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C H A P T E R 44

INDUSTRIAL APPLICATIONS OF ELECTRIC MOTORS

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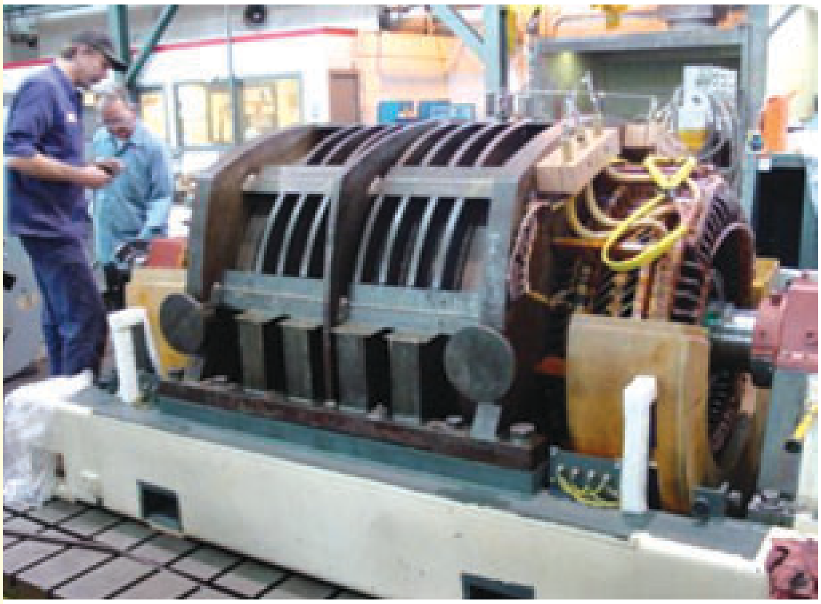

The above figure shows a squirrel cage motor. In industries electric drive is preferred over mechanical drive, because electric drive has the advantages of quick start, high torques and comparatively hassle free operation

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44.1. Advantages of Electric Drive

Almost all modern industrial and commercial undertakings employ electric drive in preference to mechanical drive because it possesses the following advantages :

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

However, electric drive system has two inherent disadvantages :

1. It comes to stop as soon as there is failure of electric supply and
2. It cannot be used at far off places which are not served by electric supply.

However, the above two disadvantages can be overcome by installing diesel-driven dc generators and turbine-driven 3-phase alternators which can be used either in the absence of or on the failure of normal electric supply.

44.2. Classification of Electric Drives

Electric drives may be grouped into three categories : group drive, individual drive and multimotor 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. In the case of an indvidual drive, each machine is driven by its own separate motor with the help of gears, pulley etc. 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. Multimotor drives are commonly used in paper mills, rolling mills, rotary printing presses and metal working machines etc.

Each type of electric drive has its own advantages and disadvantages. The group drive has following advantages :

1. It leads to saving in initial cost because one 150-kW motor costs much less than ten 15-kW motors needed for driving 10 separate machines.
2. Since all ten motors will seldomly be required to work simultaneously, a single motor of even 100-kW will be sufficient to drive the main shaft. This diversity in load reduces the initial cost still further.
3. Since a single large motor will always run at full-load, it will have higher efficiency and power factor in case it is an induction motor.
4. Group drive can be used with advantage in those industrial processes where there is a sequence of continuity in the operation and where it is desirable to stop these processes simultaneously as in a flour mill.

However, group drive is seldom used these days due to the following disadvantages :

1. Any fault in the driving motor renders all the driven equipment idle. Hence, this system is unreliable.
2. 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.

3. Considerable amount of power is lost in the energy transmitting mechanism.
4. Dlexibility of layout of different machines is lost since they have to be so located as to suit the position of the line shaft.
5. The use of line shaft, pulleys and belts etc. makes the drive look quite untidy and less safe to operate.
6. It cannot be used where constant speed is required as in paper and textile industry.
7. Noise level at the worksite is quite high.

44.3. Advantages of Individual Drive

It has the following advantages :

1. Since each machine is driven by a separate motor, it can be run and stopped as desired.
2. Machines not required can be shut down and also replaced with a minimum of dislocation.
3. There is flexibility in the installation of different machines.
4. In the case of motor fault, only its connected machine will stop whereas others will continue working undisturbed.
5. The absence of belts and line shafts greatly reduces the risk of accidents to the operating personnel.
6. Ach operator has full control of the machine which can be quickly stopped if an accident occurs.
7. Maintenance of line shafts, bearings, pulleys and belts etc. is eliminated. Similarly there is no danger of oil falling on articles being manufactured–something very important in textile industry.

The only disadvantage of individual drive is its initial high cost (Ex 44.1). However, the use of individual drives and multimotor drives has led to the introduction of automation in production processes which, apart from increasing the productivity of various undertakings, has increased the reliability and safety of operation.

Example 44.1. *A motor costing Rs. 10,000/- is used for group drive in a certain installation. How will its total annual cost compare with the case where four individual motors each costing Rs. 4000/- were used ? With group drive, the energy consumption is 50 MWh whereas it is 45 MWh for individual drive. The cost of electric energy is 20 paise/kWh. Assume depreciation, maintenance and other fixed charges at 10% in the case of group drive and 15 per cent in the case of individual drive.*

Solution. Group Drive

Capital cost = Rs. 10,000/-

Annual depreciation, maintenance
and other fixed charges = 10% of Rs. 10,000 = Rs. 1,000/-

Annual cost of energy = Rs. $50 \times 10^3 \times (20/100)$ = Rs. 10,000/-

Total annual cost = Rs. 1,000 + Rs. 10,000 = **Rs. 11,000/-**

Individual Drive

Capital cost = $4 \times$ Rs. 4000 = Rs. 16,000/-

Annual depreciation, maintenance
and other fixed charges = 15% of Rs. 16,000 = Rs. 2400/-

Annual cost of energy = Rs. $45 \times 10^3 \times (20/100)$ = Rs. 9000/-

Total annual cost = Rs. 9000 + Rs. 2400= **Rs. 11,400/-**

It is seen from the above example that individual drive is costlier than the group drive.

44.4. Selection of a Motor

The selection of a driving motor depends primarily on the conditions under which it has to operate and the type of load it has to handle. Main guiding factors for such a selection are as follows :

(*a*) Electrical characteristics

1. Starting characteristics
2. Running characteristics
3. Speed control
4. Braking

(*b*) Mechanical considerations

1. Type of enclosure
2. Type of bearings
3. Method of power transmission
4. Type of cooling
5. Noise level

(*c*) Size and rating of motors

1. Requirement for continuous, intermittent or variable load cycle
2. Overload capacity

(*d*) Cost

1. Capital cost
2. Running cost

In addition to the above factors, one has to take into consideration the type of current available whether alternating or direct. However, the basic problem is one of matching the mechanical output of the motor with the load requirement *i.e.* to select a motor with the correct speed/torque characteristics as demanded by the load. In fact, the complete selection process requires the analysis and synthesis of not only the load and the proposed motor but the complete drive assembly and the control equipment which may include rectification or frequency changing.

44.5. Electrical Characteristics

Electrical characteristics of different electric drives have been discussed in Vol. II of this book entitled "A.C. and D.C. Machines".

44.6. Types of Enclosures

The main function of an enclosure is to provide protection not only to the working personnel but also to the motor itself against the harmful ingress of dirt, abrasive dust, vapours and liquids and solid foreign bodies such as a spanner or screw driver etc. At the same time, it should not adversely affect the proper cooling of the motor. Hence, different types of enclosures are used for different motors depending upon the environmental conditions. Some of the commonly used motor enclosures are as under :

1. Open Type. In this case, the machine is open at both ends with its rotor being supported on pedestal bearings or end brackets. There is free ventilation since the stator and rotor ends are in free contact with the surrounding air. Such, machines are housed in a separate neat and clean room. This type of enclosure is used for large machines such as d.c. motors and generators.

2. Screen Protected Type. In this case, the enclosure has large openings for free ventilation. However, these openings are fitted with screen covers which safeguard against accidental contacts and rats entering the machine but afford no protection from dirt, dust and falling water. Screen-protected type motors are installed where dry and neat conditions prevail without any gases or fumes.

3. Drip Proof Type. This enclosure is used in very damp conditions. *i.e.* for pumping sets. Since motor openings are protected by over-hanging cowls, vertically falling water and dust are not able to enter the machine.

4. Splash-proof Type. In such machines, the ventilating openings are so designed that liquid or dust particles at an angle between vertical and 100° from it cannot enter the machine. Such type of motors can be safely used in rain.

5. Totally Enclosed (TE) Type. In this case, the motor is completely enclosed and no openings are left for ventilation. All the heat generated due to losses is dissipated from the outer surface which is finned to increase the cooling area. Such motors are used for dusty atmosphere *i.e.* sawmills, coal-handling plants and stone-crushing quarries etc.

Fig. 44.1. A three-phase motor

6. Totally-enclosed Fan-cooled (TEFC) Type. In this case, a fan is mounted on the shaft external to the totally enclosed casing and air is blown over the ribbed outer surfaces of the stator and endshields (Fig. 44.1). Such motors are commonly used in flour mills, cement works and sawmills etc. They require little maintenance apart from lubrication and are capable of giving years of useful service without any interruption of production.

7. Pipe-ventilated Type. Such an enclosure is used for very dusty surroundings. The motor is totally enclosed but is cooled by neat and clean air brought through a separate pipe from outside the dust-laden area. The extra cost of the piping is offset by the use of a smaller size motor on account of better cooling.

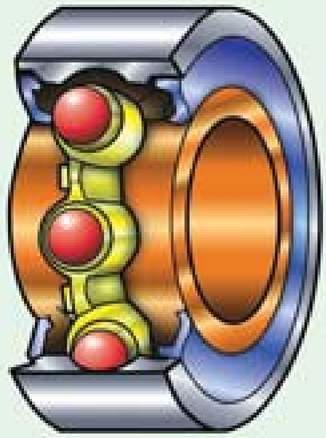
8. Flame-proof (FLP) Type. Such motors are employed in atmospheres which contain inflammable gases and vapours *i.e.* in coal mines and chemical plants. They are totally enclosed but their enclosures are so constructed that any explosion within the motor due to any spark does not ignite the gases outside. The maximum operating temperature at the surface of the motor is much less than the ignition temperature of the surrounding gases.

44.7. Bearings

These are used for supporting the rotating parts of the machines and are of two types :

1. Ball or roller bearings **2.** Sleeve or bush bearings

(*a*) Ball Bearings



A ball-bearing

Upto about 75kW motors, ball bearings are preferred to other bearings because of their following advantages :

1. They have low friction loss
2. They occupy less space
3. They require less maintenance
4. Their use allows much smaller air-gap between the stator and rotor of an induction motor
5. Their life is long.

Their main disadvantages are with regard to cost and noise particularly at high motor speeds.

(*b*) Sleeve Bearings

These are in the form of self-aligning pourous bronze bushes for fractional kW motors and in the form of journal bearings for larger motors. Since they run very silently, they are fitted on super-silent motors used for driving fans and lifts in offices or other applications where noise must be reduced to the absolute minimum.

A sleeve bearing

44.8. Transmission of Power

There are many ways of transmitting mechanical power developed by a motor to the driven machine.

