ELECTRIC DRIVES

Syllabus: Types of electric drives - choice of motor - starting and running characteristics - speed control - Temperature rise – particular applications of electric drives - types of industrial loads - Continuous – intermittent and variable loads - load equalization.

Electrical Drive: The combination of equipments to convert electrical energy into mechanical energy and to provide a control for this process is called 'Electrical Drive'.

The electrical drive mainly consists of Source, Power modulator, Motor, Load and Control unit. The block diagram of an electrical drive is as shown below

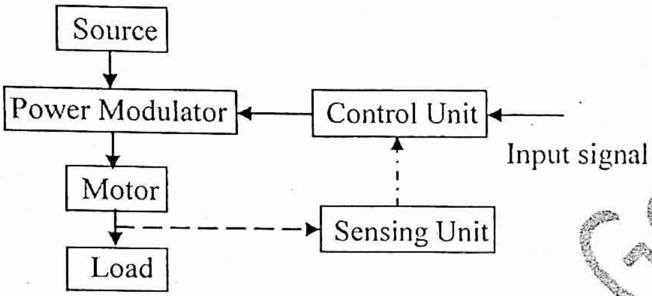


Fig-1. Block diagram of Electrical Drive

***Advantages of Electric Drive*:**

All modern industrial and commercial applications employ electric drive because of the following advantages :

- It is simple in construction and has less maintenance cost.
- Its speed control is easy and smooth.
- It is neat, clean and free from any smoke or flue gases.
- It can be installed at any desired convenient place thus affording more flexibility in the layout.
- It can be remotely controlled.
- Being compact, it requires less space.
- It can be started immediately without any loss of time.
- It has comparatively longer life.

Disadvantages of Electric Drive:

An electric drive system has two inherent disadvantages:

- Initial cost of the system is more.
- The drive comes to stop as soon as there is failure of electric supply .
- It cannot be used at far off places which are not served by electric supply.

Types (or) Classification of Electric Drives:

The electric drives are classified as three categories:

i) Group drive, ii) Individual drive and iii) Multi motor drive.

i) Group drive: In group drive, a single motor drives a number of machines through belts from a common shaft. It is also called line shaft drive. These type of drives are used in industrial applications like transportation systems, rolling mills, cementmills etc.

Advantages of group drive are :

- Saving in initial cost because one electrical motor is used. For example, practically, a 150-kW motor cost is much less than ten 15-kW motors needed for driving 10 separate machines.

- The efficiency and power factor of a group drive is more, since this drive runs at full-load.
- Group drive can be used with advantage in those industrial processes where there is a sequence of continuity in the operation.

Disadvantages: However, group drive is rarely used due to the following disadvantages:

- This type of drive does not give good appearance and is less safe to operate.
- Any fault occurred in the driving motor, all the driven equipment is idle. Hence, this system is unreliable.
- Speed control of individual drive is very complex.
- Noise level at working site is high.
- More amount of power is lost in energy transmitting mechanism.
- If all the machines driven by the line shaft do not work together, the main motor runs at reduced load. Consequently, it runs with low efficiency and with poor power factor.
- It is not suitable for constant speed applications like paper and textile industries.

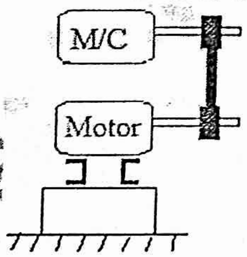
ii) Individual drive: In the case of an individual drive, each machine is driven by its own separate motor with the help of gears, pulley etc. Examples are domestic applications like Fans, centrifugal pumps, drilling machines, Electric hand tools etc.

Advantages:

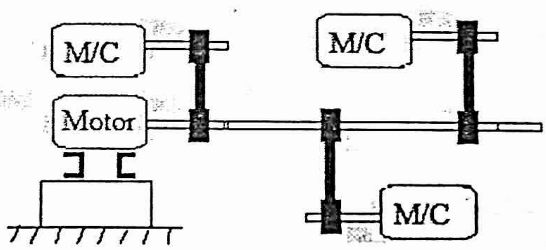
- Since each machine is driven by a separate motor, it can be run and stopped as desired.
- There is flexibility in the installation because of different machines.
- In case of motor fault, only its connected machine will stop whereas others will continue working without any disturbance.
- Each operator has full control of the machine which can be quickly stopped if an accident occurs.
- The absence of belts and line shafts greatly reduces the risk of accidents to the operating personnel.
- Maintenance of line shafts, bearings, pulleys and belts etc. is eliminated. Similarly there is no danger of oil falling on articles being manufactured.

Disadvantage

- The only disadvantage of individual drive is its initial high cost.



Individual drive



Group drive

iii) Multi-motor drives: In multi-motor drives separate motors are provided for actuating different parts of the driven mechanism. For example, in travelling cranes, three motors are used: one for hoisting, another for long travel motion and the third for cross travel motion.

- Multi-motor drives are commonly used in robots, paper mills, rolling mills, rotary printing presses and metal working machines etc.
- The use of Individual (or) Multi-motor drives introduces the automation in production processes, this result in increase of reliability and more safe in operation.

Factors for selection/choice of motor:

The selection/choice of an electric drive/motor depends mainly on the following factors.

i) Electrical characteristics

* Starting characteristics * Running characteristics * Speed control * Braking

ii) Mechanical considerations

* Type of enclosure * Type of bearings * Method of power transmission
* Type of cooling * Noise level

iii) Size and rating of motors

* Requirement for continuous, intermittent or variable load cycle * Overload capacity

iv) Steady state operation required

* Nature of speed-torque characteristics * Speed regulation * Speed range
* Efficiency * Duty Cycle * Speed fluctuations if any

v) Requirement related to the source

* Type of source i.e whether it is AC source or DC source
* Magnitude of voltage, voltage fluctuations, power factor, harmonics and its effects on other loads
* Ability to accept regenerative power.

vi) Cost

* Capital cost * Running cost * Maintenance cost if any

In addition to above factor, life, reliability, environment and location also effects the selection/ choice of an electric drive/motor.

