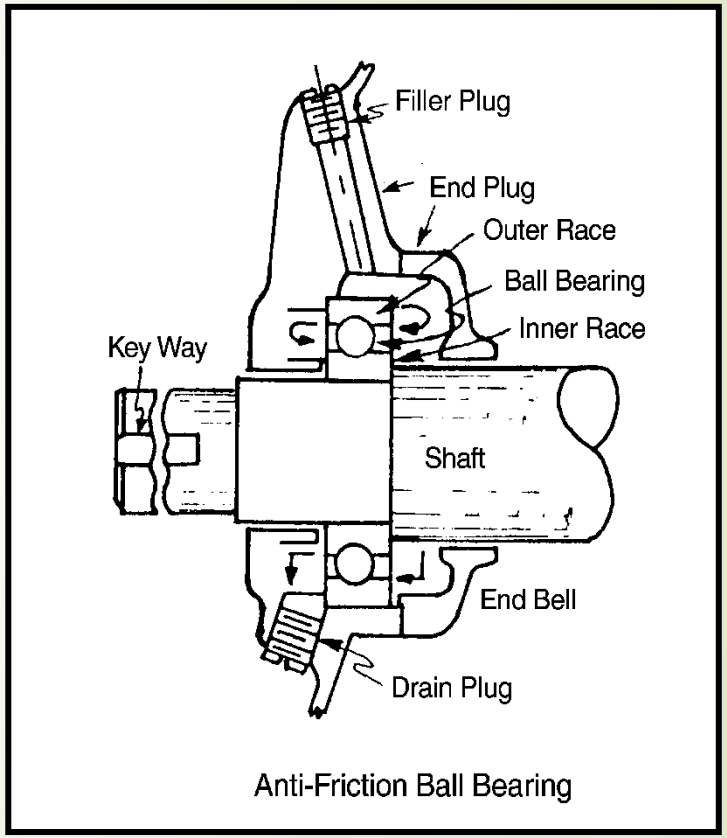
Sleeve Type Bearing

- **Advantages:**
  - Initial cost of motor is less than one with anti-friction bearings
  - Less expensive to replace
  - Used on very large (500 Hp) A.C. motors
- **Disadvantage:**
  - Motor must be mounted horizontally to allow for even, gravity force flow of oil
  - Oil flows along grooves and into window to lubricate bearing


Fill Cap
Steel Backing
Babbit Liner
Shaft
End Bell
Sleeve Bushing
Window
(Oil Passes
Through Here)
Grooves

Anti-friction Bearings

- Used with heavy alignment loads
- Made up of two separate races
- Separated by many round roller balls
- Outer race is stationary in end ball
- Inner race is firmly pressed onto motor shaft
- Inner race turns, the balls roll & outer race stands still
- Used to meet the specific demands of the load being driven
- If motor is not properly aligned, excessive bearing wear will result



Anti-Friction Ball Bearing

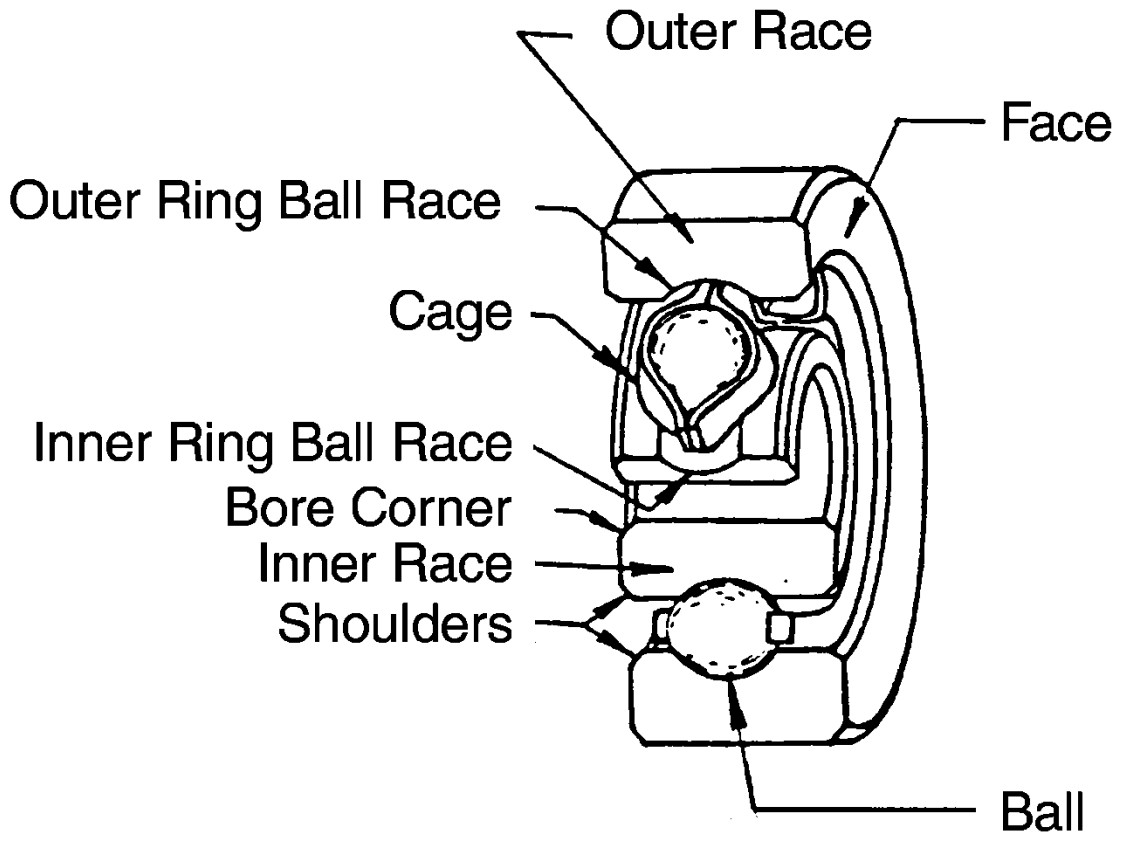
- Three types:

1. Must be removed from housing to be lubricated
2. Can remain intact and be lubricated through a filler tube with a grease gun
3. Sealed bearing—must be replaced rather than lubricated
    - Found in motors used in difficult location

Advantages:

- Motors can be mounted in any position
- Tend to roll more easily and create less drag on the motor
- Used exclusively on motors, except for fractional Hp small blower motors such as hair dryers

CROSS-SECTIONAL VIEW OF A SEALED BALL BEARING



Motor Enclosures

- Motors must operate in all kinds of environments.
- The environment in which the motor is placed helps to dictate the type of enclosure of the motor.