1. Direct Drive. In this case, motor is coupled directly to the driven machine with the help of solid or flexible coupling. Flexible coupling helps in protecting the motor from sudden jerks. Direct drive is nearly 100% efficient and requires minimum space but is used only when speed of the driven machine equals the motor speed.

2. Belt Drive. Flat belts are extensively used for line-shaft drives and can transmit a maximum power of about 250 kW. Where possible, the minimum distance between the pulley centres should be 4 times the diameter of the larger pulley with a maximum ratio between pulley diameters of 6 : 1. The power transmitted by a flat belt increases in proportion to its width and varies greatly with its quality and thickness. There is a slip of 3 to 4 per cent in the belt drive.

3. Rope Drive. In this drive, a number of ropes are run in V-grooves over the pulleys. It has negligible slip and is used when the power to be transmitted is beyond the scope of belt drive.

Fig. 44.2. Geared Motor Unit

4. Chain Drive. Though somewhat more expensive, it is more efficient and is capable of transmitting larger amounts of power. It is noiseless, slipless and smooth in operation.

5. Gear Drive. It is used when a high-speed motor is to drive a low-speed machine. The coupling between the two is through a suitable ratio gear box. In fact motors for low-speed drives are manufactured with the reduction gear incorporated in the unit itself. Fig. 44.2 shows such a unit consisting of a flange motor bolted to a high-efficiency gear box which is usually equipped with feet, the motor being overhung.

44.9. Noise

The noise produced by a motor could be magnetic noise, windage noise and mechanical noise. Noise level must be kept to the minimum in order to avoid fatigue to the workers in a workshop. Similarly, motors used for domestic and hospital appliances and in offices and theatres must be almost noiseless. Tranmission of noise from the building where the motor is installed to another building can be reduced if motor foundation is flexible *i.e.* has rubber pads and springs.

44.10. Motors for Different Industrial Drives

1. D.C. Series Motor. Since it has high starting torque and variable speed, it is used for heavy duty applications such as electric locomotives, steel rolling mills, hoists, lifts and cranes.

2. D.C. Shunt Motor. It has medium starting torque and a nearly constant speed. Hence, it is used for driving constant-speed line shafts, lathes, vacuum cleaners, wood-working machines, laundry washing machines, elevators, conveyors, grinders and small printing presses etc.

3. Cumulative Compound Motor. It is a varying-speed motor with high starting torque and is used for driving compressors, variable-head centifugal pumps, rotary presses, circular saws, shearing machines, elevators and continuous conveyors etc.

4. Three-phase Synchronous Motor. Because its speed remains constant under varying loads, it is used for driving continuously-operating equipment at constant speed such as ammonia and air compressors, motor-generator sets, continuous rolling mills, paper and cement industries.

Heavy duty hydraulic motor for high torque and low speeds

5. Squirrel Cage Induction Motor. This motor is quite simple but rugged and possesses high over-load capacity. It has a nearly constant speed and poor starting torque. Hence, it is used for low and medium power drives where speed control is not required as for water pumps, tube wells, lathes, drills, grinders, polishers, wood planers, fans, blowers, laundary washing machines and compressors etc.

6. Double Squirrel Cage Motor. It has high starting torque, large overload capacity and a nearly constant speed. Hence, it is used for driving loads which require high starting torque such as compressor pumps, reciprocating pumps, large refrigerators, crushers, boring mills, textile machinery, cranes, punches and lathes etc.

7. Slip-ring Induction Motor. It has high starting torque and large overload capacity. Its speed can be changed upto 50% of its normal speed. Hence, it is used for those industrial drives which require high starting torque and speed control such as lifts, pumps, winding machines, printing presses, line shafts, elevators and compressors etc.

8. Single-phase Synchronous Motor. Because of its constant speed, it is used in teleprinters, clocks, all kinds of timing devices, recording instruments, sound recording and reproducing systems.

9. Single-phase Series Motor. It possesses high starting torque and its speed can be controlled over a wide range. It is used for driving small domestic appliances like refrigerators and vacuum cleaners etc.

10. Repulsion Motor. It has high starting torque and is capable of wide speed control. Moreover, it has high speed at high loads. Hence, it is used for drives which require large starting torque and adjustable but constant speed as in coil winding machines.

11. Capacitor-start Induction-run Motor. It has fairly constant speed and moderately high starting torque. Speed control is not possible. It is used for compressors, refrigerators and small portable hoists.

12. Capacitor-start-and-run Motor. Its operating characteristics are similar to the above motor except that it has better power factor and higher efficiency. Hence, it is used for drives requiring quiet operations.

44.11. Advantages of Electrical Braking Over Mechanical Braking

1. In mechanical braking; due to excessive wear on brake drum, liner etc. it needs frequent and costly replacement. This is not needed in electrical braking and so electrical braking is more economical than mechanical braking.
2. Due to wear and tear of brake liner frequent adjustments are needed thereby making the maintenance costly.
3. Mechanical braking produces metal dust, which can damage bearings. Electrical braking has no such problems.
4. If mechanical brakes are not correctly adjusted it may result in shock loading of machine or machine parts in case of lift, trains which may result in discomfort to the occupants.
5. Electrical braking is smooth.

6. In mechanical braking the heat is produced at brake liner or brake drum, which may be a source of failure of the brake. In electric braking the heat is produced at convenient place, which in no way is harmful to a braking system.
7. In regenerative braking electrical energy can be returned back to the supply which is not possible in mechanical braking.
8. Noise produced is very high in mechanical braking.

Only disadvantage in electrical braking is that it is ineffective in applying holding torque.

44.12. Types of Electric Braking

There are three types of electric braking as applicable to electric motors in addition to eddy-current braking. These have already been discussed briefly in Art. 44.7.

1. Plugging or reverse-current braking.
2. Rheostatic or dynamic braking.
3. Regenerative braking.

In many cases, provision of an arrangement for stopping a motor and its driven load is as important as starting it. For example, a planing machine must be quickly stopped at the end of its stroke in order to achieve a high rate of production. In other cases, rapid stops are essential for preventing any danger to operator or damage to the product being manufactured. Similarly, in the case of lifts and hoists, effective braking must be provided for their proper functioning.

44.13. Plugging Applied to D.C. Motors

As discussed earlier in Art. 42.7, in this case, armature connections are reversed whereas ***field winding connections remains unchanged***. With reversed armature connections, the motor develops a torque in the ***opposite*** direction. When speed reduces to zero, motor will accelerate in the opposite direction. Hence, the arrangement is made to disconnect the motor from the supply as soon as it comes to rest. Fig. 44.3 shows running and reversed connections for shunt motors whereas Fig. 44.4 shows similar conditions for series motors.

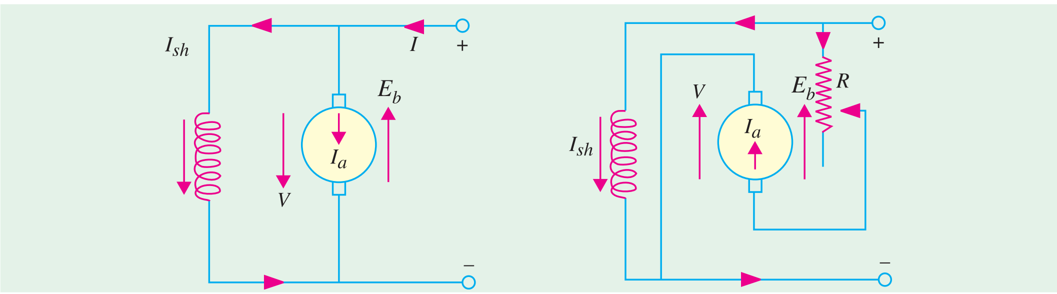


Fig. 44.3

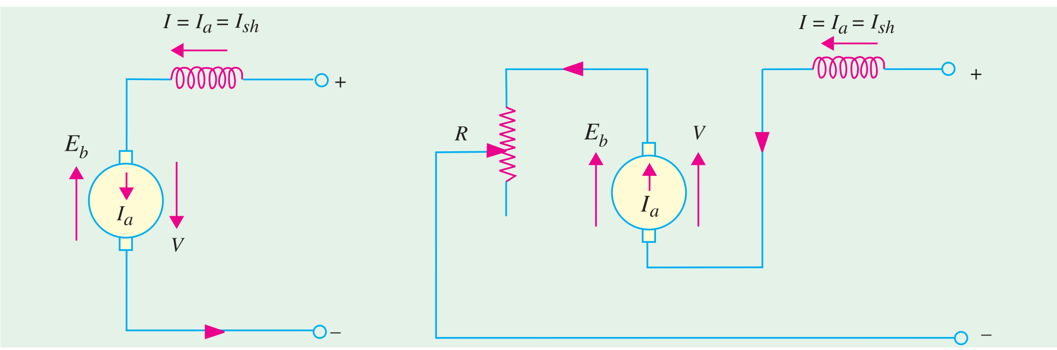


Fig. 44.4

Since with reversed connection, V and E_b are in the same direction, voltage across the armature is almost double of its normal value. In order to avoid excessive current through the armature, additional resistance R is connected in series with armature.

This method of braking is wasteful because in addition to wasting kinetic energy of the moving parts, it draws additional energy from the supply during braking.

Braking Torque. The electric braking torque is given by

$$T_B \propto \Phi I_a = k_1 \Phi I_a; \text{ Now, } I_a = (V + E_b)/R$$

$$\therefore \quad T_B = K_1 \Phi \,.\, \frac{V + E_b}{R} = k_1 \Phi \frac{V + k_2 \Phi N}{R} \qquad (\because E_b \propto \Phi N)$$

$$= \frac{K_1 \Phi V}{R} + \frac{k_1 k_2 \Phi^2 N}{R} = k_3\,\Phi + k_4\,\Phi^2 N$$

Shunt Motor

Since in the case, Φ is practically constant, $T_B = k_5 + k_6\,N$.

Series Motor

$$T_B = k_3 \Phi + k_4 \Phi^2 N = k_5 I_a + k_6 N I_a^2 \qquad (\because \phi \propto I_a)$$

The value of braking torque can be found with the help of magnetisation curve of a series motor.

Example 44.2. *A 40-kW, 440-V, d.c. shunt motor is braked by plugging. Calculate* ***(i)*** *the value of resistance that must be placed in series with the armature circuit to limit the initial braking current to 150 A* ***(ii)*** *the braking torque and* ***(iii)*** *the torque when motor speed falls to 360 rpm.*

Armature resistance R_a = 0.1W, full-load I_a = 100 A, full-load speed = 600 rpm.

(Electric Drives & Util. Punjab Univ. : 1994)

Solution. Full-load $E_b = 440 - 100 \times 0.1 = 430$ V

Voltage across the armature at the start of braking $= V + E_b = 440 + 430 = 870$ V

(i) Since initial braking current is limited to 150 A, total armature circuit resistance required is

$$R_t = 870 / 150 = 5.8\ \Omega \quad \therefore \quad R = R_t - R_a = 5.8 - 0.1 = \mathbf{5.7\ \Omega}$$

(ii) For a shunt motor, $T_B \propto \Phi\, I_a \propto I_a$ $\quad \therefore \quad \Phi$ is constant

$$\text{Now,} \quad \frac{\text{initial braking torque}}{\text{full-load toruqe}} = \frac{\text{initial braking current}}{\text{full-load current}}$$

Full-load torque $= 40 \times 103 / 2\pi\,(600/60) = 636.6$ N-m

$\therefore$ initial braking torque $= 636.6 \times 150 / 100 =$ **955 N-m**

(iii) The decrease in E_b is directly proportional to the decrease in motor speed.