Different Types of Industrial Load:

There are three different types of industrial loads under which electric motors are required to work. Those are (*i*) Continuous load (*ii*) Intermittent load and (*iii*) Variable or fluctuating load. The size of the motor depends mainly on

(i) The temperature rise (ii) The maximum torque developed by the motor.

(*i*) **Continuous Load:** In such cases, the calculation of motor size is simpler because the loads like pumps and fans require a constant power input to keep them operating. However, it is essential to calculate the KW rating of the motor correctly. If the KW rating of the motor is less than required load rating, the motor will overheat and consequently burn out. If KW rating is more than the required load rating, the motor will operate at lower efficiency and power.

(*ii*) **Intermittent Loads:** The intermittent loads are of two types:

(*a*) In this type of load, motor is loaded for a short time and then shut off for a sufficient long time, allowing the motor to cool down to room temperature as shown in Fig-2 (a). In such cases, a motor with a short time rating is used as in a kitchen mixie.

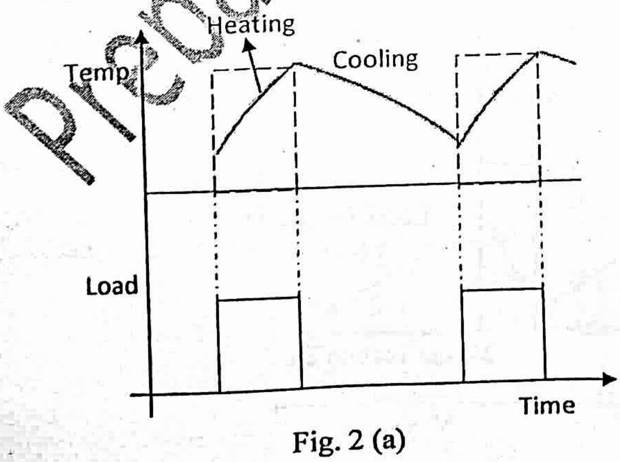


Fig. 2 (a)

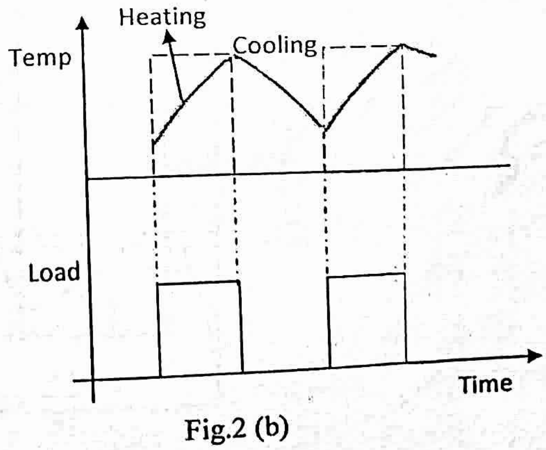


Fig.2 (b)

(*b*) In this type of load, motor is loaded for a short time and then it is shut off for a short time. The shut off time is so short that the motor cannot cool down to the room temperature as shown in Fig-2(b). In such cases, a suitable continuous or short-time rated motor is chosen which, when operating on a given load cycle, will not exceed the specified temperature limit.

(*iii*) **Variable Loads.** In the case of such loads, the most accurate method of selecting a suitable motor is to draw the heating and cooling curves as per the load fluctuations for a number of motors. The smallest size motor which does not exceed the permitted temperature rise when operating on the particular load cycle should be chosen for the purpose. However, a simpler but sufficiently accurate method of selection of a suitable rating of a motor is to assume that heating is proportional to the square of the current and hence the square of the load. The suitable continuous rating of the motor would equal the r.m.s. value of the load current.

Load Equalization:

In several industrial drives (like electrical hammers, rolling mills, reciprocating pumps etc) the load fluctuates between wide limits over a span of few seconds. It is required to smooth out the fluctuating loads, otherwise during peak load period it will draw heavy current from the supply and produces large voltage drop, power losses and more cross section area of cables and wires.

The process of smoothing out the fluctuations in load is known as load equalization.

The process of load equalization involves the storage of energy during light load and releases stored energy during the heavy load period. The load equalization is achieved by using ***fly wheel.***

Use of Flywheels

In the method of load equalization using fly wheel, the fly wheel is mounted on the motor shaft if the speed of the motor is not reversed. In case of speed reversal, the fly wheel is mounted on motor-generator set. In order that the fly wheel operates effectively, the motor must have drooping speed characteristics, that is, there should be a drop in speed as the load comes to enable flywheel to give up its stored energy. During the light load condition, the motor draws more energy than load required. The surplus energy taken is stored as kinetic energy in the fly wheel and this stored kinetic energy is released during heavy load period. The load torque required, motor torque developed and speed variations w.r.t time is as shown Fig - 3.

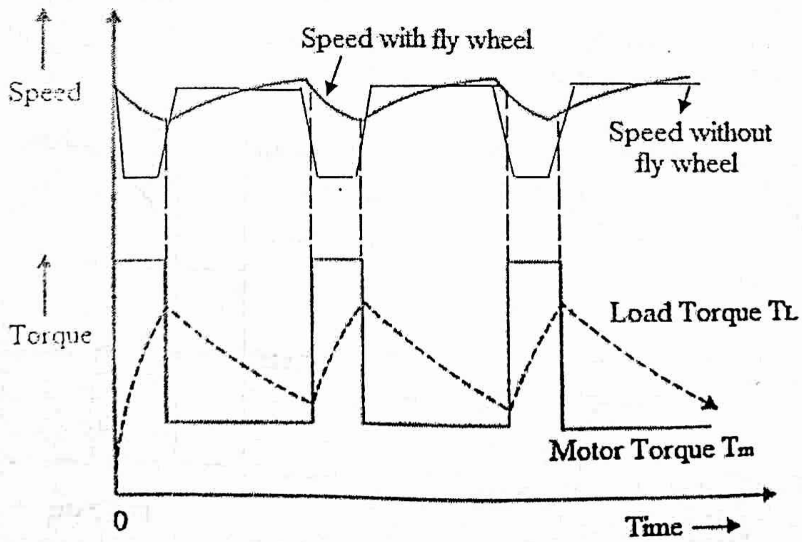


Fig – 3 : Torque developed and Speed variations

Heating of Motor or Temperature Rise

In motor, the rise in temperature is mainly due to the heat generated by the losses. The expression for this temperature rise is obtained by equating the heat is generated by the losses to the rate at which heat is absorbed by the motor for raising the temperature of motor and the rate of heat dissipation to cooling medium.