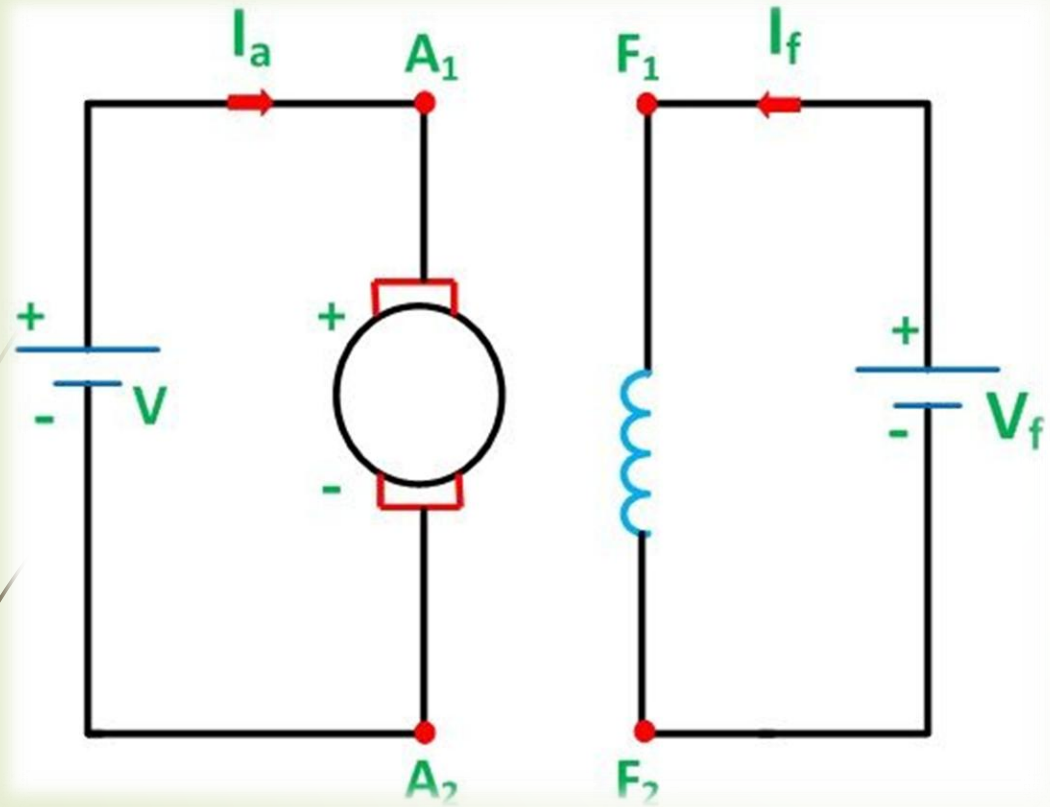
- Two types:
  - **Open Enclosure:**
    - Allow movement of air through it to help in cooling
    - May **not** be used in any situation where moisture or explosive dust or gases are present
  - **Totally Enclosed:**
    - Have fins on the housings to provide radiant and convection cooling
    - Must use a higher degree of insulation on windings to prevent overheating
    - Should be used on all motors in animal confinement situations

- Typical motor enclosures:
  - Open Drip-proof (ODP)
  - Totally-enclosed fan-cooled (TEFC)—used in outdoor or dirty applications
  - Totally-enclosed air-over (TEAO)—used in grain handling applications
  - Totally-enclosed non-ventilated (TENV)—used in milk pumps and similar applications
  - Explosion-proof

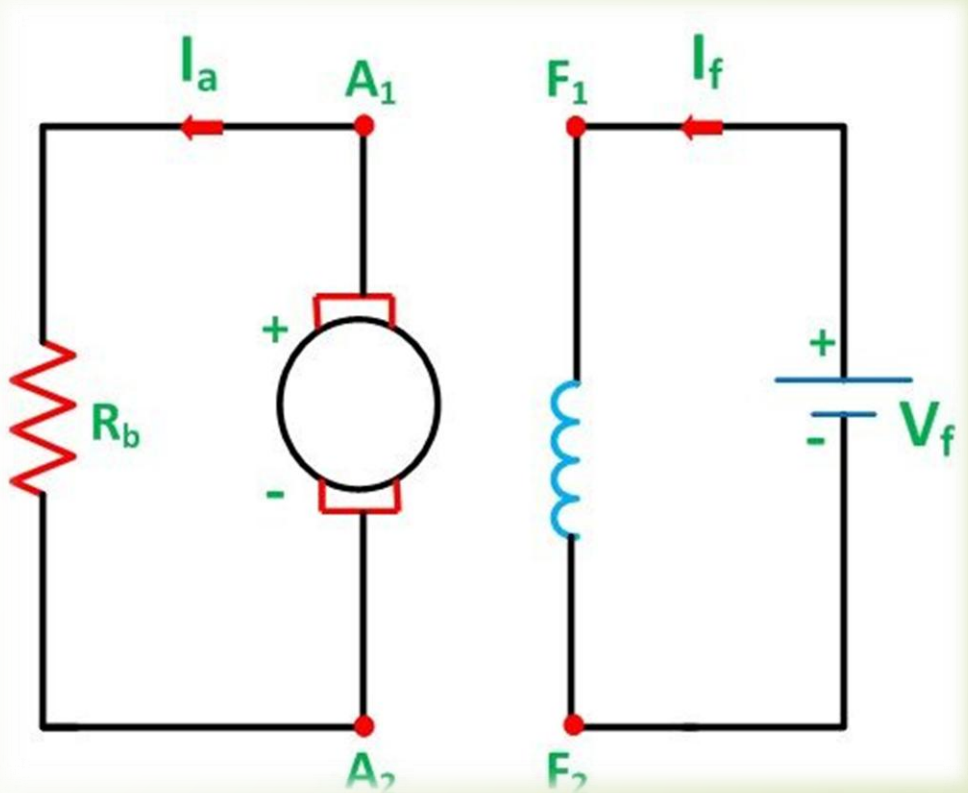
Dynamic Braking or Rheostatic Braking of DC Motor