$\therefore$ E_b at 360 rpm $= 430 \times 360/600 = 258$ V

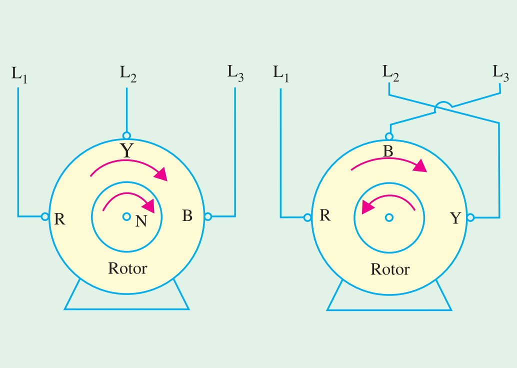
I_a at 360 rpm $= (440 + 258) / 5.8 = 120$ A

T_B at 360 rpm $= 636.6 \times 120/100 =$ **764 N-m**

44.14. Plugging of Induction Motors

This method of braking is applied to an induction motor by transposing any of its two line leads as shown in Fig. 44.5. It reverses the direction of rotation of the synchronously-rotating magnetic field which produces a torque in the reverse direction, thus applying braking on the motor. Hence, at the ***first instant*** after plugging, the rotor is running in a direction opposite to that of the stator field. It means that speed of the rotor relative to the magnetic field is $(N_s + N) \cong 2N_s$ as shown in Fig. 44.6.

In Fig 44.6. ordinate BC represents the braking torque at the instant of plugging. As seen, this torque gradually increases as motor approaches standstill condition after which motor is disconnected from the supply (otherwise it will start up again in the reverse direction).



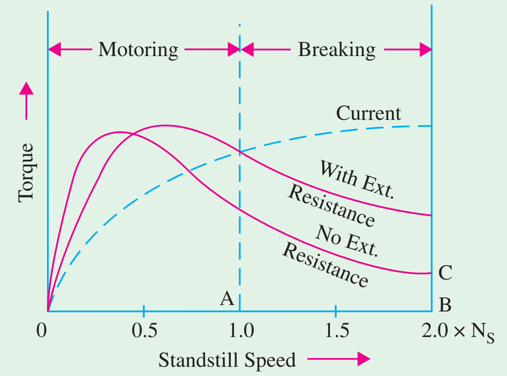


Fig. 44.5 **Fig. 44.6**

As compared to squirrel cage motors, slip-ring motors are more suitable for plugging because, in their case, external resistance can be added to get the desired braking torque.

Example 44.3. *A 30-kW, 400-V, 3-phase, 4-pole, 50-Hz induction motor has full-load slip of 5%. If the ratio of standstill reactance to resistance per motor phase is 4, estimate the plugging torque at full speed.* **(Utilisation of Elect. Energy, Punjab Univ.)**

Solution. $N_s = 120\,f/P = 120 \times 50/4 = 1500$ rpm

Full-load speed, $N_f = N_s(1-s) = 1500\,(1 - 0.05) = 1425$ rpm

Full-load torque, $T_f = \dfrac{30 \times 10^3}{2\pi \times 1425/60} = 200$ N-m

Since, $$T \propto \frac{sR_2\,E_2^2}{R_2^2 + s^2\,X_2^2} \quad \therefore \quad \frac{T_2}{T_1} = \frac{s_2\,R_2\,E_2^2/(R_2^2 + s_2^2\,X_2^2)}{s_1 R_2 E_2^2/(R_2^2 + s_1^2\,X_2^2)}$$

$$= \frac{s_2(R_2^2 + s_1^2\,X_2^2)}{s_1\,(R_2^2 + s_2^2\,X_2^2)} = \frac{s_2}{s_1} \cdot \frac{1 + s_1^2\,(X_2/R_2)^2}{1 + s_2^2\,(X_2/R_2)^2}$$

$$= \frac{s_1}{s_2} \cdot \frac{1 + 16s_1^2}{1 + 16s_2^2} \left(\frac{X_2}{R_2} = 4\right)$$

Slip, $S_p = 2 - 0.05 = 1.95$

$$\therefore \text{ plugging torque, } T_p = \frac{1.95}{0.05} \cdot \frac{1 + 16 \times (0.05)^2}{1 + 16\,(1.95)^2} \times T_f$$

$$= 39 \times \frac{1.04}{61.84} \times 200 = \mathbf{131\ N\text{-}m.}$$

44.15. Rheostatic Braking

In this method of electric braking, motor is disconnected from the supply though its field continues to be energised in ***the same direction***. The motor starts working as a generator and all the kinetic energy of the equipment to be braked is converted into electrical energy and is further dissipated in the variable external resistance R connected across the motor during the braking period. This external resistance must be less than the critical resistance otherwise there will not be enough current for generator excitation (Art. 44.3).

Rheostat

D.C. and synchronous motors can be braked this way but induction motors require separate d.c. source for field excitation.

This method has advantage over plugging because, in this case, no power is drawn from the supply during braking.

44.16. Rheostatic Braking of D.C. Motors

Fig. 44.7 shows connections for a d.c. shunt motor. For applying rheostatic braking armature is disconnected from the supply and connected to a variable external resistance R while the field remains on the supply. The motor starts working as a generator whose induced emf E_b depends upon its speed. At the start of braking, when speed is high, E_b is large, hence I_a is large. As speed decreases, E_b decreases, hence I_a decreases. Since $T_b \propto \Phi\, I_a$, it will be high at high speeds but low at low speeds. By gradually cutting out R, I_a and, hence, T_B can be kept constant throughout. Value of $I_a = E_b\,(R + R_a)$.

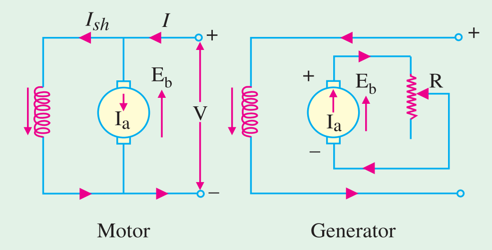


Fig. 44.7

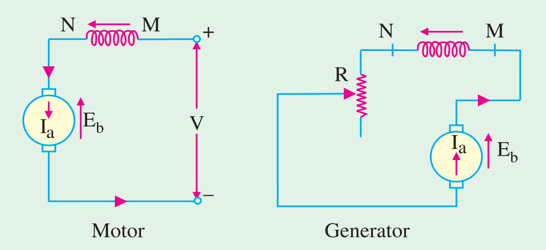


Fig. 44.8

Fig. 44.8 shows running and braking conditions for a d.c. series motor. In this case also, for rheostatic braking, the armature is disconnected from the supply and, at the same time, is connected across R. However, connections are so made that current keeps flowing through the series field ***in the same direction*** otherwise no braking torque would be produced. The motor starts working as a series generator provided R is less than the critical resistance.

44.17. Rheostatic Braking Torque

$T_B \propto \Phi\, I_a$. Now, $I_a = E_b/(R + R_a) = E_b/Rt$

Since $E_b \propto \Phi N$, $I_a \propto \Phi N/R_t$ $\therefore$ $T_B \propto \Phi^2 N/R_t = k_1 \Phi^2 N$

1. For D.C. shunt motors and synchronous motors, Φ is constant. Hence

$$T_B = k_1 N$$

2. In the case of series motors, flux depends on current. Hence, braking torque can be found from its magnetisation curve.

When rheostatic braking is to be applied to the series motors used for traction work, they are connected in parallel (Fig. 44.9) rather than in series because series connection produces excessive voltage across the loading rheostats.

However, it is essential to achieve electrical stability in parallel operation of two series generators. It can be achieved either by equalizing the exciting currents *i.e.* by connecting the two fields in parallel [Fig. 44.9 (*a*)] or by cross-connection [Fig. 44.9 (*b*)] where field of one machine is excited by the armature current of the other. If equalizer is not used, then the machine which happens to build up first will send current through the other ***in the opposite direction*** thereby exciting it with reverse voltage. Consequently, the two machines would be short-circuited upon themselves and may burn out on account of excessive voltage and, hence, current.

In the cross-connection of Fig. 44.9 (*b*), suppose the voltage of machine No. 1 is greater than that of No. 2. It would send a larger current through F_2 , thereby exciting it to a higher voltage. This results in stability of their parallel operation because stronger machine always helps the weaker one.

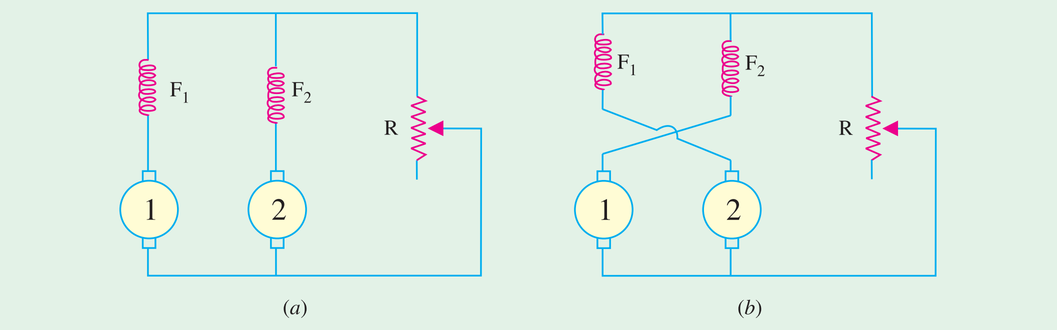


Fig. 44.9

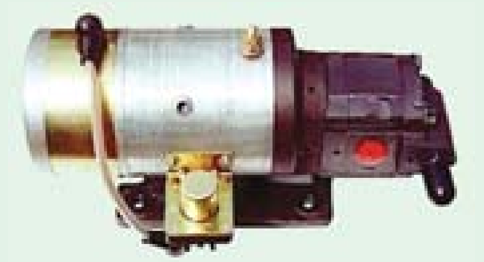
The cross-connection method has one special advantage over equalizer-connection method. If due to any reason (say, a run-back on a gradient) direction of rotation of the generators is reversed, no braking effect would be produced with connections of Fig. 44.9 (*a*) since the machines will fail to excite. However, with cross-excited fields, the machines will build up in series and being short-circuited upon themselves, will provide an emergency braking and would not allow the coach/car to run back on a gradient.

44.18. Rheostatic Braking of Induction Motors

If an induction motor is disconnected from the supply for rheostatic braking, there would be no magnetic flux and, hence, no generated emf in the rotor and no braking torque. However, if after disconnection, direct current is passed through the stator, steady flux would be set up in the air-gap which will induce current, in the short-circuited rotor. This current which is proportional to the rotor speed, will produce the required braking torque whose value can be regulated by either controlling d.c. excitation or varying the rotor resistance.

44.19. Regenerative Braking

In this method of braking, motor is not disconnected from the supply but is made to run as a generator by utilizing the kinetic energy of the moving train. Electrical energy is fed back to the supply. The magnetic drag produced on account of generator action offers the braking torque. It is the most efficient method of braking. Take the case of a shunt motor. It will run as a generator whenever its E_b becomes greater than V. Now, E_b can exceed V in two ways :



DC Shunt Motor

1. by increasing field excitation
2. by increasing motor speed beyond its normal value, field current remaining the same. It happens when load on the motor has overhauling characteristics as in the lowering of the cage or a hoist or the down-gradient movement of an electric train.

