Chapter 16

D. C MOTORS IN MINES

In the underground, most of the electric locomotives in use are powered by direct current motors working from a secondary battery supply. Series d.c. motors are usually used, as their armatures are permanently coupled to the driving wheels to prevent any possibility of their racing off load. Most locomotives have two driving motors, one at each end; on some locomotives two motors are connected in series, on others they are connected in parallel. Each motor is equipped with a bank of starting resistors, and the driver progressively switches them out by turning his control handle until all the resistances are out of circuit when the locomotive is travelling at full speed. The dirver uses the same resistors as a means of controlling the speed of the locomotives.

16.1. Locomotive Batteries

The batteries carried by a locomotive are of the lead acid type. When fully charged, the batteries must store sufficient energy to drive the locomotive for a minimum period of three to five hours. In fact, batteries having the required capacity are necessarily bulky, and they usually constitute a large part of the locomotive.

16.2. Charging Station

When the useful charge of the batteries is nearly exhausted, the locomotive is taken to an underground charging station so that the batteries can be charged. The batteries stand on a platform on the locomotive chassis. With some types of locomotives, the platform is provided with rollers so that the batteries can be pushed across to a platform beside the locomotive in a similar way. Alternatively the batteries may be loaded and unloaded by means of straps or slings. While at the charging station, batteries are put on charge and given any attention they need.

The charging of batteries is carefully controlled in order to minimise the rate at which hydrogen is produced. During the early part of the charging period a heavy charging current is passed through the battery. After a period of about five hours, gassing begins and if the heavy rate of charge were continued, dangerous quantities of hydrogen would be given off. The charge is, therefore, completed with a reduced current. Hydrogen is produced during the whole of the reduced current-charging period, but the charging current is carefully adjusted to keep gearing to a minimum. The ventilation of the charging station is carefully controlled to ensure hydrogen cannot accumulate. The total charging period for a locomotive battery is from eight to ten hours.

16.3. D. C. Motor

The two main parts of a direct current motor are a rotating part called the *armature*, and a stationary part called the *field*. In addition, there is a commutator mounted on the armature shaft, through which current is supplied to the armature winding and a set of brushes which make contact with the commutator and complete a circuit to the armature.

Now let us see what are the important parts of D.C. motors. A short description is given below:

(1) Armature :

The armature consists of a cylindrial core built up of soft iron laminations, and mounted on a

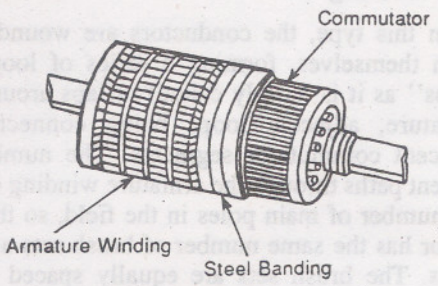


Fig. 16.1

steel shaft. The armature carries a winding, the conductors of which are usually laid in longitudinal slots cut into the outer surface of the core. The individual conductors are insulated from one another and from the core. They are usually kept in place by wedges of wood or moulded insulation such as prespahn bakelite which seal the open ends of the slots. The windings and slot wedges are held in place by bands of steel strips or wires, to prevent them from flying out when the armature is rotating at speed, as shown in Fig. 16.1. The armature shaft is supported by bearing at both the ends and sealed with inner and outer bearing caps.

(2) Commutator :

The commutator consists of a round part built of copper segments, which are insulated from one another by thin sheets of best quality mica. The segments are usually held in place by two installed vee-rings clamped tight by bolts, or a disc nut as shown in Fig. 16.2. The surface of the round