In **Dynamic Braking**, a braking resistor Rb is connected across the armature as soon as the DC motor is disconnected from the supply mains. The motor now works as a generator, producing the braking torque.For the braking operation in Dynamic Braking, the motor is connected in two ways.

Firstly the separately excited or shunt motor can be connected either as a separately excited generator, where the flux is kept constant. The second way is that it can be connected to a self-excited shunt generator, with the field winding in parallel with the armature. The connection diagram of Dynamic Braking of separately excited DC motor is shown below. When the machine works in the motoring mode.

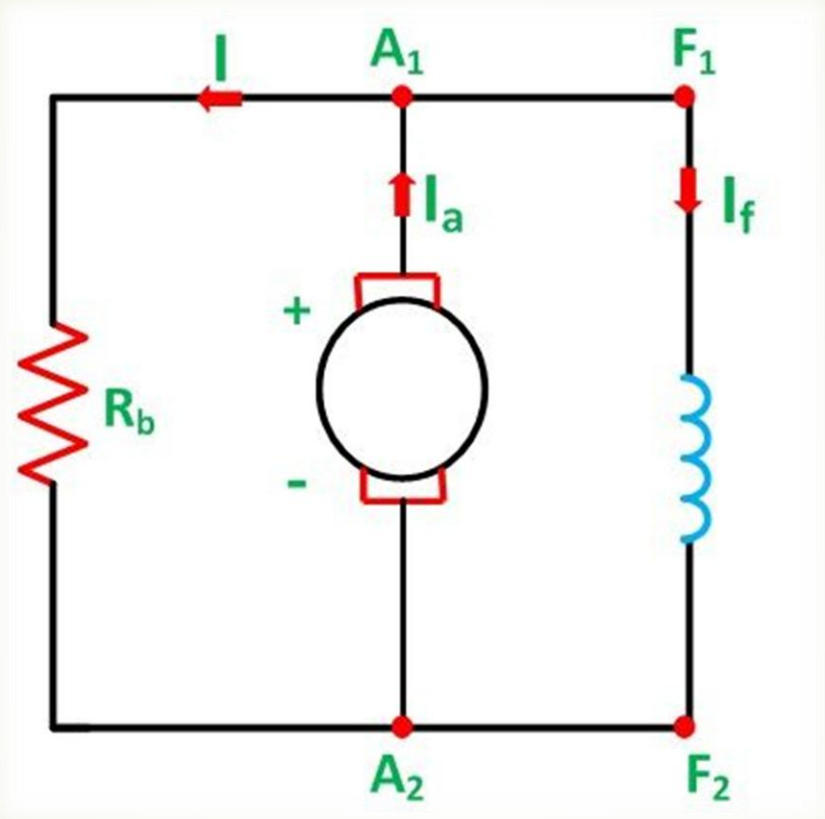


Motoring Mode



Braking Mode

- The connection diagram is shown below when braking with self-excitation is performed.



This method is also known as **Rheostatic Braking** because an external braking resistance R_b is connecte across the armature terminals for electric braking. During an electric braking, the kinetic energy stored in the rotatin parts of the machine and the connected load is converted into electric energy, when the motor is working as a generato The energy is dissipated as heat in the braking resistance R_b and armature circuit resistance R_a.

The connection diagram of Dynamic Braking of DC Shunt Motor is shown below.

When the machine is working in the motoring mode.