Regenerative braking can be easily applied to d.c. shunt motors though not down to very low speeds because it is not possible to increase field current sufficiently.

In the case of d.c. series motors, reversal of current necessary to produce regeneration would cause reversal of the field and hence of E_b. Consequently, modifications are necessary if regenerative braking is to be employed with d.c. series motors used in electric traction.

It may, however, be clearly understood that regenerative braking cannot be used for stopping a motor. Its main advantages are ***(i)*** reduced energy consumption particularly on main-line railways having long gradients and mountain railways ***(ii)*** reduced wear of brake shoes and wheel tyres and ***(iii)*** lower maintenance cost for these items.

44.20. Energy Saving in Regenerative Braking

We will now compute the amount of energy recuperated between any two points on a level track during which regenerative braking is employed. The amount of energy thus recovered and then returned to the supply lines depends on :

(i) initial and final velocities of the train during braking

(ii) efficiency of the system and ***(iii)*** train resistance.

Suppose regenerative braking is applied when train velocity is V_1 km/h and ceases when it is V_2 km/h. If M_e tonne is the effective mass of the train, then

$$\text{K.E. of the train at } V_1 = \frac{1}{2}M_eV_1^2 = \frac{1}{2}(1000\,M_e)\times\left(\frac{1000\,V_1}{3600}\right)^2 \text{ joules}$$

$$= \frac{1}{2}(1000\,M_e)\left(\frac{1000\,V_1}{3600}\right)^2\times\frac{1}{3600}\text{ Wh}$$

$$= 0.01072\,M_eV_1^2\text{ Wh} = 0.01072\,\frac{M_e}{M}V_1^2\text{ Wh/tonne}$$

$$\text{K.E. at } V_2 = 0.01072\,\frac{M_e}{M}V_2^2\text{ Wh/tonne}$$

Hence, energy available for recovery is $= 0.01072\,\dfrac{M_e}{M}(V_1^2 - V_2^2)$ Wh/tonne

If r N/t is the specific resistance of the train, then total resistance = rM newton.

If d km is the distance travelled during braking, then

energy spent = $rM \times (1000\,d)$ joules = $rMd \propto \dfrac{1000}{3600}$ Wh = $0.2778\,rd$ Wh/tonne

Hence, net energy recuperated during regenerative braking is

$$= 0.01072\,\frac{M_e}{M}(V_1^2 - V_2^2) - 0.2778\,rd\text{ Wh/tonne}$$

Gradient. If there is a *descending* gradient of G per cent over the same distance of d km, then downward force is = 98 MG newton

Energy provided during braking

$$= 98\,MG \times (1000\,d)\text{ joules} = 98\,MG\,d\,(1000/3600)\text{ Wh} = 27.25\,Gd\text{ Wh/tonne}$$

Hence, net energy recuperated in this case is

$$= \left[0.01072\,\frac{M_e}{M}(V_1^2 - V_2^2) - 0.2778\,rd + 2725\,Gd\right]\text{ Wh/tonne}$$

$$= 0.01072\,\frac{M_e}{M}(V_1^2 - V_2^2) + d\,(27.75\,G - 0.2778\,r)\text{ Wh/tonne}$$

If η is the system efficiency, net energy returned to the line is

***(i)* level track**

$$= \eta\left[0.01072\,\frac{M_e}{M}(V_1^2 - V_2^2) - 0.2778\,rd\right]\text{ Wh/tonne}$$

***(ii)* descending gradient**

$$= \eta\left[0.01072\,\frac{M_e}{M}\,(V_1^2 - V_2^2) + d\,(27.25\,G - 0.2778\,r)\right] \text{ Wh/tonne}$$

Example 44.4. *A 500-t electric trains travels down a descending gradient of 1 in 80 for 90 seconds during which period its speed is reduced from 100 km/h to 60 km/h by regenerative braking. Compute the energy returned to the lines of kWh if tractive resistance = 50 N/t; allowance for rotational inertia = 10% ; overall efficiency of the system = 75 %.*

Solution. Here $G = 1 \times 100 / 80 = 1.25\%$ $\quad M_e/M = 1.1$

$$d = \left(\frac{V_1 + V_2}{2}\right) \times t = \left(\frac{100 + 60}{2}\right) \times \frac{90}{3600} = 2 \text{ km}$$

Hence, energy returned to the supply line

$$= 0.75\ [(0.01072 \times 1.1\ (1002 - 602) + 2\ (27.25 \times 1.25 - 0.2778 \times 50)]\ \text{Wh/t}$$

$$= 0.75\ [75.5 + 2\ (34 - 13.9)] = 86.77 \text{ Wh/t}$$

$$= 86.77 \times 500 \text{ Wh} = 86.77 \times 500 \times 10^{-3} \text{ kWh} = \mathbf{43.4\ kWh}$$

Example 44.5. *A 350-t electric train has its speed reduced by regenerative braking from 60 to 40 km/h over a distance of 2 km along down gradient of 1.5%. Caculate **(i)** electrical energy and **(ii)** average power returned to the line. Assume specific train resistance = 50 N/t ; rotational inertia effect = 10% ; conversion efficiency of the system = 75%.* **(Elect. Power, Bombay Univ.)**

Solution . *(i)* Energy returned to the line is

$$= 0.75\ [0.01072 \times 1.1\ (60^2 - 40^2) + 2\ (27.25 \times 1.5 - 0.2778 \times 50)]\ \text{Wh/t}$$

$$= 58.2 \text{ Wh/t} = 58.2 \times 350 \times 10^{-3} = \mathbf{20.4\ kWh}$$

(ii) Average speed $= (60 + 40)/2 = 50$ km/h ; time taken $= 2/50$ h $= 1/25$ h

$$\therefore \quad \text{power returned} = \frac{20.4 \text{ kWh}}{1/25\text{h}} = \mathbf{510\ kW}$$

Example 44.6. *If in Example 42.4, regenerative braking is applied in such a way that train speed on down gradient remains constant at 60 km/h, what would be the power fed into the line?*

Solution : Since no acceleration is involved, the down-gradient tractive effort which drives the motors as generators is

$$F_t = (98\,MG - Mr) \text{ newton} = (98 \times 350 \times 1.5 - 350 \times 50) = 33{,}950 \text{ N}$$

Power that can be recuperated is

$$= F_t \times \left(\frac{1000}{3600}\right) V = 0.2778\,F_t\,V \text{ watt} = 0.2778 \times 33{,}950 \times 60 = 565{,}878 \text{ W}$$

Since $\eta = 0.75$, the power that is actually returned to the line is

$$= 0.75 \times 565{,}878 \times 10^{-3} = \mathbf{424.4\ kW}$$

Example 44.7. *A train weighing 500 tonne is going down a gradient of 20 in 1000. It is desired to maintain train speed at 40 km/h by regenerative braking. Calculate the power fed into the line. Tractive resistance is 40 N/t and allow rotational intertia of 10% and efficiency of conversion of 75%.* **(Util. of Elect. Power, A.M.I.E. Sec. B.)**

Solution. Down-gradient tractive effort which drives the motors as generators is

$$F_t = (98\,MG - Mr) = (98{,}000 \times 500 \times 2 - 500 \times 40) = 78{,}000 \text{ N}$$

Power that can be recuperated is $= 0.2778\,F_tV = 0.2778 \times 78{,}000 \times 40 = 866{,}736$ W

Since $\eta = 0.75$, the power that is actually fed into the lines is

$$= 0.75 \times 866{,}736 \times 10^{-3} = \mathbf{650\ kW.}$$

Example 44.8. *A 250-V d.c. shunt motor, taking an armature current of 150 A and running at 550 r.p.m. is braked by reversing the connections to the armature and inserting additional resistance in series with it. Calculate :*

(a) *the value of series resistance required to limit the initial current to 240 A.*

(b) *the initial value of braking torque.*

(c) *the value of braking torque when the speed has fallen to 200 r.p.m.*

The armature resistance is 0.09 Ω. Neglect winding friction and iron losses.

(Traction and Util. of Elect. Power, Agra Univ.)

Solution. Induced emf at full-load, $E_b = 250 - 150 \times 0.09 = 236.5$ V

Voltage across the armature at braking instant = $V + E_b = 250 + 236.5 = 486.5$ V

(a) Resistance required in the armature circuit to limit the initial current to 240 A

$$= \frac{486.5}{240} = \mathbf{2.027\ \Omega}$$

Resistance to be added in the armature circuit = 2.027 – 0.09 = **1.937 Ω**

(b) F.L. Torque, $T_f = VI/2\pi\,(N/60) = 250 \times (550/60) = 650$ N-m

$$\text{Initial braking torque} = T_f \frac{\text{initial braking current}}{\text{full-load current}} = \frac{650 \times 240}{150} = \mathbf{1040\ N\text{-}m}$$

(c) When speed falls to 200 r.p.m., back emf also falls in the same proportion as the speed.

$\therefore$ $E_b = E_b \times 200/550 = 236.5 \times 200.550 = 94.6$ V

$\therefore$ current drawn = (250 + 94.6)/2.027 = 170 A

$\therefore$ braking torque = 650 × 170/150= **737 N-m**

Example 44.9. *A 400 V 3-ph squirrel cage induction motor has a full load slip of 4%. A stand-still impedance of 1.54Ω and the full load current = 30A. The maximum starting current which may be taken from line is 75A. What taping must be provided on an auto-transformer starter to limit the current to this value and what would be the starting torque available in terms of full load torque ?*

[Nagpur University, Winter 1994]

Solution.
$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = X$$

or
$$V_1 I_1 = V_2 I_2 = X$$

$$I_1 = 75\text{A}$$

$$V_1 = \frac{400}{\sqrt{3}} = 231 \text{ V and } I_1 = I_2 X$$

$$I_1 = \frac{V_2}{Z} X$$

$$I_1 = \frac{XV_1}{1.54} X$$

$$I_1 = \frac{X^2 \times 231}{1.54}$$

$$\Rightarrow \quad 75 = \frac{X^2 \times 231}{1.54}$$

$$\Rightarrow \quad X^2 = \frac{75 \times 1.54}{231}$$

$$X = 0.7071$$

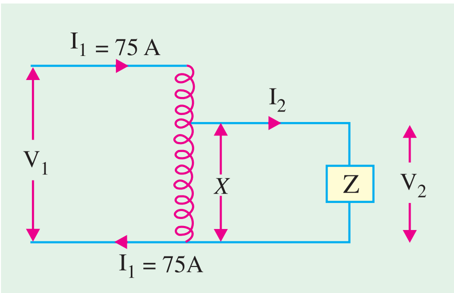


Fig. 44.10

$$\frac{T_s}{T_{FL}} = X^2\left(\frac{I_S}{I_{FL}}\right)^2 \times \text{Slip}_{(FL)}$$

Now $$I_2 = I_s = \frac{I_1}{X} = \frac{75}{0.708} = 106\ A$$

$$s_{FL} = 0.04. \quad I_s = 106\text{ A} \quad I_{FL} = 30\text{ A.}$$

$\therefore$ $$\frac{T_s}{T_{HL}} = (0.701)^2\left(\frac{106}{30}\right)^2 \times 0.04$$

$\therefore$ $$T_s = 0.25\ T_{FL}$$

Example 44.10. *A 220V, 10 H.P. shunt motor has field and armature resistances of 122W and 0.3W. respectively. Calculate the resistance to be inserted in the armature circuit to reduce the speed to 80% assuming motor η at full load to be 80%.*

(a) When torque is to remain constant.