Heat generation in motor = Rate of heat absorption by the motor + Rate of heat dissipation to cooling medium.

Assumptions

- Losses remains constant during temperature rise.
- Heat dissipation is proportional to the temperature difference between motor and cooling medium.
- Temperature of cooling medium remains constant.

Let

Q = Heat generated in motor due to power loss; m = Weight of motor (kg)

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

ms = 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 λ = Rate of heat dissipation in Watts /°C rise in temperature for a motor.

Heat generation in motor = Rate of heat absorption by the motor + Rate of heat dissipation to cooling medium.

$$Q = ms\frac{d\theta}{dt} + A\lambda\theta \quad \text{------------------------------ (1)}$$

$$Q - A\lambda\theta = ms\frac{d\theta}{dt} \rightarrow A\lambda\left(\frac{Q}{A\lambda} - \theta\right) = ms\frac{d\theta}{dt}$$

$$\frac{Q}{A\lambda} - \theta = \frac{ms}{A\lambda}\frac{d\theta}{dt}$$

$$\frac{d\theta}{\left[\frac{Q}{A\lambda} - \theta\right]} = \frac{dt}{\left[\frac{ms}{A\lambda}\right]} \rightarrow \frac{d\theta}{\left[\frac{Q}{A\lambda} - \theta\right]} = \frac{A\lambda}{ms}dt$$

Integrating on both sides we get,

$$ln\left(\frac{Q}{A\lambda} - \theta\right) = -\frac{A\lambda}{ms}t + C \quad \text{---------------------- (2)}$$

At $t = 0$, $\theta = \theta_1$. Substituting the values of t and θ in equation (2)

From equation (2), we can get $C = ln\left(\frac{Q}{A\lambda} - \theta_1\right)$

Substitute 'C' in equation (2), we get

$$ln\left(\frac{Q}{A\lambda} - \theta\right) = -\frac{A\lambda}{ms}t + ln\left(\frac{Q}{A\lambda} - \theta_1\right)$$

$$ln\left(\frac{Q}{A\lambda} - \theta\right) - ln\left(\frac{Q}{A\lambda} - \theta_1\right) = -\frac{A\lambda}{ms}t$$

$$ln\left(\frac{\frac{Q}{A\lambda}-\theta}{\frac{Q}{A\lambda}-\theta_1}\right) = -\frac{A\lambda}{ms}t$$

Taking anti logarithm on both sides, $\dfrac{\frac{Q}{A\lambda}-\theta}{\frac{Q}{A\lambda}-\theta_1} = e^{-\frac{A\lambda}{ms}t}$

$$\frac{Q}{A\lambda}-\theta = \left(\frac{Q}{A\lambda}-\theta_1\right)e^{-\frac{A\lambda}{ms}t}$$

$$\theta = \frac{Q}{A\lambda}-\left(\frac{Q}{A\lambda}-\theta_1\right)e^{-\frac{A\lambda}{ms}t} \quad \text{-----------------(3)}$$

When, the final temperature rise of θ_f is reached i.e $\theta = \theta_f$, total heat generated is dissipated from the cooling surface. From equation (1) $Q = A\,\lambda\,\theta_f$ → $\theta_f = \dfrac{Q}{A\lambda}$

Let heat time constant = $\dfrac{ms}{A\lambda} = \dfrac{1}{T}$

Then equations (3) becomes, $\boxed{\text{Temperature rise, } \theta = \theta_f - (\theta_f - \theta_1)\,e^{-t/T}}$

If start form cold, then $\theta_1 = 0$ $\boxed{\text{Temperature rise, } \theta = \theta_f\,(1 - e^{-t/T})}$

Heating Time Constant

Heating time constant of motor is defined as the time required to heat up the motor upto 63.3% of its final temperature rise i.e $\theta = \theta_f (1 - e^{-t/T})$

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

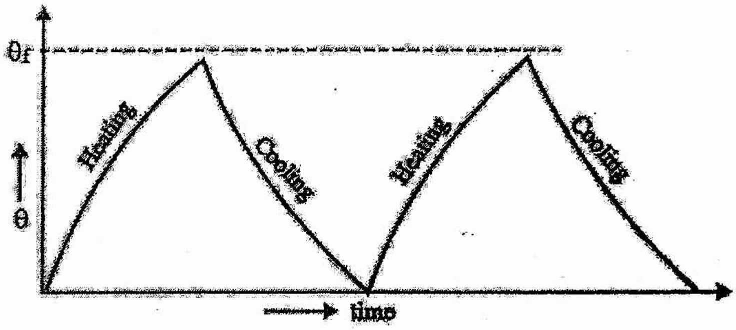
After time $t = T$, θ reaches to 63.3 % of θ_f

$t = 2T$, 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



Practically, T = Heating time constant is 90 min for motors upto 20 H.P and 300 min for larger motors.

Prob: The heating and cooling time constants of a motor are 1 hour and 2 hours respectively. Final temperature rise attained is 100°C. This motor runs at full load for 30 min and then kept idle for 12 min. and the cycle is repeated indefinitely. Determine the temperature rise of motor after one cycle.