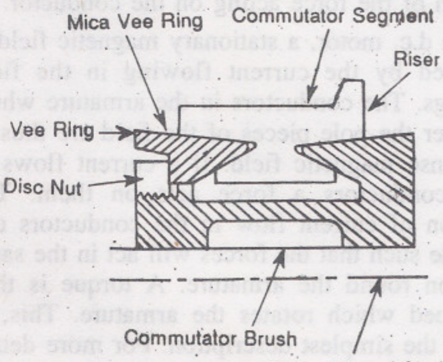


Fig. 16.2

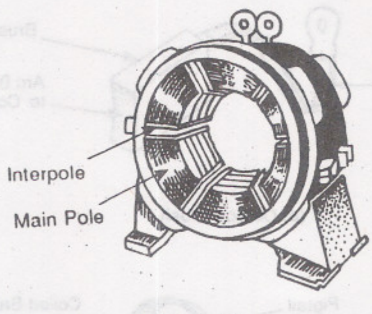


Fig. 16.3

commutator is machined to a very smooth finish, so that brushes bearing on its surface can make good electrical contact, as the armature rotates, with the least possible friction, vibration and rocking. Each segment of the commutator is connected to a point in the armature winding. The armature core is usually of larger diameter than the commutator and the connections are, therefore, made by copper bars radiating from the commutator. The connections are called commutator risers or commutator radials.

(3) Field Yoke :

The field consists of windings designed to create an intense static magnetic field when connected to the supply. The field windings are in fact placed in a hollow cylinder or *yoke*. Pole pieces, or pole shoes, built up of laminations of soft iron, are bolted inside the yoke and the field winding consists of coils wound round the pole pieces. Fig. 16.3. shows the yoke with field of a d. c. motor. The figure gives a simple isometric view of a yoke.

(4) Brush Gear :

In a d.c. motor, the current is supplied to the armature through carbon brushes which bear on the surface of the commutator. A brush is usually rectangular in section, and the end is bedded to the arc of the commutator in order to ensure maximum contact area, and therefore, minimum contact resistance. Fig. 16.4.(a) shows one carbon brush. The brushes are held in open-ended brush holder (or brush boxes) in which they are a snug fit, but free to slide. A spring, or spring loaded lever, bears on the top end of the brush keeping

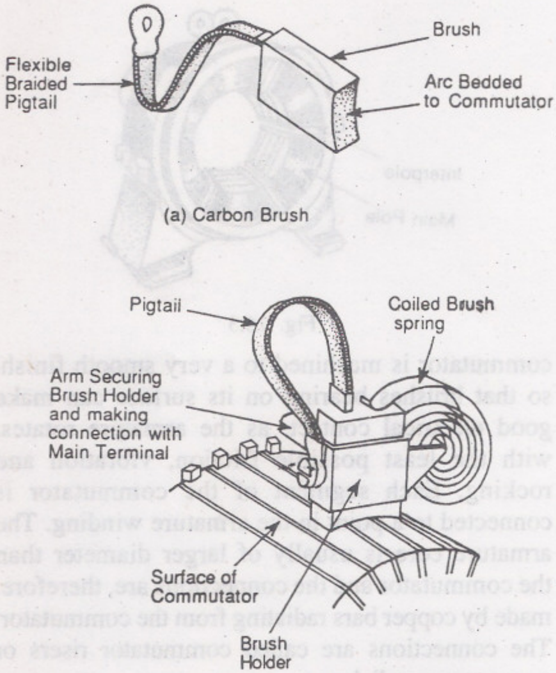


Fig. 16.4(a) & (b)

the brush in contact with the commutator surface. The pressure exerted by the spring is sufficient to maintain a good electrical contact between the brush and the commutator and to prevent the brush from bouncing. Fig. 16.4(b) shows the brush in a brush holder, for easy reference. Each brush is connected to a fixed terminal by a flexible copper braid connector. One end of the connector is embedded in the top of the brush and the other end has a terminal tag which is used to secure it to the terminal.

Generally the brushes are divided into a number of sets. A set on a small motor may consist of a single brush, but on a larger machine a set will consist of two or more brushes making contact with the commutator at the same radial position. The brush sets are mounted in an insulated brush ring which is bolted to the yoke or motor housing.

The number of brush sets required by a motor depends upon the way in which the armature is wound. Two types of armature windings are in general use, i.e. lap winding and wave winding.

Lap Winding

In this type, the conductors are wound back upon themselves, forming a series of loops (or ''laps'' as it is loosely called) or laps around the armature, adjacent loops being connected to adjacent commutator segments. The number of current paths through the armature winding equals the number of main poles in the field, so that the motor has the same number of brush sets as field poles. The brush sets are equally spaced round the commutator and connected to the positive and negative supply lines.