(b) When torque is proportional to square of the speed. **[Nagpur University, Winter 1994]**

Solution. $$I_f = \frac{220}{112} = 1.8\text{ Amp.}$$

Motor $$O/P = 10 \times 746 = 7460\text{ W}$$

$\therefore$ $$\text{Motor } I/P = \frac{7460}{0.8} = 9300\text{ W}$$

Line current $$I_L = \frac{9300}{220} = 42.2\text{ Amp.}$$

$\therefore$ $$I_a = 42.2 - 1.8 = 40.4\text{ A}$$

$\therefore$ $$E_{b_1} = 220 - 40.4 \times 0.3 = 208\text{ V}$$

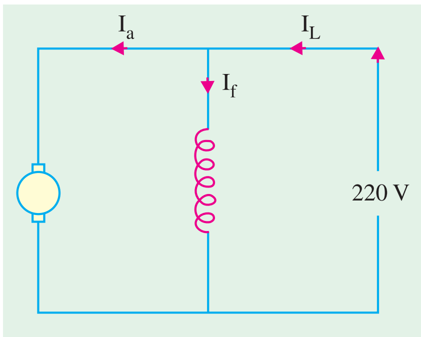


Fig. 44.11

Now $$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \quad \because \phi \text{ is constant}$$

$$0.8 = \frac{E_{b_2}}{E_{b_1}} \quad \therefore 0.8 = \frac{E_{b_2}}{208} \quad \Rightarrow \quad E_{b_2} = \mathbf{166.4\ V}$$

(a) $\because$ Torque remains constant and ϕ is constant

$\therefore$ I_a at reduced speed will also remain same

$\therefore$ $$E_{b_2} = V - I_{a_2} R \quad \text{where } R \text{ is total resistance}$$

$$166.4 = 220 - 40.4 \times R \quad \therefore \quad R = \frac{220 - 166.4}{40.0} = 1.34\ \Omega$$

$\therefore$ Additional resistance in armature circuit = 1.34 – 0.3 = **1.04 Ω**

(b) $$\frac{T_2}{T_1} = \left(\frac{N_2}{N_1}\right)^2$$

$$T \propto I_a \quad \text{also} \quad T \propto \phi\, I_a$$

$\because$ $T \propto I_a$ ($\because$ ϕ is constant)

$$\frac{T_2}{T_1} = (0.8)^2 = 0.64$$

$\therefore$ $$\frac{T_2}{T_1} = \frac{I_{a_2}}{I_{a_2}} \quad \therefore 0.64 = \frac{I_{a_2}}{40.4} \quad \Rightarrow \quad I_{a_2} = 25.3\text{ A}$$

$$E_{b_2} = 220 - 25.3 \times R$$

$$166.4 = 220 - 25.5936 \times R$$

$\therefore$ $R = \mathbf{2.0943\ \Omega}$

$\therefore$ Additional resistance $= 2.0943 - 0.3 = \mathbf{1.7943\ \Omega}$

Example 44.11. *A 37.5 H.P., 220 V D.C. shunt motor with a full load speed of 535 r.p.m. is to be braked by plugging. Estimate the value of resistance which should be placed in series with it to limit the initial braking current to 200 amps. What would be the initial value of the electric braking torque and the value when the speed had fallen to half its full load value? Armature resistance of motor is 0.086 Ω and full load armature current is 140 amps.*

Solution. $E = V - I_a R_a$

Back e.m.f. of motor $= E = 220 - 140 \times 0.086 = 220 - 12 = 208$ Volts.

Total voltage during braking $= E + V$

$= 220 + 208 = 428$ V

$$R = \frac{V}{I}$$

Resistance required $= \dfrac{428}{200} = 2.14\ \Omega$

There is already 0.086 Ω present in aramature.

$\therefore$ Resistance to be added $= 2.14 - 0.086 = 2.054\ \Omega$

Torque $\propto \phi I$ or Torque $\propto I$ ($\because$ ϕ is constant for shunt motor)

$$\frac{\text{Initial braking torque}}{\text{Initial braking current}} = \frac{\text{F.L. toruqe}}{\text{F.L. current}}$$

$$\text{Power} = \text{Torque} \times \omega$$

$$\omega = \frac{2\pi N}{60} \text{ rad/sec.}$$

$$37.5 \times 746 = T \times \frac{2\pi \times 535}{60}$$

Full load torque $= 499.33$ Nw-m.

Initial braking torque $= 499.33 \times \dfrac{200}{140} = 713.328$ Nw-m.

$\rightarrow$ At half – speed back e.m.f. falls to half its original value $= 208/2 = 104$ V

$$\text{Current} = \frac{220 + 104}{2.14} = 151 \text{ Amps.}$$

Electric braking torque at $\dfrac{1}{2}$ speed $= 499.33 \times \dfrac{151}{140} = \mathbf{538.56\ Nw\text{-}m.}$

Example 44.12. *A 500 V series motor having armature and field resistances of 0.2 and 0.3 Ω, runs at 500 r.p.m. when taking 70 Amps. Assuming unsaturated field find out its speed when field diverter of 0.684 Ω is used for following load whose torque*

(a) *remains constant*

(b) *varies as square of speed.*

Solution. When no diverter connected, $E_{b_1} = 500 - 70\,(0.2 + 0.3) = 465$ V

(a) If I_{a_2} be the armature current when diverter is used, then current flowing through

$$\text{field} = I_{f2} = I_{a_2} \times \frac{0.684}{0.3 + 0.684} = 0.695\, I_{a_2}$$

$\because$ Load torque is constant

$$\therefore \quad I_{a_1} \phi_1 = I_{a_2} \phi_2 \qquad (\because \phi \propto I_a)$$

$$\therefore \quad I_{a_1}\phi_1 = I_{a_2}(0.695)\,I_{a_2} \Rightarrow I_{a_2} = \frac{I_{a1}}{\sqrt{0.695}} = \frac{70}{\sqrt{0.695}} = 84 \text{ A}$$

$$\therefore \text{ Field current} = I_{f_2} = 0.695\, I_{a_2} = 0.695 \times 84 = 58.4 \text{ A}$$

Resistance of field with diverter $= \dfrac{0.3 \times 0.684}{0.3 + 0.684} = 0.208\ \Omega$

Total field and armature resistance = 0.2 + 0.208 = 0.408 Ω

$$E_{b_2} = 500 - 84\ (0.408) = 465.8 \text{ V}$$

$$\frac{N_1}{N_2} = \frac{E_{b_1}}{E_{b_2}} \times \frac{\phi_2}{\phi_1}$$

$$\frac{500}{N_2} = \frac{465}{465.8} \times \frac{58.4}{70} \Rightarrow N_2 = \mathbf{600\ r.p.m}$$

(*b*)
$$\frac{T_1}{T_2} = \left(\frac{N_1}{N_2}\right)^2 \quad \because \frac{T_1}{T_2} = \frac{I_{a_1}\phi_1}{I_{a_2}\phi_2} = \frac{I_{a_1}\cdot I_{a_1}}{I_{a_2} \times 0.695\, I_{a_2}}$$

$$\therefore \quad \left(\frac{N_1}{N_2}\right)^2 = \frac{I_{a_1}\cdot I_{a_1}}{Ia_2^2 \times 0.695} \Rightarrow \frac{N_1}{N_2} = \frac{I_{a_1}}{I_{a_2}\sqrt{0.695}} = \frac{70}{I_{a_2}\sqrt{0.695}}$$

$$\frac{N_1}{N_2} = \frac{E_{b_1}}{E_{b_2}} \times \frac{\phi_2}{\phi_1}$$

$$\frac{70}{I_{a_2}\sqrt{0.695}} = \frac{465}{500 - I_{a_2}\ (0.2)\ 0.208)} \times \frac{0.695\, I_{a_2}}{70}$$

$$I_{a_2}^2 + 7.42\, I_{a_2} - 9093 = 0$$

$$\Rightarrow \quad I_{a_2} = 91.7 \text{ A} \qquad \because \text{ negative value is absurd.}$$

$$\frac{N_1}{N_2} = \frac{70}{I_{a_2}\sqrt{0.695}} \Rightarrow \frac{500}{N_2} = \frac{70}{91.7\sqrt{0.695}}$$

$$\therefore \quad N_2 = \mathbf{546\ r.p.m.}$$

Example 44.13. *A 200 V series motor runs at 1000 r.p.m. and takes 20 Amps. Armature and field resistance is 0.4 W. 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.*

Solution.
$$\frac{T_1}{T_2} = \left(\frac{N_1}{N_2}\right)^3 = \left(\frac{1000}{800}\right)^3 = \frac{125}{64}$$

$$\therefore \quad \frac{T_1}{T_2} = \frac{I_{a_1}\phi_1}{I_{a_2}\phi_2} = \frac{20 \times 20}{I_{a_2} \times I_{a_2}} \qquad \because\ \phi \propto I_a \text{ for series motor.}$$

$$\frac{125}{64} = \frac{20^2}{I_{a_2}^2} \quad I_{a_2}\ I_{a_2} = 14.3 \text{ Amp}$$

$$E_{b_1} = 200 - 20 \times 0.4 = 192 \text{ V.}$$

$$\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2} \times \frac{\phi_1}{\phi_2}$$

$$\frac{192}{E_{b_2}} = \frac{1000}{800} \times \frac{20}{14.3}$$

$$E_{b_2} = 110 \text{ V} ; \quad E_{b_2} = V - IR$$

$$110 = 200 - 14.3 \times R \; ; \quad R = \frac{90}{14.3} = 6.3\ \Omega$$

Additional resistance required $= 6.3 - 0.4 =$ **5.9 Ω**

Example 44.14. *A 220V, 500 r.p.m. D.C. shunt motor with an armature resistance of 0.08Ω and full load armature current of 150 Amp. is to be braked by plugging. Estimate the value of resistance which is to be placed in series with the armature to limit initial braking current to 200 Amps. What would be the speed at which the electric braking torque is 75% of its initial value.*

Solution. Back e.m.f. of motor $= E_{b_1} = V - I_a R_a$

$$= 220 - 150 \times 0.08 = 208 \text{ V}$$

Voltage across armature when braking starts

$$= 220 + 208 = 428 \text{ V}$$

Initial braking current to be limited to 200 A.

$\therefore$ Resistance in armature circuit $= \dfrac{428}{200} = 2.14\ \Omega$

$\therefore$ External resistance required $= 2.14 - 0.08 = 2.06\ \Omega$

Since field Flux ϕ is constant therefore 75% torque will be produced when armature current is 75% of 200 Amp. *i.e.* 150Amp.