Solve: Heat time constant T =1 hour = 60min; Motor time constant t = 30min; Final Temp. θ_f = 100°C

We have temperature rise, $\theta = \theta_f\left(1-e^{\frac{-t}{T}}\right) = 100\left(1-e^{\frac{-30}{60}}\right) = 39.34°C$

Also $\theta = \theta_0\,e^{-\frac{t}{T'}}$; Temperature rise of motor after 1 cycle = $39.34\,e^{\frac{-12}{120}} = 35.6°C$

Particular applications of Electric Drives

The motors for different industrial drives/applications are listed as shown in below table with their characteristics.

Type of motor	Characteristics	Industrial drives/applications
DC Shunt Motor	* Medium starting torque * Nearly constant speed	- Laths, Vacuum cleaners - Elevators, Conveyers, Grinders - Small printing presses -Wood working machines - Laundry washing machines etc
DC Series Motor	* High starting torque * Variable speed	- Electric Locomotive - Steel, Rolling mills - Lifts, Cranes, Hoists etc
DC Compound Motor	* High starting torque * Variable speed	- Compresses, Elevators - Shearing machines, Conveyers - Variable head centrifugal pumps
3 - Ph Synchronous Motor	* Speed remains constant irrespective of load variations	- Motor-Generator set - Air compressors - Rolling mills - Paper and Cement industries
Squirrel Cage Induction Motor	* Simple, rugged construction * High overload capacity	- Water pumps, Tube wells, Drills - Lathes, Grinders, Fans and Blowers - Compressors, Polishers etc
Slip Ring Induction Motor	* High starting torque * More overload capacity * Speed can be changed upto 50% of its normal speeds.	- Lifts, Pumps, Line shafts, Elevators - Printing presses, Compressors etc
1 – Ph Synchronous Motor	* Constant speed	- Recording instruments, clocks - All kinds of timing devices
1 – Ph Series Motor	* High starting torque * Wide range speed control	- Refrigerators, Vacuum cleaners etc
Capacitor Start Induction Motor	* Moderately high starting torque * Fairly constant speed	- Compressors, Refrigerators - Small portable hoists
Capacitor Start - Run Motor	* Moderately high starting torque * Fairly constant speed * Better power factor * Higher efficiency	- Drives requires noise less operation
Repulsion Motor	* High starting torque * Wide range speed control * High speed at heavy loads	- Coil winding machines

Prob: A 200V series motor runs at 1000 r.p.m. and takes 20A. Armature and field resistance is 0.4 Ω. Calculate the resistance to be inserted in series so as to reduce the speed to 800 r.p.m., assuming torque to vary as cube of the speed and unsaturated field.

Ans: Additional resistance required = 6.3 – 0.4 = 5.9 Ω

Starting and Running Characteristics:

DC Motors:

i) DC Shunt Motor:

In DC shunt motor, the field winding is connected across the armature. Since the field current I_{sh} (V/R_{sh}) is constant, the shunt field current is constant.

Speed (N) Vs Armature current (Ia) characteristics:

We have back emf $E_b = \frac{\phi ZN}{60}\frac{P}{A}$, the speed $N \alpha E_b/\phi$. Since flux ϕ is constant, the speed $N \alpha E_b$ or speed $N \alpha (V - I_aR_a)$. If I_aR_a is negligible, the speed is constant for all loads as shown in figure (a). But practically the armature current increases with increase of the load. With the increase of I_a, I_aR_a drop increases hence the speed falls slightly. Since there no lot of change in speed from no load to full load, the dc shunt motor has good speed regulation.

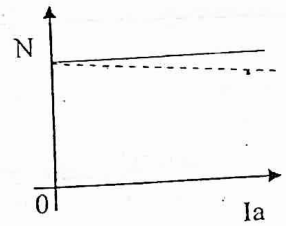


Figure (a)

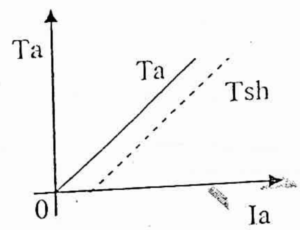


Figure (b)

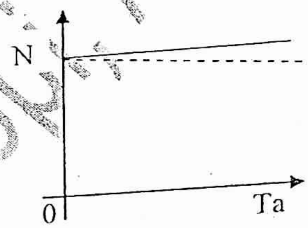


Figure (c)

Armature torque (Ta) Vs Armature current (Ia) characteristics:

The armature torque of the shunt motor $T_a \alpha \phi Ia$. Since the flux is constant, $T_a \alpha Ia$. From above equation, the torque – armature current characteristics are straight line passing through origin as shown in figure (b). From figure (b) it is clear that, the dc shunt motor take more current to start on heavy load. So the *shunt motor should not start on heavy load.*

Speed (N) Vs Armature torque (Ta) characteristics:

The armature torque is $T_a = 9.55\frac{E_bI_a}{N}$ i.e $T_a \alpha 1/N$. When load increases the speed decreases but torque increases as shown in figure (c).

Since the dc shunt motor runs at constant speed, it is used in line shafts in group drives, lathes, drilling machines, grinders etc.

ii) DC Series Motor:

In DC series motor, the field winding is connected in series with the armature. Since the field current $I_{se} = I_a$, the series field current is viable up to pole saturation. After pole saturation the flux is constant.

Speed (N) Vs Armature current (Ia) characteristics:

In dc series motor, the speed $N \alpha E_b/\phi$, or speed $N \alpha V - I_a(R_a+R_{se})/\phi$. When the load increases, the back emf falls due to $I_a(R_a+R_{se})$ drop but flux ϕ increases with increase of I_a upto saturation because $I_a \alpha \phi$. Thus before the saturation the speed-current characteristics are hyperbola as shown in figure (a). After saturation flux is constant then the speed $N \alpha E_b$, or speed $N \alpha V - I_a(R_a+R_{se})$ i.e speed falls.