Wave Windings

In this type of windings the conductors are wound forward in waves round the armature (and thus the name wave winding), so that each conductor 'visits' each pole of the field in turn. There are only two current paths through the armature winding so that the machine needs only two brush sets, irrespective of the number of field poles. The spacing of the brush sets depends upon the number of poles ; on a four-pole machine, the brush sets would be placed actually at right angles.

16.4. Operation of a. d.c. motor

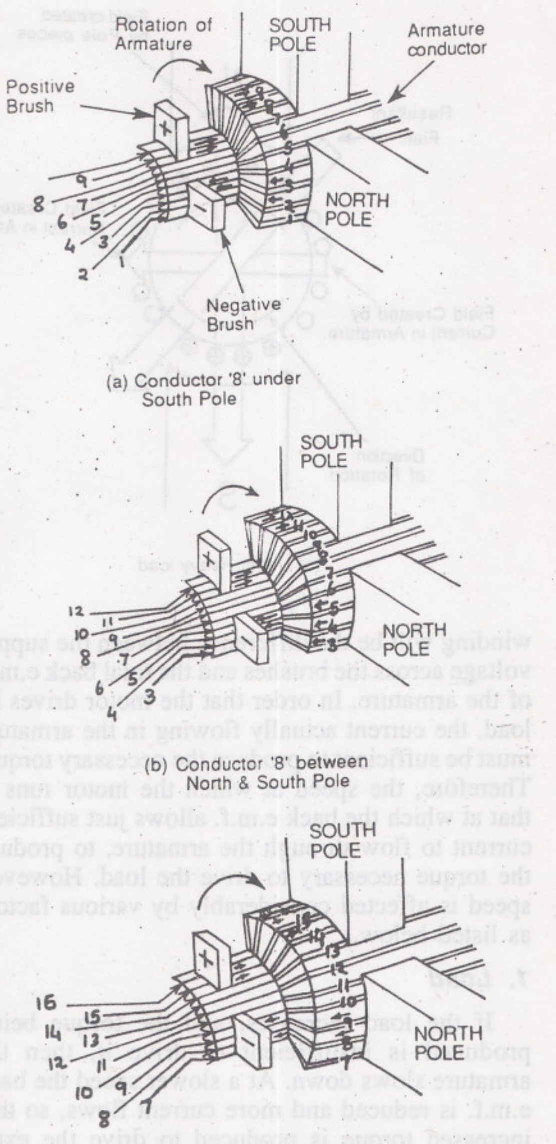
We know from the first principle that a conductor carrying a current and placed in a magnetic field will tend to move throughout the magnetic field. The direction of motion depends upon the direction of the current in the conductor and the polarity of the field as per Fleming's left hand rule of motors. In fact the strength of the magnetic field and the strengh of the current flowing in the conductor together determine the strength of the force acting on the conductor.

In a d.c. motor, a stationary magnetic field is produced by the current flowing in the field windings. The conductors in the armature which lie under the pole pieces of the field are thus in an intense magnetic field. If a current flows in these conductors a force acts on them. The direction of current flow in the conductors can be made such that the forces will act in the same direction round the armature. A torque is then developed which rotates the armature. This, in fact, is the simplest description. For more detail, the books dealing extensively with theory can be referred to.

Commutation :

During the revolution of the armature, at any point, circuits are made through the armature winding from the commutator segments in contact with positive brushes, through conductors immediately under the poles, to segments in contact with negative brushes. As the armature rotates, new conductors come under each pole and new segments make contact with each set of brushes. As a conductor moves away from, say, a north pole, the circuit through it is broken by the commutator segments passing from under the brushes. As the armature continues to rotate, this conductor then comes under a south pole. A circuit is again completed through it by the same two commutator segments coming under brushes of opposite polarity. Current flows through the conductor in the opposite direction. The conductor, therefore, continues to develop torque in the same direction. Since the conductors pass alternately under poles of opposite polarity, each conductor carries, in effect, an alternating current.