Let N_2 be the speed in r.p.m. at which 75% braking torque is produced. At this speed generated e.m.f. in armature

$$\because \quad \frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2} \; ; \quad \frac{208}{E_{b_2}} = \frac{500}{N_2} \quad \therefore \quad E_{b_2} = \frac{208}{500} N_2$$

Voltage across armature when braking starts

$$150 \times 2.14 = \left(220 + \frac{208}{500} N_2\right) \text{Volts}$$

$\therefore \quad N_2 =$ **243 r.p.m.**

Example 44.15. *A D.C. series motor operating at 250 V D.C. mains and draws 25 A and runs at 1200 r.p.m. R_a = 0.1 Ω and R_{se} = 0.3 Ω.*

A resistance of 25 Ω is placed in parallel with the armature of motor. Determine:

(i) The speed of motor with the shunted armature connection, if the magnetic circuit remains unsaturated and the load torque remains constant.

(ii) No load speed of motor. **[Nagpur University Winter 1995]**

Solution. $$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

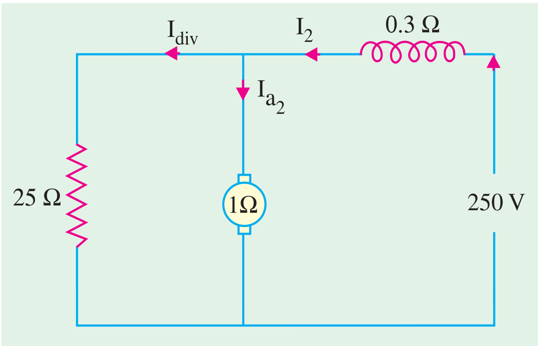


Fig. 44.12

Voltage across diverter $= 250 - 0.3\, I_2$

$$I_{div} = \frac{250 - 0.3 I_2}{25}$$

$$I_{a_2} = I_2 - \frac{250 - 0.3 I_2}{25}$$

$$= 1.012\ I_2 - 10$$

As T is constant $\therefore \quad \phi_1 I_{a_1} = \phi_2 I_{a_2}$

$$\therefore \quad I_{a_1}^2 = I_2 (I_{a_2})$$

$$(25)^2 = I_2\ (1.012\ I_2 - 10)$$

$$1.012\, I_2^{\,2} - 10 \times I_2 - 625 = 0 \Rightarrow I_2 = 30.27\,A \text{ (neglecting negative value)}$$

$$(25)^2 = (30.27)\, I_{a_2} \Rightarrow I_{a_2} = 20.65 \text{ A}$$

$$E_{b_1} = V - I_{a_1}\,(R_a + R_{se}) = 250 - 25\,(0.4) = 240 \text{ Volts}$$

$$E_{b_2} = V - I_2\,(R_{se}) - I_{a_2}\,(R_a) = 250 - 30.27\,(0.3) - 0.1\,(20.65) = 238.85 \text{ V.}$$

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

$$\frac{N_2}{1200} = \frac{238.85}{240} \times \frac{2.5}{20.27} \quad \therefore \quad N_2 = \mathbf{986 \text{ r.p.m.}}$$

(ii) Series motor on no load.

Series motor can't be started on no load. When flux is zero, motor tries to run at infinite speed, which is not possible. So in the process, it tries to draw very high current from supply and fuse blows-out.

Example 44.16. *A 4 pole, 50Hz, slip ring Induction Motor has rotor resistance and stand still reactance referred to stator of 0.2 Ω and 1 Ω per phase respectively. At full load, it runs at 1440 r.p.m. Determine the value of resistance to be inserted in rotor in ohm/ph to operate at a speed of 1200 r.p.m., if :*

(i) Load torque remains constant. (ii) Load torque varies as square of the speed.

Neglect rtator resistance and leakage reactance.

Solution. ***(i)*** Load torque constant

$$\Rightarrow T \propto \frac{s}{R_2} \qquad N_s = 1500 \text{ rpm}$$

$$\therefore \quad T_1 \propto \frac{s_1}{R_2} \qquad T_2 \propto \frac{s_2}{(R_1 + r)}$$

$$s_1 = \frac{1500 - 1400}{1500} = 0.04 \; s_2 = \frac{1500 - 1240}{1500} = 0.2$$

As $$T_1 = T_2 \quad \therefore \quad \frac{s_1}{R_2} = \frac{s_2}{R_1 + r}$$

$$\frac{0.04}{0.2} = \frac{0.2}{0.2 + r}$$

$$\therefore \quad r = 0.8\ \Omega$$

(ii) Load torque varies as square of the speed.

$$\frac{T_1}{T_2} = \left[\frac{N_1}{N_2}\right]^2 = \left[\frac{1440}{1200}\right]^2 = 1.44$$

$$\frac{T_1}{T_2} = 1.44 = \frac{\dfrac{R_2 s_1}{R_2^2 + (s_1 X_2)^2}}{\dfrac{(R_2 + r)\, s_2}{(R_2 + r)^2 + (s_2 X_2)^2}} = \frac{\dfrac{0.2 \times 0.04}{0.2^2 + (0.04 \times 1)^2}}{\dfrac{(0.02 + r)\,(0.2)}{(0.2 + r)^2 + (0.2 \times 1)^2}}$$

Substituting $$R_2 + r = R$$

$$1.44 = \frac{0.1923}{\dfrac{0.2\,R}{R^2 + 0.04}}$$

$$\therefore \quad 0.1923\, R^2 - 0.288\, R + 0.007652 = 0$$

$$\Rightarrow \quad R = 1.47 \text{ and } 0.0272, \text{ But } R > 0.2 \;\therefore\; R = 1.47\ \Omega$$

$$\therefore \quad R = 0.2 + r\,;\; 1.47 = 0.2 + r \Rightarrow r = 1.27\ \Omega$$

Tutorial Problem No. 44.1

1. The characteristics of a series traction motor at 525 V are as follows :

current	:	50	70	80	90	A
speed	:	33.8	26.9	25.1	23.7	km/h
Gross torque	:	217	352	423	502	N-m

Determine the gross braking torque at a speed of 25.7 km/h when operating as self-excited series generator and loaded with an external resistance of 6 Ω. Resistance of motor = 0.5 Ω.
[382.4 N-m] (*London Univ.*)

2. The characteristics of a series motor at 525 V are as follows :

current	:	75	125	175	225	A
speed	:	1200	950	840	745	r.p.m.

Calculate the current when operating as a generator at 1000 r.p.m. and loaded on a rheostat having a resistance of 3.25 Ω. The resistance of motor is 3.5 Ω. **[150 A] (*London Univ.*)**

3. A train weighing 400 tonne travels a distance of 10 km down a gradient of 2%, getting its speed reduced from 40 to 20 km/h, the train resistance is = 50 N/t, allowance for rotational inertia = 10% and overall efficiency = 72%. Estimate (*i*) power and (*ii*) energy returned to the line.
[(*i*) 363 kW (*ii*) 121 kWh] (*Elect. Power, Bombay Univ.*)

4. A 400-tonne train travels down a gradient of in 100 for 20 seconds during which period its speed is reduced from 80 km/h to 50 km/h by regenerative braking. Find the energy returned to the lines if the tractive resistance is 49 N/t and allowance for rotational inertia is 7.5%. Overall efficiency of motors is 75%. **[28.2 kWh] (*A.M.I.E.*)**

5. A 400-tonne train travels down a gradient of 1 in 70 for 120 seconds during which period its speed is reduced from 80 km/h to 50 km/h by regenerative braking. Find the energy returned to the line if tractive resistance is 49 N/t and allowance for rotational inertia is 7.5%. Overall efficiency of motors is 75%. **[30.12 kWh] (*A.M.I.E.*)**

6. A train weighing 500 tonne is going down a gradient of 20 in 1000. It is desired to maintain train speed at 40 km/h by regenerative braking. Calculate the power fed into the line. Tractive resistance is 40 N/t and allow rotational inertia of 10% and efficiency of conversion of 75%.
[650 kW] (*Utilization of Elect. Power, A.M.I.E.*)

7. A 18.65 kW, 220-V D.C. shunt motor whith a full-load speed of 600 r.p.m. is to be braked by plugging. Estimate the value of the resistance which should be placed in series with it to limit the current to 130A. What would be the initial value of the electric braking torque and value when speed has fallen to half of its full-load vlaue ? Armature resistance of motor is 0.1 W. Full-load armature current is 95 A. **[3.211 Ω, 400.5 N-m, 302.57 N-m] (*Util of Elect. Power, A.M.I.E. Sec. B.*)**

8. A 400-tonne train travels down a gradient of 1 in 70 for 120 seconds during which period its speed is reduced from 80 km/h to 50 km/h by regenerative braking. Find the energy returned to the lines if tractive resistance is 5 kg / tonne and allowance for rotational inertia is 7.5 %. Overall efficiency of motor is 75%. **[30.64%]**

9. What are the advantages of Electrical Drive over other Drives? What are the mainfeatures of Group Drive and an Individual Drive? ***(Nagpur University, Summer 2004)***

10. What are the essential requirements of starting of any motor? With the help of neat diagram explain 'open circuit transition' and 'closed circuit transition' in Auto transformer starting of Induction Motor. ***(Nagpur University, Summer 2004)***

11. What is the principle of speed control of D.C. motors for, below the base speed and above the base speed.Explain with neat N-T characteristics. ***(Nagpur University, Summer 2004)***

12. A 400 V, 25 h.p., 450 rpm, D.C. shunt motor is braked by plugging when running on full load. Determine the braking resistance necessary if the maximum braking current is not to exceed twice the full load current. Determine also the maximum braking torque and the braking torque when the motor is just reaching zero speed. The efficiency of the motor is 74.6% and the armature resistance is 0.2 Ω. ***(Nagpur University, Summer 2004)***

13. Mention the Advantage of PLC over conventional motor control.
(Nagpur University, Summer 2004)

14. Suggest the motors required for following Drives :-
(*i*) Rolling mills (*ii*) Marine drive (*iii*) Home appliances (*iv*) Pump
(*v*) Refrigeration and air-conditioning (*vi*) Lifts. *(Nagpur University, Summer 2004)*

15. Explain with neat block diagram the digital control of Electrical Drives.
(Nagpur University, Summer 2004)

16. Explain Series parallel control of traction motor. *(Nagpur University, Summer 2004)*

17. Write short Notes on Speed reversal by contactor and relay. *(Nagpur University, Summer 2004)*

18. Write short Notes on Ratings of contactors. *(Nagpur University, Summer 2004)*

19. Write short Notes on Magnetic time-delay relay. *(Nagpur University, Summer 2004)*

20. Discuss the advantages and disadvantages of electric drive over other drives.
(J.N. University, Hyderabad, November 2003)

21. Though a.c. is superior to d.c. for electric drives, sometimes d.c. is preferred. Give the reasons and mention some of the applications. *(J.N. University, Hyderabad, November 2003)*

22. A d.c. series motor drives a load, the torque of which varies as the square of the speed. The motor takes current of 30 amps, when the speed is 600 r.p.m. Determine the speed and current when the field winding is shunted by a diverter, the resistance of which is 1.5 times that of the field winding. The losses may be neglected. *(J.N. University, Hyderabad, November 2003)*

23. State the condition under which regenerative braking with d.c. services motor is possible and with the aid of diagrams of connection, explain the various methods of providing regeneration.
(J.N. University, Hyderabad, November 2003)

24. Explain what you mean by ''Individual drive'' and ''Group drive''. Discuss their relative merits and demerits. *(J.N. University, Hyderabad, November 2003)*