From figure (a), at no load the flux is minimum hence the speed is very high since $N \alpha 1/\phi$. Therefore a *series motor should not run at no load.*

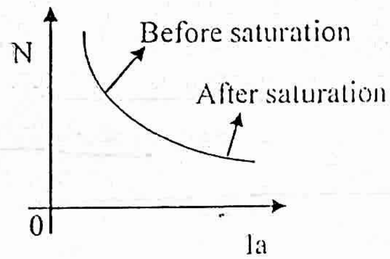


Figure (a)

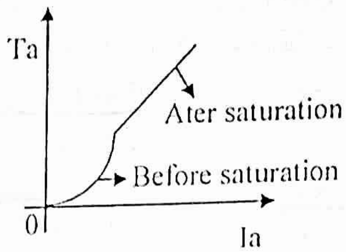


Figure (b)

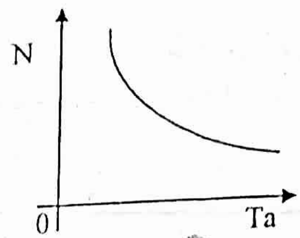


Figure (c)

Armature torque (Ta) Vs Armature current (Ia) characteristics:

The armature torque of the shunt motor $T_a \alpha \phi I_a$. Since the flux depends on I_a, $T_a \alpha I_a^2$. It is true upto field pole saturation i.e before field pole saturation armature torque proportional to square of the armature current, hence the characteristics are parabola. After saturation, the flux ϕ is constant hence $T_a \alpha I_a$. Now the characteristics are straight line as shown in figure (b).

Speed (N) Vs Armature torque (Ta) characteristics:

The armature torque is $T_a = 9.55 \frac{E_b I_a}{N}$ i.e $T_a \alpha I_a/N$. At no load or light load, I_a is small, torque small but speed is high. As load increases, I_a increases, torque also increases but speed falls rapidly as shown in figure (c).

Since the dc series motor has high starting torque, it is used in electric traction, cranes, lifts, elevators, sewing machines, fans and air compressors etc.

AC Motors:

i) Induction Motor:

Since the speed of the synchronous motor is constant irrespective of load fluctuations, it has flat speed-torque characteristics. The most of the loads in industry or on power system are 3 - Ph Induction Motors, hence we study here the speed-torque characteristics of 3 - Ph Induction Motors.

The expression for torque developed by the 3-Ph induction motor is

$$\text{Torque} = K \frac{sE_{2s}^2 R_{2s}}{R_{2s}^2 + (sX_{2s})^2} \text{ N-m} \quad \text{------- (1)}$$

The torque – slip characteristics of a 3-ph induction motor can explain as follows:

(i) When the rotor speed is equal to synchronous speed i.e $N_r = N_s$, Slip (s) = 0 and from equation (1) the torque is zero.

(ii) When the load on the motor is increases, the speed decreases and slip increases. The value of sX_{2s} is very small compared to R_2 and is neglected for constant rotor emf E_2.

From equation (1) $\quad \text{Torque} = K \frac{s R_{2s}}{R_{2s}^2} \rightarrow$ Torque α slip(s)

Hence for low value of slip, the torque – slip curve is represented as a straight line

As the load increases further, the speed decreases and slip increases. This result in increasein torque and reaches to maximum when slip = R_{2s} / X_{2s}.

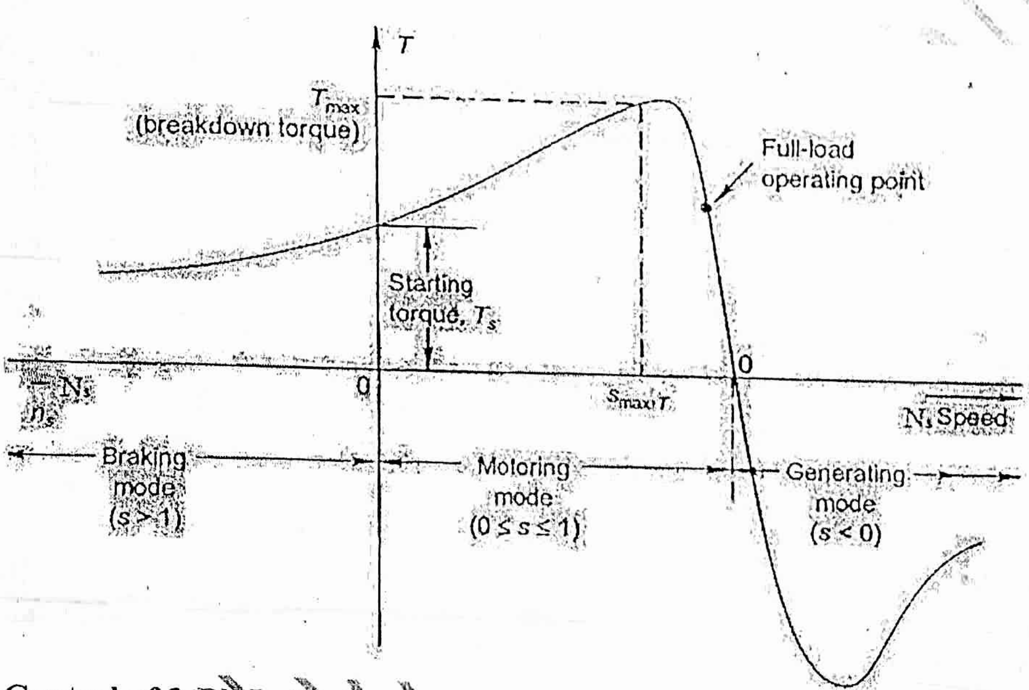
(iii) With the increase load beyond maximum torque (T_{max}), the slip increases further. Now the value of sX_2 is more compared to R_2 and R_2 is neglected, so

From equation (1) Torque = K $\frac{s}{s^2 X_{2s}^2}$ or Torque $\alpha \frac{1}{slip(s)}$

When s is positive i.e $0 < s < 1$: The motor speed lies between zero and synchronous speed and the direction rotation of rotor is same as the stator field. The power P is positive and machine act as motor.

When s is negative i.e $s < 0$: The rotor rotates in same direction as the stator field but at a speed higher than the synchronous speed. Since the rotor speed is more than the synchronous speed, the machine act as generator.