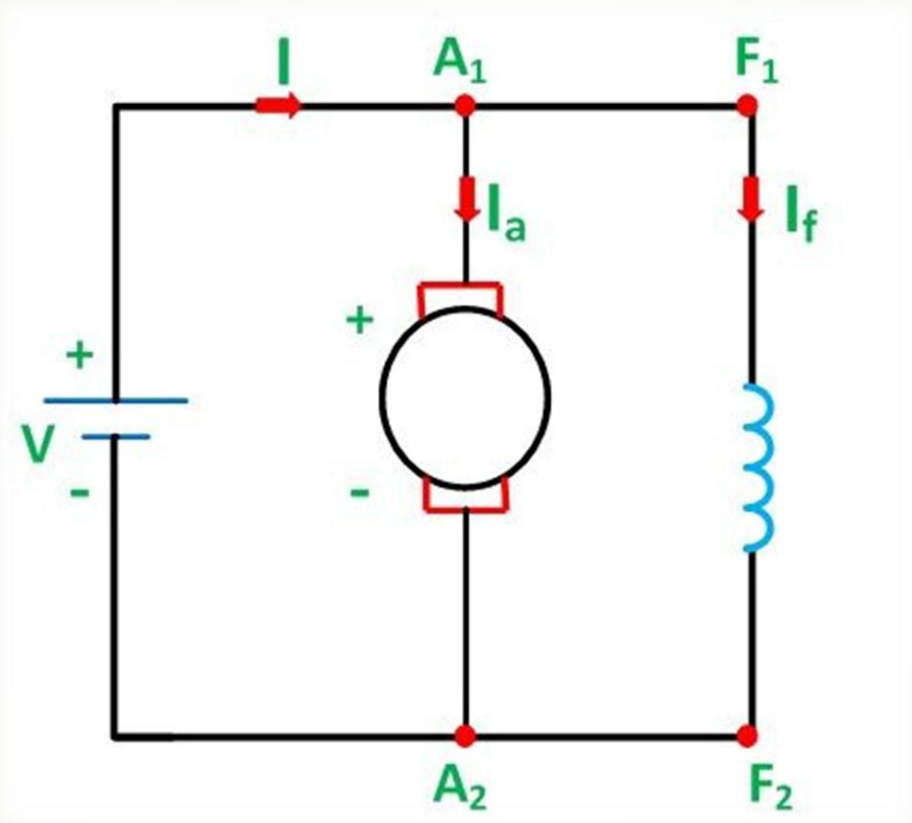
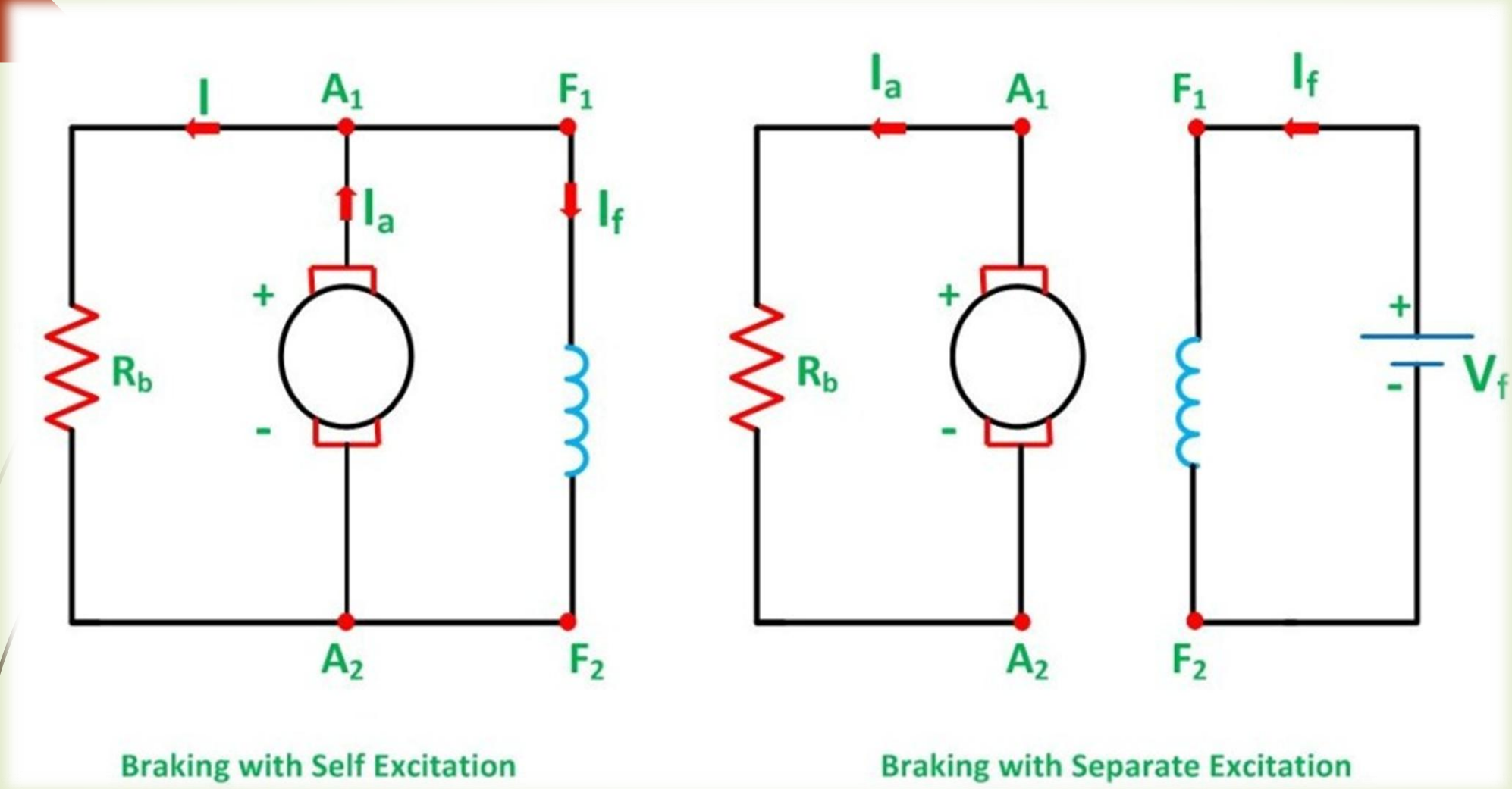


Fig. Dynamic Braking of DC Shunt Motor

- The connection diagram of shunt motor Braking with self and separate excitation is shown in the



For Dynamic Braking, the series motor is disconnected from the supply. A variable resistance R_b as shown in the figure below is connected in series, and the connections of the field windings are reversed.