25. A 500 V d.c. series motor runs at 500 r.p.m. and takes 60 amps. The resistances of the field and the armature are 0.3 and 0.2 Ohms, respectively. Calculate the value of the resistance to be shunted with the series field winding in order that the speed may be increased to 600 r.p.m., if the torque were to remain constant. Saturation may be neglected.
(J.N. University, Hyderabad, November 2003)

26. A motor has the following duty cycle :
Load rising from 200 to 400 h.p. – 4 minutes
Uniform load 300 h.p. – 2 minutes
Regenerative braking h.p. Returned to supply from 50 to zero – 1 minute.
Remains idle for 1 minute.
Estimate the h.p. of the motor. *(J.N. University, Hyderabad, November 2003)*

27. What are various types of electric braking used? *(J.N. University, Hyderabad, November 2003)*

28. Explain how rheostatic braking is done in D.C. shunt motors and series motors.
(J.N. University, Hyderabad, November 2003)

29. Describe how plegging, rheostics braking and regenerative braking are employed with D.C. series motor. *(J.N. University, Hyderabad, November 2003)*

30. Where is the use of Individual drive recommended and why?
(J.N. University, Hyderabad, November 2003)

31. The speed of a 15 h.p. (Metric) 400 V d.c. shunt motor is to be reduced by 25% by the use of a controller. The field current is 2.5 amps and the armature resistance is 0.5 Ohm. Calculate the resistance of the controller, if the torque remains constant and the efficiency is 82%.
(J.N. University, Hyderabad, November 2003)

32. Explain regenerative braking of electric motors. *(J.N. University, Hyderabad, November 2003)*

33. ''If a high degree of speed control is required, d.c. is perferable to a.c. for an electric drive''. Justify.
(J.N. University, Hyderabad, April 2003)

34. A 200 V shunt motor has an armature resistance of 0.5 ohm. It takes a current of 16 amps on full load and runs at 600 r.p.m. If a resistance of 0.5 ohm is placed in the armature circuit, find the ratio of the stalling torque to the full load torque. *(J.N. University, Hyderabad, April 2003)*

35. What are the requirements of good electric braking? *(J.N. University, Hyderabad, April 2003)*
36. Explain the method of rheostatic braking. *(J.N. University, Hyderabad, April 2003; Anna University, Chennai 2003)*
37. Mean horizontal Candlepower *(J.N. University, Hyderabad, April 2003)*
38. Mean hemispherical Candlepower *(J.N. University, Hyderabad, April 2003)*
39. Luminous flux. *(J.N. University, Hyderabad, April 2003)*
40. Define : (*i*) Luminous intensity (*ii*) Point source (*iii*) Lumen and (*iv*) Uniform point source. *(J.N. University, Hyderabad, April 2003)*
41. Prove that Luminous intensity of a point source is equal to the luminous flux per unit solid angle. *(J.N. University, Hyderabad, April 2003)*
42. Discuss the various factors that govern the choice of a motor for a given service. *(J.N. University, Hyderabad, April 2003)*
43. A 6 pole, 50 Hz slip ring induction motor with a rotor resistance per phase of 0.2 ohm and a stand still reactance of 1.0 ohm per phase runs at 960 r.p.m. at full load. Calculate the resistance to be inserted in the rotor circuit to reduce the speed to 800 r.p.m., if the torque remains unaltered. *(J.N. University, Hyderabad, April 2003)*
44. Compare the features of individual and group drives. *(J.N. University, Hyderabad, April 2003)*
45. What is an electric drive? Classify various types of electric drives and discuss their merits and demerits. *(J.N. University, Hyderabad, December 2002/January 2003)*
46. Suggest, with reasons the electric drive used for the following applications. (*i*) Rolling mills (*ii*) Textile mills (*iii*) Cement mills (*iv*) Paper mills (*v*) Coal mining (*vi*) Lift, Cranes, Lathes and pumps. *(J.N. University, Hyderabad, December 2002/January 2003)*
47. A 100 hp, 500 rpm d.c. shunt motor is driving a grinding mill through gears. The moment of inertia of the mill is 1265 kgm^2. If the current taken by the motor must not exceed twice full load current during starting, estimate the minimum time taken to run the mill upto full speed. *(J.N. University, Hyderabad, December 2002/January 2003)*
48. Explain the different methods of electric braking of a 3 phase induction motor. *(J.N. University, Hyderabad, December 2002/January 2003)*
49. A 50 hp, 400V, 750 rpm synchronous motor has a moment of inertia 20 kgm^2 and employs rheostatic braking for obtaining rapid stopping in case of emergency when the motor is running at full load, star connected braking resistor of 2 ohm per phase is switched on. Determine the time taken and the number of revolutions made before the motor is stopped. Assume as efficiency of 90% and a full load power factor of 0.95. *(J.N. University, Hyderabad, December 2002/January 2003)*
50. Explain regenerative braking of induction motor. *(J.N. University, Hyderabad, December 2002/January 2003)*
51. What is dynamic braking? *(Anna University, Chenni, Summer 2003)*
52. What is regenerative braking? *(Anna University, Chenni, Summer 2003)*
53. What are braking systems applicable to a DC shunt motor? *(Anna University, Chenni, Summer 2003)*
54. What for Series motor Regenerative Braking is not suited? *(Anna University, Chenni, Summer 2003)*
55. What are the important stages in controlling an electrical drive. *(Anna University, Chenni, Summer 2003)*
56. Explain rheostatic braking of D.C. motors. *(Anna University, Chennai 2003)*

OBJECTIVE TESTS – 44

1. A steel mill requires a motor having high starting torque, wide speed range and precise speed control. Which one of the following motors will you choose ?
   (*a*) d.c. shunt motor
   (*b*) synchronous motor
   (*c*) d.c. series motor
   (*d*) slip-ring induction motor.
2. Heavy-duty steel-works cranes which have wide load variations are equipped with .... motor.
   (*a*) double squirrel-cage

(*b*) d.c. series
(*c*) slip-ring induction
(*d*) cumulative compound.

3. A reciprocating pump which is required to start under load will need ....motor.
(*a*) repulsion
(*b*) squirrel-cage induction
(*c*) synchronous
(*d*) double squirrel-cage induction.

4. Motors used in wood-working industry have .... enclosure.
(*a*) screen protected (*b*) drip proof
(*c*) TEFC (*d*) TE

5. Single-phase synchronous motors are used in teleprinters, clocks and all kinds of timing devices becasue of their
(*a*) low starting torque
(*b*) high power factor
(*c*) constant speed
(*d*) over-load capacity.

6. Which motor is generally used in rolling mills, paper and cement industries ?
(*a*) d.c. shunt motor
(*b*) double squirrel-cage motor
(*c*) slip-ring induction motor
(*d*) three-phase synchronous motor

7. Direct drive is used for power transmission only when
(*a*) negligible slip is required
(*b*) large amount of power is invloved
(*c*) speed of the driven machine equals the motor speed
(*d*) high-speed motor is to drive a low-speed machine.

8. Which type of enclosure will be most suitable for motors employed in atmospheres containing inflammable gases and vapours ?
(*a*) pipe-ventilated
(*b*) totally enclosed, fan-cool
(*c*) flame proof
(*d*) screen-protected.

9. While plugging d.c. motors, ... connections are reversed
(*a*) supply
(*b*) armature
(*c*) field
(*d*) both armature and field

10. During rheostatic braking of a d.c., motor,
(*a*) its field is disconnected from the supply
(*b*) its armature is reverse-connected
(*c*) it works as a d.c. generator
(*d*) direction of its field current is reversed.

11. Rheostatic braking may be applied to an induction motor provided
(*a*) separate d.c. source for field excitation is available
(*b*) it is a squirrel cage type
(*c*) it is slip-ring type
(*d*) variable external resistance is available

12. During regenerative braking of electric motors, they are
(*a*) disconnected from the supply
(*b*) reverse-connected to the supply
(*c*) made to run as generators
(*d*) made to stop.

13. Regenerative braking
(*a*) can be used for stopping a motor
(*b*) cannot be easily applied to d.c. series motors
(*c*) can be easily applied to d.c. shunt motors
(*d*) cannot be used wen motor load has over-hauling characteristics

14. Net energy saved during regenerative braking of an electric train
(*a*) increases with increase in specific resistance
(*b*) is high with high down gradient
(*c*) decreases with reduction in train speed due to braking
(*d*) is independent of the train weight.

15. The selection of an electric motor for any application depends on which of the following factors?
(*a*) Electrical characteristics
(*b*) Mechanical characteristics
(*c*) Size and reating of motors
(*d*) cost
(*e*) All of teh above

16. For a particular application the type of electric and control gear are determined by which of the following considerations?
(*a*) Starting torque
(*b*) Conditions of environment
(*c*) Limitation on starting current
(*d*) Speed control range and its nature
(*e*) all of the above

17. Which of the following motors is preferred for traction work?
(*a*) Universal motor
(*b*) D.C. series motor
(*c*) Synchronous motor
(*d*) three-phase induction motor

18. Which of the following motors always starts

on load?
(*a*) Conveyor motor (*b*) Floor mill motor
(*c*) Fan motor (*d*) All of the above

19. .... is preferred for automatic drives.
(*a*) Squirrel cage induction motor
(*b*) Synchronous motors
(*c*) Ward-Leonard controlled D.C. motors
(*d*) Any of the above

20. When the load is above .... a synchronous motor is found to be more economical.
(*a*) 2 kW (*b*) 20 kW
(*c*) 50 kW (*d*) 100 kW

21. The load cycle for a motor driving a power press will be ....
(*a*) variable load
(*b*) continuous
(*c*) continuous but periodical
(*d*) intermittent and variable load

22. Light duty cranes are used in which of the following?
(*a*) Power houses
(*b*) Pumping station
(*c*) Automobile workshops
(*d*) all of the above

23. While selecting an electric motor for a floor mill, which electrical characteristics will be of least significance?
(*a*) Running characteristics
(*b*) Starting charasteristics
(*c*) Efficiency
(*d*) Braking

24. Which of the following motors are preferred for overhead travelling cranes?
(*a*) Slow speed motors
(*b*) Continuous duty motors
(*c*) Short time rated motors
(*d*) None of the above

25. .... is preferred for synthetic fibre mills.
(*a*) Synchronous motor
(*b*) Reluctance motor
(*c*) Series motor
(*d*) Shunt motor

26. Ward-Leonard controlled D.C. drives are generally used for .... excavators.
(*a*) Light duty (*b*) Medium duty
(*c*) Heavy duty (*d*) All of the above

27. Which of the following motors is used for elevators?
(*a*) Induction motor
(*b*) Synchronous motor
(*c*) Capacitor start single phase motor
(*d*) Any of the above

28. Which part of a motor needs maximum attention for maintenance?
(*a*) Frame (*b*) Bearing
(*c*) Stator winding (*d*) Rotor winding

29. .... need frequent starting and stopping of electric motors.
(*a*) Paper mills
(*b*) Grinding mills
(*c*) Air-conditioners
(*d*) Lifts and hoists

30. Which feature, while selecting a motor for centrifugal pump, will be of least significance?
(*a*) Starting characteristics
(*b*) Operating speed
(*c*) Horse power
(*d*) Speed control

31. ...... motor is a constant speed motor.
(*a*) Synchronous motor
(*b*) Schrage motor
(*c*) Induction motor
(*d*) Universal motor

32. The starting torque is case of centrifugal pumps is generally
(*a*) less than running torque
(*b*) same as running torque
(*c*) slightly more than running torque
(*d*) double the running torque