The object of commutation is to keep the current paths of the armature winding stationary in space as far as possible, while the armature itself rotates so that torque is continuously developed. Fig. 16.5 illustrates the point. Note, however, that the armature arrangement has been simplified to aid the illustration, and does not present an operational armature winding.



(a) Conductor '8' under South Pole

(b) Conductor '8' between North & South Pole

(c) Conductor '8' under North Pole

Fig. 16.5

Reversal of rotation :

The direction of the rotation of a d.c. motor is reversed by reversing the connections to either the field or the brushes. The direction of rotation remains the same if both sets of connections are reversed.

Back E.M.F. :

When the armature is rotating within the magnetic field, e.m.f.s. are induced in its conductors because of the relative motion between the conductors and the field. The e.m.f. induced at any moment in any conductor is opposed to the e.m.f. driving current through that conductor. The induced e.m.f. is therefore a back e.m.f. The back e.m.f.s. in the individual conductors jointly form an armature back e.m.f., opposing the supply voltage connected across the brushes. The strength of the back e.m.f. in the armature is proportional to the strength of the field and the speed of rotation of the armature. Since the resistance of the armature winding is low (generally less than 1.0 ohm), back e.m.f. is the principal factor in limiting current in the armature circuit.

Speed :

When the motor is running, the potential difference driving current through the armature

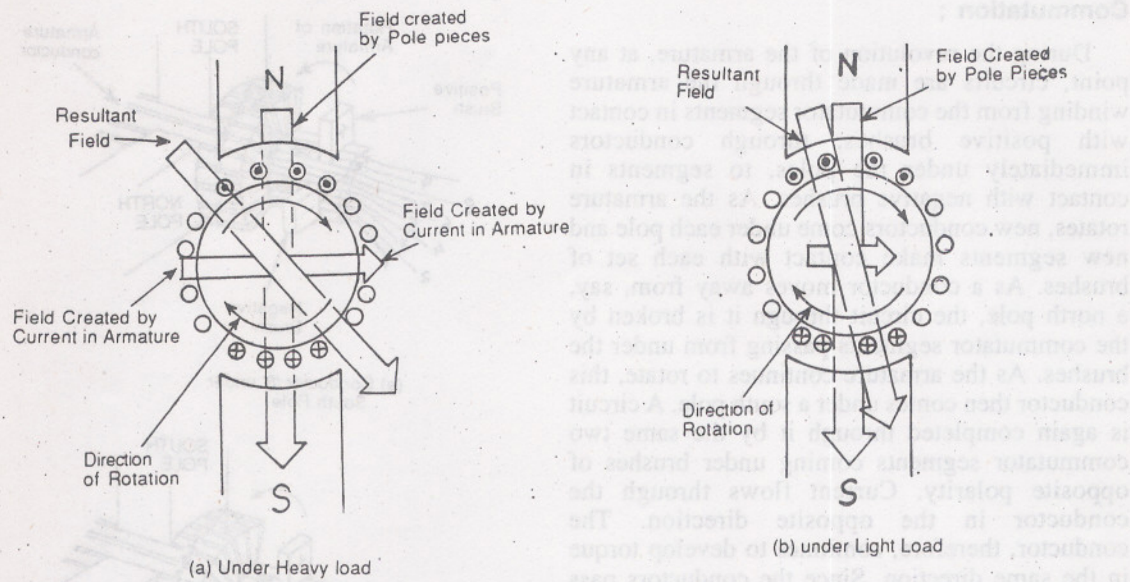


Fig. 16.6

winding will be the difference between the supply voltage across the brushes and the total back e.m.f. of the armature. In order that the motor drives its load, the current actually flowing in the armature must be sufficient to produce the necessary torque. Therefore, the speed at which the motor runs is that at which the back e.m.f. allows just sufficient current to flow through the armature, to produce the torque necessary to drive the load. However, speed is affected considerably by various factors as listed below.

1. Load

If the load increases, and the torque being produced is insufficient to drive it, then the armature slows down. At a slower speed the back e.m.f. is reduced and more current flows, so that increased torque is produced to drive the extra load. Conversely, if the load is reduced, a smaller torque, and therefore, less current is required to drive it. The armature then speeds up, and eventually increases the back e.m.f.