When s is positive i.e $s > 1$: The rotor rotate in opposite direction to the direction of rotation of stator field. This indicate that the rotor is decelerating, it is called electrical brake. The torque – speed curves are drawn as shown in below Fig.



Speed Control of 3-Ph Induction Motor:

The rotor speed of 3-Ph Induction Motor is given by $N_r = (1 - S)N_s$, Where $N_s = 120f/P$. The torque produced by the induction motor is assumed as constant for speed control of induction motor. From this equation, the speed of motor can be controlled by controlling the stator side or rotor side parameters i.e

a) Reduced supply voltage
b) Variable frequency
} Control from Stator side

c) Addition of Rotor resistance
d) Voltage injection in rotor circuit
} Control from Rotor side

Reduced supply voltage:

By changing the supply voltage the speed of the induction motor changes. Let the full load torque of the induction motor as $T_{fl} = K \frac{sE_{2s}^2 R_{2s}}{R_{2s}^2 + (sX_{2s})^2}$.

Since the slip is low so $(sX_{2s})^2$ is very low compared to R_{2s}^2, hence $(sX_{2s})^2$ is neglected. Therefore $T \alpha S E_{2s}^2$, but $E_{2s} \alpha V$. Therefore $T \alpha S V^2$ or for the given torque, slip (S) $\alpha 1/V^2$ i.e as the supply voltage changes, slip (S) changes which result in change in rotor speed (N_r). This method is simple and easy but it is rarely used because a large change in voltage is required for small change in speed. The torque - slip characteristics for variations voltages are as shown in Fig (a).

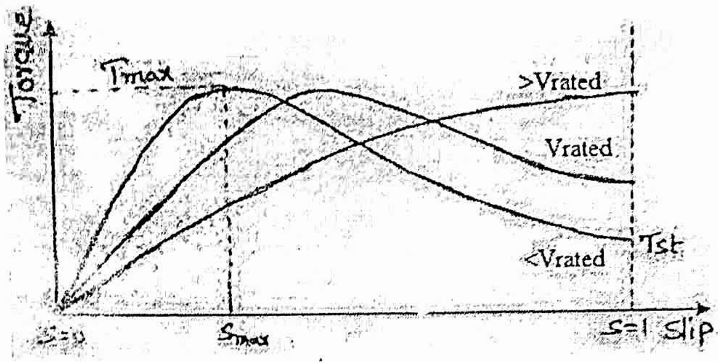


Fig. a) Reduced supply voltage control

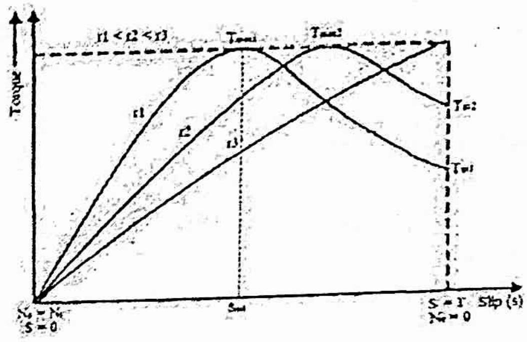


Fig. b): Addition of rotor resistance control

Variable frequency:

The speed of the induction motor is a function of frequency f and is given by f = NP/120. The variable frequency can be obtained by separate generator or by speed changer. For an induction motor $V \alpha f \phi$ or $\frac{V}{f} = K\phi$. So in order to maintain the constant flux ϕ, $\frac{V}{f}$ should be kept constant. The variable frequency control provides speed control over the range 10:1 to 12:1 with high smooth control.

Addition of Rotor resistance:

This method of speed control is suitable for only slip ring induction motor because in squirrel cage induction motor, the rotor resistance cannot be varied. We know that Slip = $\frac{\text{Rotor cu losses}}{\text{Rotor input}}$. By increasing the rotor resistance, rotor cu losses increases, this result in increase in slip and decrease in speed and vice versa as shown in Fig. (b).

The main advantages this method is by adding additional resistance to rotor circuit

(i) The starting current drown by the motor is limited.
(ii) Starting torque increases.
(iii) Speed control is possible.

The disadvantage of this method is that the motor effiency decreases because of more rotor culosses.

Voltage injection in rotor circuit:

Let the supply voltage, frequency and load torque as constant, the applied voltage $V_1 \approx E_1 = K\phi$ = constant. The induced emf in the rotor is sE_{2S} where 's' is slip and E_{2S} is the rotor induced emf at standstill. The rotor current $I_2 = \frac{sE_{2S}}{\sqrt{R_{2s}^2 + (sX_{2S})^2}}$.

Practically, $R_2^2 >> (sX_2)^2$ therefore current I_2 is in-phase with E_{2S}, so $I_2 = \frac{sE_{2S}}{R_{2s}}$.

Suppose if an emf E_1 (with slip frequency) is in phase opposition with E_{2S} is injected into the rotor, the speed cannot change instantaneously because of rotor inertia and the net rotor emf is $E_{2S} - E_1$. This result in decrease in rotor current, torque and speed. Similarly, if the injected emf is in phse with the rotor induced emf, the speed of the motor increases.

Speed Control of DC Motor :-

Factors Controlling DC Motor Speed:

We know that back emf $(E_b) = \frac{\phi Z N}{60} \times P/A$ i.e Back emf $E_b \propto \phi N$ (or)

Speed of the DC Motor $N \propto \frac{E_b}{\phi}$ (or) $N \propto \frac{V - I_a R_a}{\phi}$

From the above equations, the speed can be controlled by varying

(i) Flux per pole (ϕ) – called as Flux Control Method.

(ii) Armature resistance (R_a) – called as Armature Control method (or) Rheostatic Control.

(iii) Applied voltage (V) – called as voltage control method.

Speed Control of DC Shunt motor :-

(i) Flux Control Method :-

We have the speed $(N) \propto \frac{1}{\phi}$ i.e If the flux decreases, the speed increases and vice versa. The flux of the dc motor can be changed by changing I_{sh} with the help of shunt field Rheostat as shown in figure ⓐ.