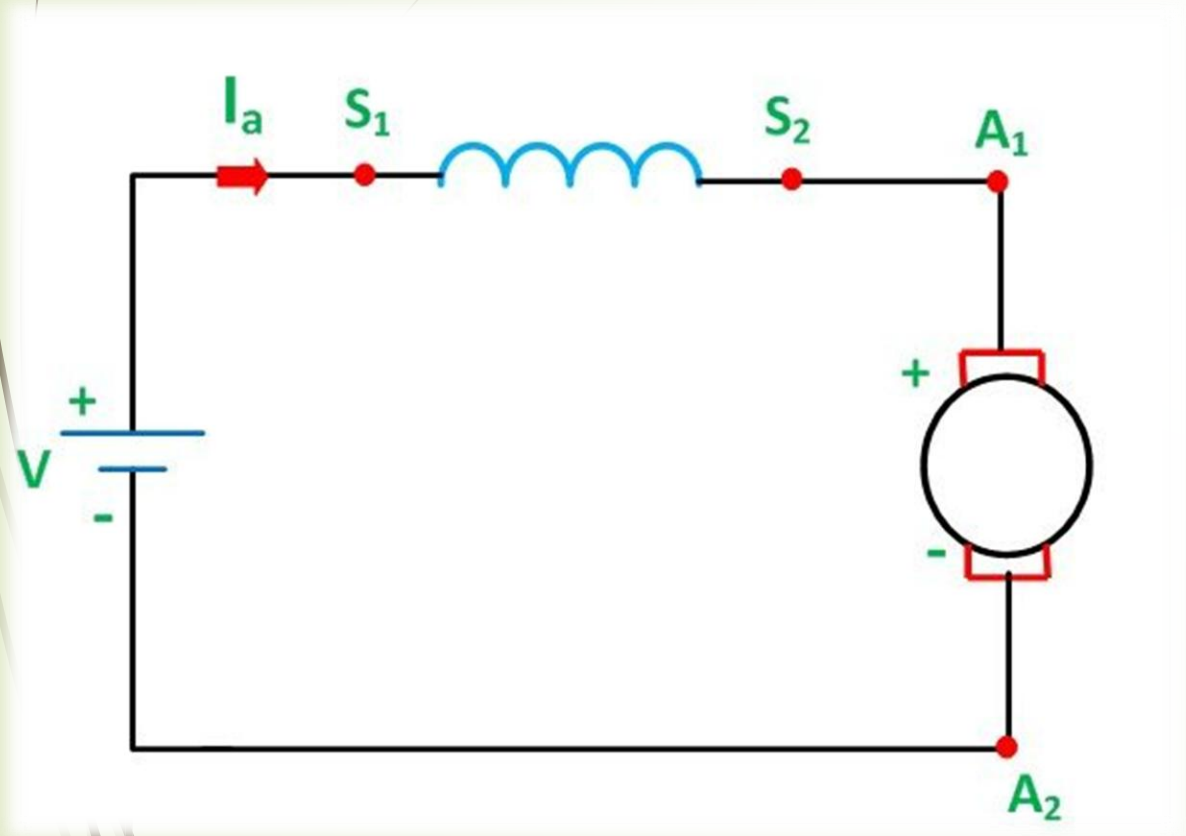


fig. Motoring

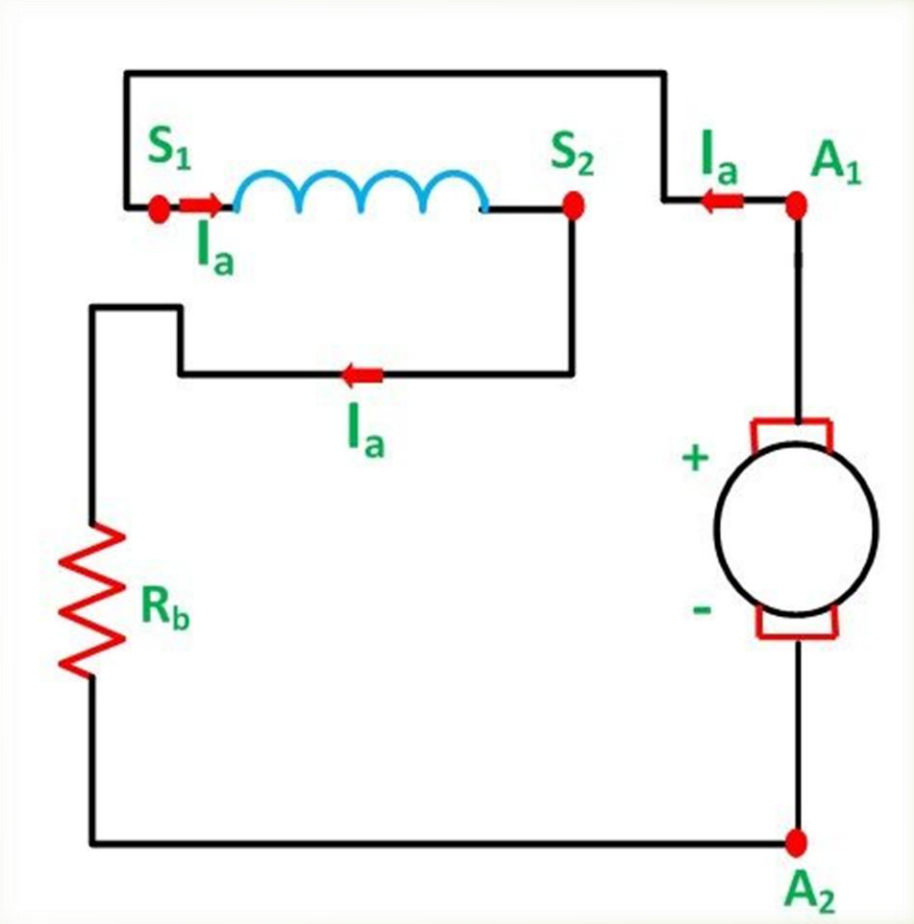
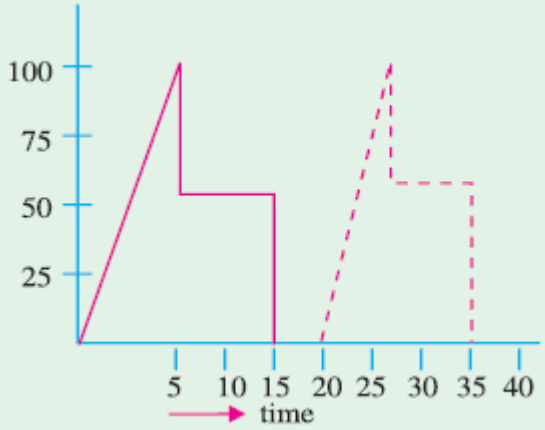