2. Voltage applied to Armature

The current flowing in the armature is proportional to the difference between the applied voltage and the voltage of the back e.m.f. If the voltage applied to the armature is increased the difference between it and the back e.m.f. increases and so does the current flowing in the armature. The speed of the armature increases, restoring the difference between the applied voltage and the back e.m.f. Conversely, if the voltage applied to the armature is decreased, then the armature slows up so that the back e.m.f. is reduced.

3. Strength of Field

If the strength of the field increases, the back e.m.f. induced at any speed of rotation increases. The armature current decreases and so does the torque. To drive its load, therefore, the armature must rotate more slowly. Conversely, if the strength of the field is reduced, the back e.m.f. at any speed of rotation is reduced and the armature current increases. The motor, therefore, tends to drive its load faster if the field strength is reduced. However, as the torque depends both upon the strength of the field and the strength of the armature current, more current is required in the armature to drive a given load, if the field strength is reduced.

4. Armature Reaction

When a motor is running, current circulates in the windings of the armature and creates a magnetic field. The strength of the armature field depends upon the strength of the current flowing in the armature and, therefore upon the torque exerted by the motor.

The field created by the armature is stationary in space but its polarity does not coincide with the polarity of the main field. The effective field in which the armature is running is the resultant of the main field and the armature field as shown in Fig. 16.6. The axis of polarity of the resultant field does not coincide with the axis of the mechanical poles pieces, and its position varies with the load driven by the motor. The distortion of the effective field of the motor is called armature reaction.

5. Brush Position

Brushes have to be placed around the commutator in a way that the direction of current in each conductor is changed whilst that conductor is in a neutral position between two pieces. If the brush position is incorrect, the change in current direction occurs under a pole ; so that, for part of the time the conductor is under a pole, current flows in the wrong direction. Heavy sparking occurs at the brushes and the commutator is likely to be charged in consequence. The poles under which the conductors pass are the poles of effective magnetic field and not the physical pole pieces of the field winding.

The effective magnetic field is the resultant between the magnetic field produced by the field windings and that produced by the armature. The precise position of the effective poles, and therefore, the correct position of the brushes, is consequently determined by the strength of the armature current. Since the strength of the armature current is determined by the speed of the motor and the load driven, the precise position of the effective poles, and therefore, correct brush position, also depends upon the speed and load. A direct current motor as so far described, with brushes in a fixed position, could therefore operate efficiently at only one speed and load.

6. Brush Rocking

One method of accomodating change of the position of the resultant field is to move the brushes on the brush ring which can be rotated (or rocked) about the axis of the commutator. The position of the brushes can, therefore, be set for whatever load the motor happens to be driving. This method is suitable only for motors which are used for driving a load at constant speed and when changes in load occur at infrequent intervals. It is unsuitable for motors which are intended to run under varying load and speed conditions and is rarely used on modern machines.

7. Interpoles

Motors designed to run at variable speeds, or to take widely differing loads, are usually provided with interpoles i.e. small pole windings placed between the main poles of the field to stabilise the resultant field. Interpoles create a magnetic field which opposes the effect of the armature reaction. The windings are connected in series with the armature so that the strength of the interpole field increases or decreases with the strength of the armature reaction. The interpoles stabilise the effective magnetic field over a range of loads and speeds. One brush position remains correct over this range so that the motor can drive varying loads efficiently and without sparking at the brushes.

16.5. Types of Direct Current Motors

The field windings of the motor may either be connected in series with the armature or in parallel with it. These two methods of field connection produce two different types of motor with different characteristics. A third type of motor combines their characteristics.

1. Shunt Motor :

The field windings are connected in parallel with the armature as shown in Fig, 16.7. Both the field and the armature are therefore connected directly across the supply. The current flowing in the field windings is constant, so that field strength is also constant. The current flowing in the armature, and therefore, the speed of the motor, depends upon the load, but the speed variation necessary is usually a fairly small percentage of the overall speed of the motor. A shunt motor is, therefore, used where a nearly constant speed is required over a wide range of loading.