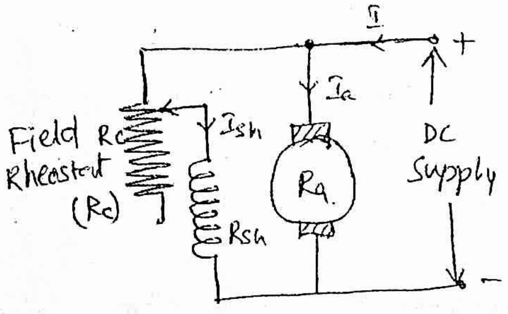


figure ⓐ

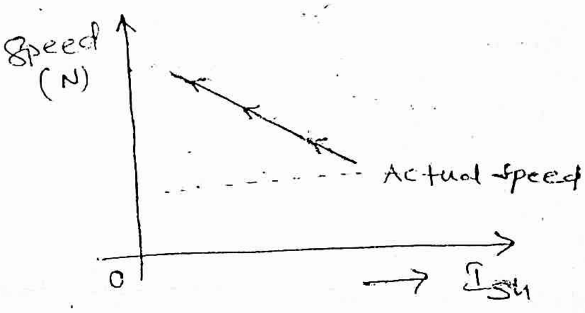


fig ⓑ

Initially the field Rheostat position is in minimum, shunt field current $I_{sh} = \frac{V}{R_{sh}}$ which is more, hence the shunt field flux(ϕ) also more. This results in low speed at starting. If the shunt field resistance is increased, the shunt field current $\left(I_{sh} = \frac{V}{R_{sh}+R}\right)$ decrease hence the speed increases. The speed-current char are as shown in fig ⓑ.

Advantages:

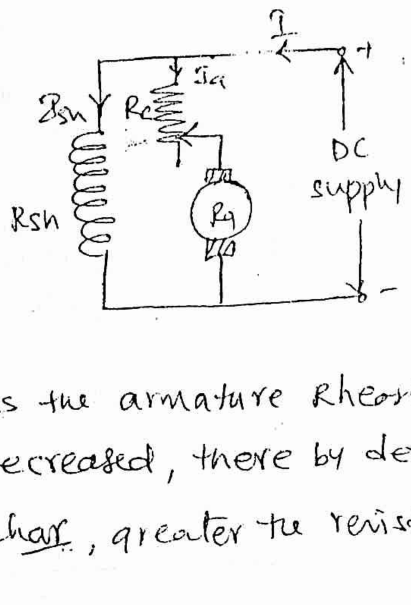
1) Since the shunt field current is small, the power losses ($I_{sh}^2 R_{sh}$) are also small
2) It is efficient method because of low power losses
3) This method is Easy & convienient.

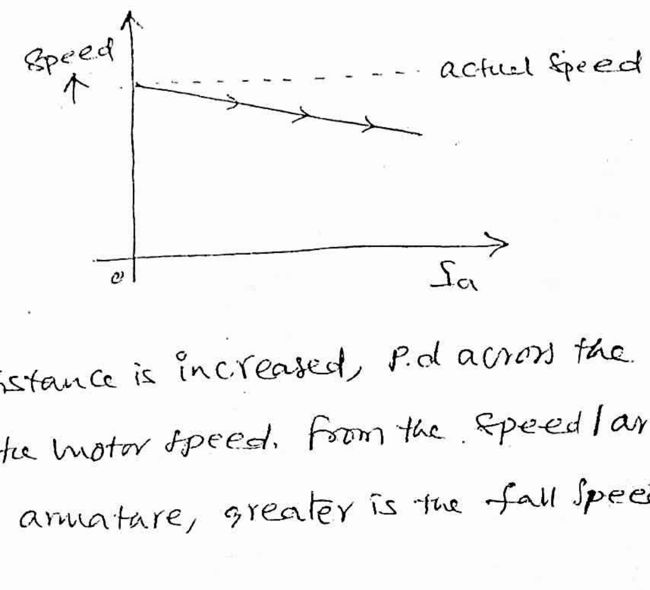
Disadvantages:

1) This method is applicable for only limited range of speed control.
2) only above actual speeds will get with this method.

Armature control Method (or) Rheostatic Method :-

This method is used when the speeds below the actual speeds required. We have $N \propto \frac{E_b}{\phi}$ (or) $N \propto \frac{V - I_a R_a}{\phi}$. Let the current through the shunt field wdg is constant (hence ϕ is constant) and applied voltage (V) is constant. Now by changing the armature current the speed can be changed. To change it armature current, a variable Rheostat is connected in series with the Armature as shown in fig (i).





As the armature Rheostat resistance is increased, P.d across the armature decreased, there by decreasing the motor speed. From the speed/armature current char, greater the resistance in armature, greater is the fall speed.

Dis Advantages:

1) Large amount of power is wasted in external armature resistance.
2) This method is restricted to get speeds below its actual (or) Normal speed
3) This speed control method is suitable for small size motors only.

Speed Control of DC series Motor :- (i) Field (or) Flux Control method:-

The variations of field current (or) field flux (ϕ_{se}) in a series motor is obtained by (i) Field diverter method (ii) Armature diverter method (iii) Tapped field control method (iv) parallel field coils Method

... method :-

A variable resistance which is connected across the series field wdg, as shown in figure, is called field diverter. The figure (a) shows the connection diagram for field diverter method. By adjusting the resistance of field diverter any desired current is allowed through the diverter. Hence the flux is decreased and speed is increased since Speed (N) $\propto \frac{1}{\phi}$.

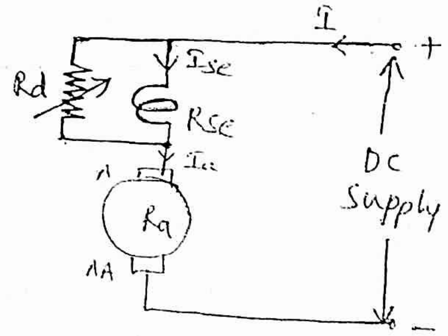


fig (a)

Tapped field Control Method :-

~~The No of series field turns~~

We know the magnetic flux (ϕ) = $\frac{MMF}{Reluctance}$. MMF is the product of No. of turns & current through the wdg. If No. of turns are decreased, the MMF value decreases hence the flux decreases. Since the speed is inversly proportional to flux, speed increases.