33. Which of the following motors are best for the rolling mills?
(*a*) Single phase motors
(*b*) Squirrel cage induction motors
(*c*) Slip ring induction motors
(*d*) D.C. motors

34. .... is not a part of ball bearing?
(*a*) Inner race (*b*) Outer race
(*c*) Cage (*d*) Bush

35. The starting torque of a D.C. motor is independent of which of the following?
(*a*) Flux
(*b*) Armature current
(*c*) Flux and armature current
(*d*) Speed

36. Rotor of a motor is usually supported on .... bearings.
(*a*) ball or roller (*b*) needle
(*c*) bush (*d*) thrust

37. For which of the following applications D.C. motors are still preferred?
(*a*) High efficiency operation
(*b*) Reversibility

(*c*) Variable speed drive
(*d*) High starting torque

38. In a paper mill where constant speed is required
(*a*) synchronous motors are preferred
(*b*) A.C. motors are preferred
(*c*) individual drive is preferred
(*d*) group drive is preferred

39. A reluctance motor ......
(*a*) is provided with slip rings
(*b*) requires starting gear
(*c*) has high cost
(*d*) is compact

40. The size of an excavator is usually expressed in terms of
(*a*) 'crowd' motion (*b*) angle of swing
(*c*) cubic metres (*d*) travel in metres

41. For blowers which of the following motors in preferred?
(*a*) d.C. series motor
(*b*) D.C. shunt motor
(*c*) Squirrel cage induction motor
(*d*) Wound rotor induction motor

42. Belted slip ring induction motor is almost invariably used for
(*a*) water pumps
(*b*) jaw crushers
(*c*) centrifugal blowers
(*d*) none of the above

43. Which of the following is essentially needed while selecting a motor?
(*a*) Pulley (*b*) Starter
(*c*) Foundation pedal (*d*) Bearings

44. Reluctance motor is a ....
(*a*) variable torque motor
(*b*) low torque variable speed motor
(*c*) self starting type synchronous motor
(*d*) low noise, slow speed motor

45. .... method of starting a three phase induction motor needs six terminals.
(*a*) Star-delta
(*b*) Resistance starting
(*c*) Auto-transformer
(*d*) None of the above

46. In .... method of starting three phase induction motors the starting voltage is not reduced.
(*a*) auto-transformer
(*b*) star-delta
(*c*) slip ring
(*d*) any of the above

47. In jaw crushers a motor has to often start against ...... load.
(*a*) heavy (*b*) medium
(*c*) normal (*d*) low

48. For a motor-generator set which of the following motors will be preferred?
(*a*) Synchronous motor
(*b*) Slip ring induction motor
(*c*) Pole changing induction motor
(*d*) Squirrel cage induction motor

49. Which of the following motors is usually preferred for kiln drives?
(*a*) Cascade controlled A.C. motor
(*b*) slip ring induction motor
(*c*) three phase shunt would commutator motor
(*d*) Any of the above

50. Heat control switches are used in ....
(*a*) transformers
(*b*) cooling ranges
(*c*) three phase induction motors
(*d*) single phase

51. .... has relatively wider range of speed control
(*a*) Synchronous motor
(*b*) Ship ring induction motor
(*c*) Squirrel cage induction motor
(*d*) D.C. shunt motor

52. In squirrel cage induction motors which of the following methods of starting cannot be used?
(*a*) Resistance in rotor circuit
(*b*) Resistance in stator circuit
(*c*) Auto-transformer starting
(*d*) Star-delta starting

53. In which of the following applications the load on motor changes in cyclic order?
(*a*) Electric shovels
(*b*) Cranes
(*c*) Rolling mills
(*d*) All of the above

54. Flame proof motors are used in
(*a*) paper mills
(*b*) steel mills
(*c*) moist atmospheres
(*d*) explosive atmospheres

55. Which of the following machines has heavy fluctuation of load?
(*a*) Printing machine
(*b*) Punching machine
(*c*) Planer
(*d*) Lathe

56. For derries and winches which of the following drives can be used?
(*a*) Pole changing squirrel cage motors
(*b*) D.C. motors with Ward-leonard control

(c) A.C. slip ring motors with variable resistance
(d) Any of the above

57. Battery operated scooter for braking uses
(a) plugging
(b) mechanical braking
(c) regenerative braking
(d) rheostatic braking

58. .... has least range of speed control.
(a) Slip ring induction motor
(b) Synchronous motor
(c) D.C. shunt motor
(d) Schrage motor

59. .... has the least value of starting torque to full load torque ratio.
(a) D.C. shunt motor
(b) D.C. series motor
(c) Squirrel cage induction motor
(d) Slip ring induction motor

60. In case of .... speed control by injecting e.m.f. in the rotor circuit is possible.
(a) d.c. shunt motor
(b) schrage motor
(c) synchronous motor
(d) slip ring induction motor

61. A pony motor is used for the starting which of the following motors?
(a) Squirel cage induction motor
(b) Schrage motor
(c) Synchronous motor
(d) None of the above

62. In .... the speed can be varied by changing the position of brushes.
(a) slip ring motor
(b) schrage motor
(c) induction motor
(d) repulsion motor

63. In which of the following applications variable speed operation is preferred?
(a) Exhaust fan
(b) Ceiling fan
(c) Refrigerator
(d) Water pump

64. Heavy duty cranes are used in
(a) ore handling plants
(b) steel plants
(c) heavy engineering workshops
(d) all of the above

65. the travelling speed of cranes varies from
(a) 20 to 30 m/s
(b) 10 to 15 m/s
(c) 5 to 10 m/s
(d) 1 to 2.5 m/s

66. Besides a constant speed a synchronous rotor possesses which of the following advantages?
(a) Lower cost
(b) Batter efficiency
(c) High power factor
(d) All of the above

67. By the use of which of the following D.C. can be obtained from A.C.?
(a) Silicon diodes
(b) Mercury are rectifier
(c) Motor generator set
(d) any of the above

68. Which of the following motors is preferred when quick speed reversal is the main consideration?
(a) Squirrel cage induction motor
(b) Wound rotor induction motor
(c) Synchronous motor
(d) D.C. motor

69. Which of the following motors is preferred when smooth and precise speed control over a wide range is desired?
(a) D.C. motor
(b) Squirrel cage induction motor
(c) Wound rotor induction motor
(d) Synchronous motor

70. For crane travel which of the following motors is normally used?
(a) Synchronous motor
(b) D.C. differentially compound motor
(c) Ward-Leonard controlled D.C. shunt motor
(d) A.C. slip ring motor

71. The capacity of a crane is expressed in terms of
(a) type of drive
(b) span
(c) tonnes
(d) any of the above

72. the characteristics of drive for crane hoisting and lowering are which of the following?
(a) Precise control
(b) Smooth movement
(c) Fast speed control
(d) All of the above

73. Which of the following motors is preferred for boom hoist of a travelling crane?
(a) Single phase motor
(b) Synchronous motor
(c) A.C. slip ring motor

(*d*) Ward-Leonard controlled D.C. shunt motor

74. A wound rotor induction motor is preferred, as compared to squirrel cage induction motor, when major consideration is
(*a*) slop speed operation
(*b*) high starting torque
(*c*) low windage losses
(*d*) all of the above

75. Which of the following motors has series characteristics?
(*a*) Shadel pole motor
(*b*) Repulsion motor
(*c*) Capacitor start motor
(*d*) None of the above

76. Which of the following happens when star-delta starter is used?
(*a*) Starting voltage is reduced
(*b*) Starting current is reduced
(*c*) Both (*a*) and (*b*)
(*d*) None of the above

77. For a D.C. shunt motor which of the following is incorrect?
(*a*) Unsuitable for heavy duty starting
(*b*) Torque varies as armature current
(*c*) Torque-armature current is a straight line
(*d*) Torque is zero for zero armature current

78. For which of the following applications motor has to start with high acceleration?
(*a*) Oil expeller
(*b*) Floor mill
(*c*) Lifts and hoists
(*d*) centrifugal pump

79. Which of the following types of motor enclosure is safest?
(*a*) totally enclosed
(*b*) Totally enclosed fan cooled
(*c*) Open type
(*d*) Semi closed

80. While selecting motor for an air conditioner which of the following characteristics is of great importance?
(*a*) Type of bearings
(*b*) Type of enclosure
(*c*) Noise
(*d*) Arrangement for power transmission
(*e*) None of the above

81. The diameter of the rotor shaft for an electric motor depends on which of the following?
(*a*) r.p.m. only
(*b*) Horse power only
(*c*) Horse power and r.p.m.
(*d*) Horse power, r.p.m. and power factor

82. Which of the following alternatives will be cheaper?
(*a*) A 100 H.P. A.C. three phase motor
(*b*) Four motors of 25 H.P. each
(*c*) Five motors of 20 H.P. each
(*d*) Ten motors of 10 H.P. each

83. The cost of an induction motor will increase as
(*a*) horsepower rating increases but r.p.m. decreases
(*b*) horsepower rating decreases but r.p.m. increases
(*c*) horsepower rating and operating speed increases
(*d*) horsepower rating and operating speed decreases

84. in series motor which of the following methods can be used for changing the flux per pole?
(*a*) Tapped field control
(*b*) Diverter field control
(*c*) Series-parallel control
(*d*) Any of the above

ANSWERS

1. (*c*)	**2.** (*b*)	**3.** (*d*)	**4.** (*c*)	**5.** (*c*)	**6.** (*d*)	**7.** (*c*)	**8.** (*c*)	**9.** (*b*)	**10.** (*c*)
11. (*a*)	**12.** (*c*)	**13.** (*c*)	**14.** (*b*)	**15.** (*e*)	**16.** (*e*)	**17.** (*b*)	**18.** (*d*)	**19.** (*c*)	**20.** (*d*)
21. (*d*)	**22.** (*d*)	**23.** (*d*)	**24.** (*c*)	**25.** (*b*)	**26.** (*c*)	**27.** (*a*)	**28.** (*b*)	**29.** (*d*)	**30.** (*d*)
31. (*a*)	**32.** (*a*)	**33.** (*d*)	**34.** (*d*)	**35.** (*d*)	**36.** (*a*)	**37.** (*c*)	**38.** (*c*)	**39.** (*d*)	**40.** (*c*)
41. (*c*)	**42.** (*b*)	**43.** (*b*)	**44.** (*c*)	**45.** (*a*)	**46.** (*c*)	**47.** (*a*)	**48.** (*a*)	**49.** (*d*)	**50.** (*b*)
51. (*d*)	**52.** (*a*)	**53.** (*d*)	**54.** (*d*)	**55.** (*b*)	**56.** (*d*)	**57.** (*b*)	**58.** (*b*)	**59.** (*c*)	**60.** (*d*)
61. (*c*)	**62.** (*b*)	**63.** (*b*)	**64.** (*d*)	**65.** (*d*)	**66.** (*c*)	**67.** (*d*)	**68.** (*c*)	**69.** (*a*)	**70.** (*d*)
71. (*c*)	**72.** (*d*)	**73.** (*c*)	**74.** (*b*)	**75.** (*b*)	**76.** (*c*)	**77.** (*a*)	**78.** (*c*)	**79.** (*b*)	**80.** (*c*)
81. (*c*)	**82.** (*a*)	**83.** (*a*)	**84.** (*d*)						

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