Fig. Braking with Self excitation

Example 45.5. *A motor working in a coal mine has to exert power starting from zero and rising uniformly to 100 H.P. in 5 min after which it works at a constant rate of 50 H.P. for 10 min. Then, a no load period of 3 min. The cycle is repeated indefinitely, estimate suitable size of motor.*



(*a*) For time period : 0 - 5 min

$$\Rightarrow \quad y = mx + c$$

$$\text{Slope} = \frac{(100-0)}{5}$$

$$m = 20 \text{ HP/min}$$

$$\therefore \quad y = 20x + 0$$

$$y = 20x$$

(*b*) For total time period : 0 - 18 min

R.M.S. H P^2

$$= \left\{ \left[\int_0^5 y^2 \, dx \right] + 50^2 \times 10 + 0^2 \times 3 \right\} / 18$$

$$\Rightarrow \text{H.P.}^2 \times 18 = \left[\int_0^5 (20x)^2 \, dx \right] + 25000 = \left[\frac{400x^3}{3} \right]_0^5 + 25000$$

$$\therefore \text{H.P.}^2 \times 18 = \frac{400 \times 125}{3} + 25000$$

$$\Rightarrow \text{H.P.} = \sqrt{\frac{41666.67}{18}} = 48.11 \text{ H.P.} = 50 \text{ H.P. motor can used}$$

or Same problem can be solved by Simpson's 1/3rd Rule of Integration

$$\text{H. P.} = \sqrt{\frac{\frac{1}{3} \times 100^2 \times 5 + 50^2 \times 10}{18}}$$

H. P. = 48.11 H.P. ; $\therefore$ H. P. $\simeq$ 50 H.P.

Example 45.8. *A motor driving a colliery winder has the following acceleration period*

load cycle 0 - 15 sec.	:	*Load rising uniformly from 0 - 1000 H.P.*
Full speed period	:	*15 - 85 sec. Load const. at 600 H.P.*
Decceleration period	:	*85 to 95 sec. regenerative braking the H. P. returned uniformly from 200 to 0 H. P.*
95 - 120 sec.	:	*Motor stationary.*

Estimate the size of continuously rated motor.

Solution.

$$\text{R.M.S. H. P.} = \left[\frac{\frac{1}{3}(1000)^2 \times 15 + 600^2 \times 70 + \frac{1}{3}(200)^2 \times 10}{120}\right]^{\frac{1}{2}}$$

$$= 502 \text{ H. P.}$$

$$\cong \textbf{505 H. P. motor can be used.}$$

Example 45.17. *A 6 pole, 50 Hz Induction Motor has a flywheel of 1200 kg-m² as moment of inertia. Load torque is 100 kg - m. for 10 sec. No load period is long enough for the flywheel, to regain its full speed. Motor has a slip of 6% at a torque of 50 kg-m. Calculate*

(i) Maximum torque exerted by motor.

(ii) Speed at the end of deaceleration period. **[Nagpur University Winter 1996]**

Solution. *(i)* $T_m = T_L - (T_L - T_0)e^{\frac{-tg}{IK}}$

Assume $T_0 = 0, \rightarrow T_m = T_L(1 - e^{\frac{-tg}{IK}})$

$T_L = 100\ \text{kg} - m, \quad t = 10\ \text{sec}, \quad g = 9.81\ \text{m/sec}^2,$

$I = 1200\ \text{kg} - \text{m}^2 \quad s = \omega_0 - \omega$

$s = KT \quad \therefore \quad \text{slip speed} = s = \frac{2\pi}{60}(N_0 - N)$

$N_S = \frac{120f}{p} = \frac{120 \times 50}{6} = 1000\ \text{rpm} = N_0$

$N = 0.94 \times 1000 = 940\ \text{rpm}.$

$\therefore \quad S = \frac{2\pi}{60}(1000 - 940) = 2\pi\ \text{rad/sec} \quad \text{or} \quad s = \frac{2\pi N}{60} = \frac{2\pi \times 1000 \times 0.06}{60}$

$s = 2\pi = 6.283\ \text{rad/sec}$

$\therefore K = \frac{S}{T} = \frac{2\pi}{50} = 0.04\pi = 0.125$

$\therefore \quad T_m = T_L(1 - e^{\frac{-tg}{IK}}) = \left(1 - e^{\frac{-10 \times 9.81}{1200 \times 0.04\pi}}\right)$

$T_m =$ **47.83 kg - m**

(ii) Slip speed $= 0.04\ \pi \times 47.8\ \text{rad/sec}$

$s = KT_m$

$s = 0.125\ (47.83)$

$s = 5.98\ \text{rad/sec}$

$s = 5.98\frac{60}{2\pi}\text{rpm} = 57.5\,\text{rpm} = \text{slip speed}$

$\therefore$ Actual speed $= 1000 - 57.5 =$ **942.5 rpm**

Heating of Electric motor

- The rise in temperature of a motor results from the heat generated by the losses and an expression for this temperature rise is obtained by equating the rate at which heat is being generated by these losses to the rate at which heat is being absorbed by the motor for raising the temperature of motor and in dissipation from the surfaces exposed to cooling media.
- If the temperature of body rises, it has to store heat. The amount of heat *i.e.* stored depends upon the heat capacity of the body. If the temperature of the machine remains constant *i.e.* it doesn't rise, then no further storage of heat takes place and all the heat *i.e.* generated must be dissipated. So rate of heat generation in motor equals rate of heat dissipation from the cooling surface. This is called a stable situation.

Let,

W → Heat generated in motor due to powerloss in watts.

G → Weight of motor (kg)

S → Average specific heat in (Watt - Sec.) to raise the temperature of unit weight through 1°C.