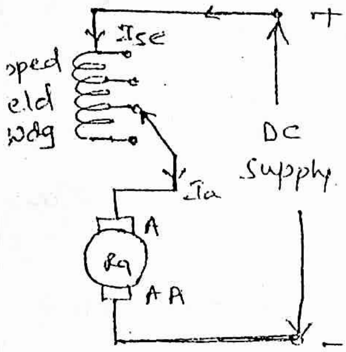


fig (b)

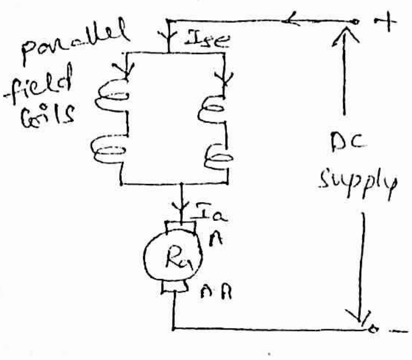


fig (c)

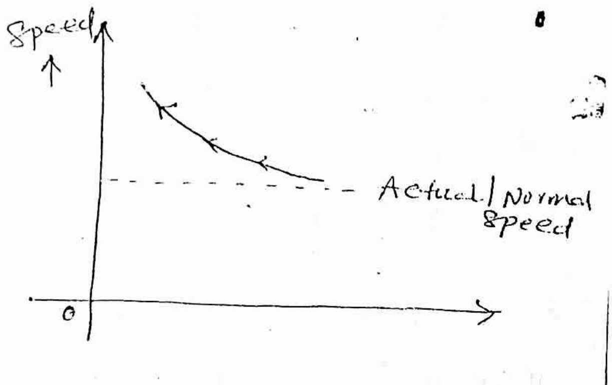


fig (d)

Advantages

1) This method is economical and convenient

2) The power wastage in this method is less, so it is efficient method.

Drawbacks (or) limitations :-

This method will gives the speed above normal / actual speeds only.

Armature Control (or) Rheostatic Method :-

We have back emf $E_b \propto N\phi$. Speed $(N) \propto \frac{E_b}{\phi} \propto \frac{V - I_a(R_a + R_{se})}{\phi}$. The current through the armature is changed by changing the armature resistance. This can be obtained by placing a variable rheostat in series with armature as shown in fig (a). The figure (b) shows the variation in speed w.r.t the armature current.

By increasing the resistance (R_c) in series with the armature, the applied voltage across armature terminal can be decreased.

With reduced voltage across armature, the speed is reduced.

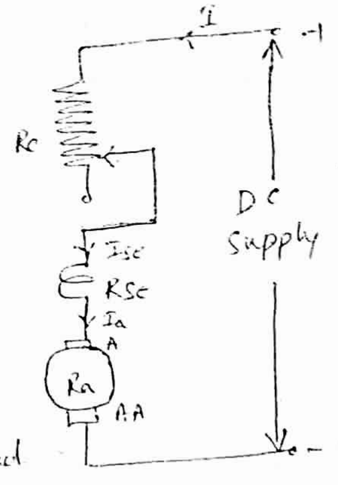


fig (a)

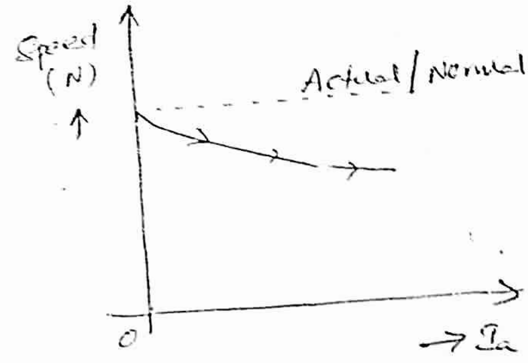


fig (b)

This method mainly suffers from (i) large amount of power losses

(ii) This method will gives the speeds below its normal/actual speeds.

Prob A 200V dc series motor runs at 1000 rpm and takes 20A. Combined resistance armature & field is 0.4 Ω. Calculate the resistance to be inserted in series so as to reduce the speed to 80%, assume torque varies as square of the speed.

Solve

For series motor $I_L = I_{a1} = 20A$; $R_a + R_{se} = 0.4\,\Omega$; Speed $N_1 = 1000$ rpm

Speed is reduced to 80% i.e $N_2 = 0.8 N_1 = 0.8 \times 1000 = 800$ rpm

Given that $T \propto N^2$ i.e $\frac{T_2}{T_1} = \left(\frac{N_2}{N_1}\right)^2$ —(1) but $T_a \propto \phi I_a$ i.e $\frac{T_{a2}}{T_{a1}} = \left(\frac{I_{a2}}{I_{a1}}\right)^2$

from eq (1) & (2) $\left(\frac{N_2}{N_1}\right)^2 = \left(\frac{I_{a2}}{I_{a1}}\right)^2 \Rightarrow I_{a2} = \frac{N_2}{N_1} I_{a1} = \frac{800}{1000} \times 20 = 16A$

Back emf $E_{b1} = V - I_{a1}(R_a + R_{se}) = 200 - 20 \times 0.4 = 192V$

$E_{b2} = V - I_{a2}(R_a + R_{se} + R_c) = 200 - 16(0.4 + R_c)$

$= 200 - 6.4 + 16R_c$

$= 193.6 - 16R_c$

but $N \propto \frac{E_b}{\phi} \Rightarrow \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \cdot \frac{\phi_1}{\phi_2} = \frac{E_{b2}}{E_{b1}} * \frac{I_{a1}}{I_{a2}}$ $(\because \phi \propto I_a)$

$\frac{800}{} = 193.6 + 16R_c * \frac{20}{}$