$G \times S$ → Heat required to raise the temperature of motor through 1°C (Watt - Sec.)

θ → Temperature rise above cooling medium in °C.

θ_f → Final temperature rise in °C.

A → Cooling surface area of motor.

λ → Rate of heat dissipation from the cooling surface.
[(Watts/Unit area/°C rise in temperature.) above cooling medium]

$A\lambda$ → Rate of heat dissipation in Watts /°C rise in temperature for a motor.

Assumptions

1. Loss 'W' remains constant during temperature rise.
2. Heat dissipation is proportional to the temperature difference between motor and cooling medium.
3. Temperature of cooling medium remains constant.

{Rate of heat generation in motor}
= {Rate of heat absorption by the motor} + {Rate of heat dissipation from cooling surface}

$$\rightarrow \quad W = GS\frac{d\theta}{dt} + A\lambda\theta$$

or $$W - A\lambda\theta = GS\frac{d\theta}{dt}$$

$$\rightarrow \quad \frac{W}{A\lambda} - \theta = \frac{GS}{A\lambda}\frac{d\theta}{dt}$$

$$\rightarrow \quad \frac{d\theta}{\left(\frac{W}{A\lambda} - \theta\right)} = \frac{dt}{\frac{GS}{A\lambda}}$$

By integrating,

$$\log_e\left(\frac{W}{A\lambda} - \theta\right) = -\frac{A\lambda}{GS}t + C \qquad \text{..... (2)}$$

At $t = 0$, $\theta = \theta_1$ [Initial temperature rise *i.e.* difference between the temperature of cooling medium and temperature of motor, during starting]

If starting from cold position, $\theta_1 = 0$

Substituting the values of t and θ in above equation.

$$C = \log_e\left(\frac{W}{A\lambda} - \theta_1\right)$$

$$\therefore \quad (2) \Rightarrow \log_e\left[\frac{\left(\frac{W}{A\lambda} - \theta\right)}{\left(\frac{W}{A\lambda} - \theta_1\right)}\right] = -\frac{A\lambda}{GS}t$$

by taking antilog, $$\frac{\left(\frac{W}{A\lambda} - \theta\right)}{\left(\frac{W}{A\lambda} - \theta_1\right)} = e^{-\frac{A\lambda}{GS}t}$$

$$\therefore \quad \theta = \frac{W}{A\lambda} - \left(\frac{W}{A\lambda} - \theta_1\right)e^{-\frac{A\lambda}{GS}t} \qquad \text{..... (3)}$$

When, the final temperature rise of θ_f is reached, all the heat generated is dissipated from the cooling surface so that,

equation (1) becomes $W = A\lambda\ \theta_f$ or $\theta_f = \frac{W}{A\lambda}$

And $\frac{GS}{A\lambda}$ = Heating time constant

$$\therefore \quad \frac{A\lambda}{GS} = \frac{1}{T}$$

Then equation (3) becomes;

$$\theta = \theta_f - (\theta_f - \theta_1)\, e^{\frac{-t}{T}}$$

If starting from cold, then $\theta_1 = 0$

$$\therefore \quad \theta = \theta_f\left(1 - e^{\frac{-t}{T}}\right)$$

45.6. Heating Time Constant

Heating time constant of motor is defined as the time required to heat up the motor upto 0.633 times its final temperature rise.

$$\theta = (1 - e^{-t/T})$$

At $t = T$, $\theta = 0.633\,\theta_f$

After time	$t = T$	θ reaches to 63.3 % of θ_f
	$t = 2T$	θ reaches to 86.5 % of θ_f
	$t = 3T$	θ reaches to 95 % of θ_f
	$t = 4T$	θ reaches to 98.2 % of θ_f
	$t = 5T$	θ reaches to 99.3 % of θ_f

T = Heating time constant.

= 90 min for motors upto 20 H.P.

= 300 min for larger motors.

45.7. Equation for Cooling of Motor or Temperature Fall

If rate of heat generation is less than rate of heat dissipation, cooling will take place.

$\therefore$ {Rate of heat generation in motor}+{Rate of heat absorption by motor}={Rate of heat dissipation from cooling surface}

$$W + GS\frac{d\theta}{dt} = A\lambda'\theta \quad \text{where } \lambda' = \text{Rate of heat dissipation during cooling surface}$$

$$W - A\lambda'\theta = -GS\frac{d\theta}{dt} \qquad \Rightarrow \frac{W}{A\lambda'} - \theta = -\frac{GS}{A\lambda'}\frac{d\theta}{dt}$$

$$\theta - \frac{W}{A\lambda'} = \frac{GS}{A\lambda'}\frac{d\theta}{dt} \quad \Rightarrow \quad \frac{d\theta}{\theta - \frac{W}{A\lambda'}} = \frac{dt}{\frac{GS}{A\lambda'}}$$

$$\therefore \quad \int \frac{d\theta}{\theta - \frac{W}{A\lambda'}} = \int \frac{dt}{\frac{GS}{A\lambda'}}$$

$$\log_e\left(\theta - \frac{W}{A\lambda'}\right) = -\frac{A\lambda'}{GS}t + C$$

At $t = 0$ Let $\theta = \theta_0$ Difference of temperature between cooling medium and motor (Temperature rise at which cooling starts.)

$$\therefore \quad C = \log_e\left(\theta_0 - \frac{W}{A\lambda'}\right)$$ Put this value of C in the abve equation.

$$\therefore \quad \log_e \frac{\theta - \frac{W}{A\lambda'}}{\theta_0 - \frac{W}{A\lambda'}} = -\frac{A\lambda'}{GS}t$$

If θ_f' is final temperature drop (above that of cooling medium), then at this temperature whatever heat is generated will be dissipated.

$$\therefore \quad W = A\lambda' \theta_f' \quad \Rightarrow \quad \theta_f' = \frac{W}{A\lambda'}$$

$$\therefore \quad \log_e \left\{ \frac{\theta - \theta_f'}{\theta_0 - \theta_f} \right\} = -\frac{t}{T'} \qquad \text{Where } T' \text{ is cooling time constant } = \frac{GS}{A\lambda'}$$

$$\therefore \quad \frac{\theta - \theta_f'}{\theta_0 - \theta_f'} = e^{-t/T} \quad \Rightarrow \quad (\theta - \theta_f') = (\theta_0 - \theta_f') e^{\frac{-t}{T'}}$$

$$\theta = \theta_f' + (\theta_0 - \theta_f') e^{\frac{-t}{T'}}$$

If motor is disconnected from supply, there will be no losses taking place and so final temperature reached will be ambient temperature. Hence $\theta_f' = 0$ ($\because W = 0$)

$$\therefore \quad \theta = \theta_0 . e^{\frac{-t}{T'}}$$

If $t = T'$, then $\theta = \theta_0 . e^{-1} \Rightarrow \theta = \frac{\theta_0}{e} = 0.368\ \theta_0$; $\therefore \theta = 0.368\ \theta_0$

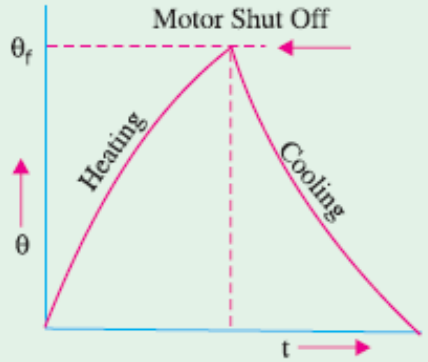
45.8. Cooling Time Constant

Cooling time constant is defined as the time required to cool machine down to 0.368 times the initial temperature rise above ambient temperature.

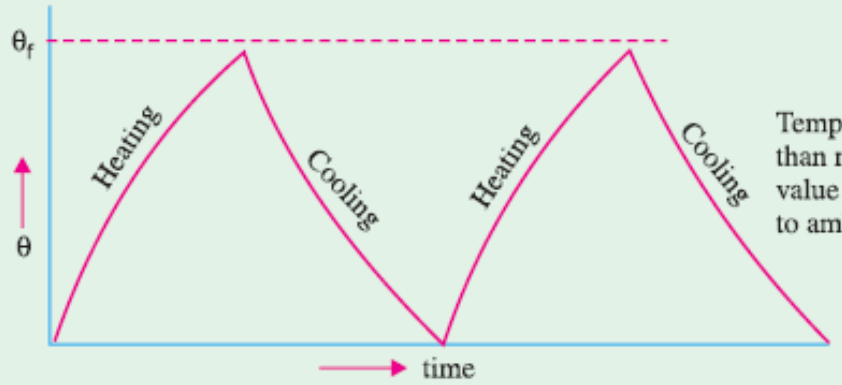
By putting different values of T' in $\theta = \theta_0 . e^{-t/T'}$

$\therefore$ After time t	=	T'	θ has fallen to	36.8% of θ_0
t	=	$2T'$	θ has fallen to	13.5% of θ_0
t	=	$3T'$	θ has fallen to	5% of θ_0

(*a*) Motor continuously worked on Full Load.

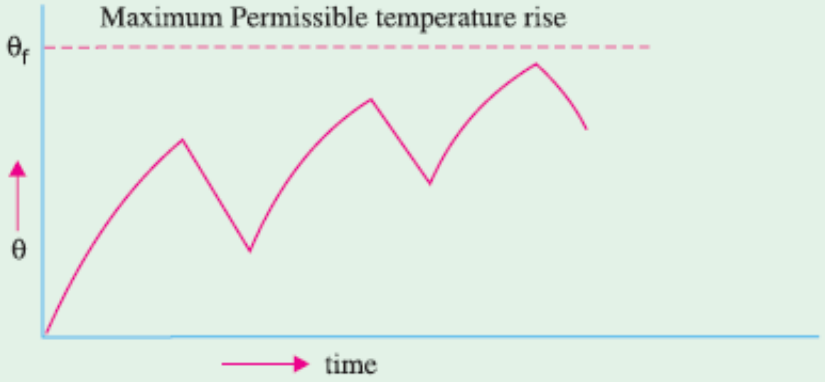


(*b*) Motor Run for short time



Temperature rise is less than maximum permissible value and the motor cooled to ambient temperature.

(*c*) Cooling period not sufficient to cool down the motor to its ambient temperature.



Example 45.9. *A 40 KW motor when run continuously on full load, attains a temperature of 35°C, above the surrounding air. Its heating time constant is 90 min. What would be the 1/2 hour rating of the motor for this temperature rise? Assume that the machine cools down completely between each load period and that the losses are proportional to square of the load,*

Solution.

Let 'P' KW be the ½ hour rating of the motor

θ_f – Final temperature rise at P K W

θ_f' – Final temperature rise at 40 KW

$\therefore$ Losses at P KW $\propto P^2$

Losses at 40 K W $\propto 40^2$

$$\Rightarrow \quad \frac{\theta_f}{\theta_f'} = \frac{\text{Losses at } P\text{KW}}{\text{Losses at } 40\text{KW}} = \left(\frac{P}{40}\right)^2 \quad \therefore \quad \theta_f = \left(\frac{P}{40}\right)^2 \theta_f'$$

As the machine cools down completely, for 'P' KW the equation will be

$$\theta = \theta_f \left(1 - e^{\frac{1}{T}}\right) \quad \text{where} \quad \theta_f = \left(\frac{P}{40}\right)^2 \times 35$$

$$\Rightarrow \quad 35 = \left(\frac{P}{40}\right)^2 \times 35 \left(1 - e^{-\frac{0.5}{1.5}}\right); \qquad \therefore \text{ P } = \textbf{75.13 KW}$$

THANK YOU