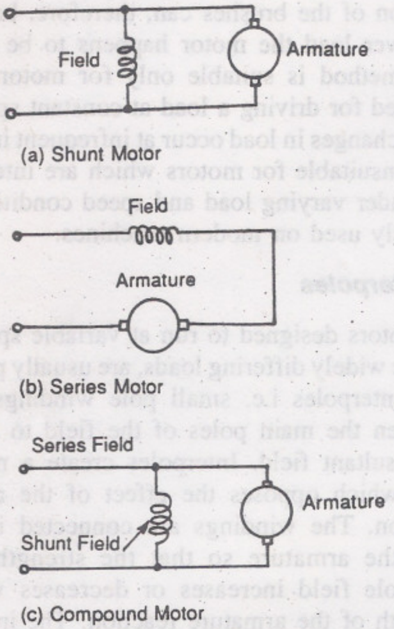


Fig. 16.7

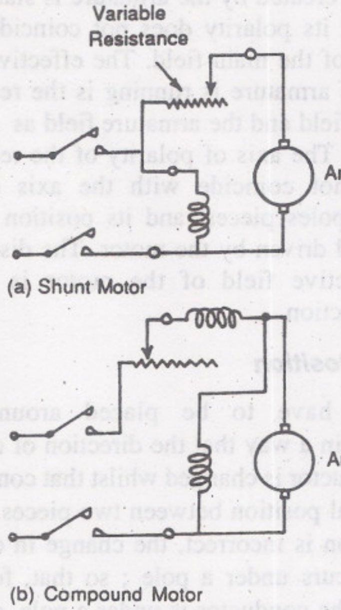


Fig. 16.8

2. Series Motors :

In Fig. 16.7(b) it is shown that the field windings are connected in series with the armature. The field current, and hence the field strength, is therefore determined by the armature current. When the armature current is high the field is strong, and when the armature current is low the field is weak.

The speed of a series motor varies considerably with the load. When driving a heavy load, a heavy current is required. The field naturally is strong, and a strong back e.m.f. is induced at a fairly slow speed so that the armature turns slowly. On light loads, a smaller armature current is required so that the field is weak. The armature therefore, reaches a high speed before the required back e.m.f. is induced. A series motor is used where speed control and a heavy starting torque are required, e.g. as in a traction motor for an electric locomotive. In fact a series motor should never be allowed to run without a load because it is liable to race out of control and the armature would be in danger of disintegration and causing serious damage to the insulation.

3. Compound Motor :

In this type of motor there are two field windings, one in series with the armature and one in parallel with it, as shown in Fig. 16.7(c). A compound motor in fact, can, like a series motor, exert heavy torque at slow speeds, but is prevented by the shunt winding from racing when at off load.

16.6. Starting of a D. C. Motor

Some shunt motors can be started by connecting the supply directly to the motor. The armature winding have a very low resistance usually less than 1 ohm. At the moment of starting there is no back e.m.f. If the full supply voltage is connected to the armature a very heavy current will flow, and the armature may burn out before it can start rotating. A resistance is, therefore, connected in series with the armature to limit current on starting. The resistance is progressively reduced as the motor speeds up, and fully cut out of circuit when full running speed is reached, as shown in Fig. 16.8. A series or compound wound motor however can be started by direct switching, since the combined resistance of the series field and armature is sufficient to prevent a dangerously strong current flowing. The total resistance of the motor is likely to be no more than a few ohms,

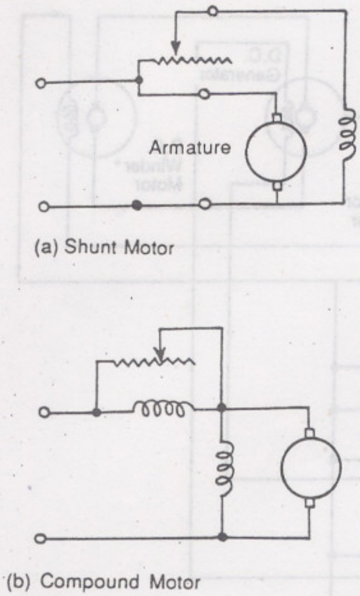


Fig. 16.9

so that starting current will be several times greater than full load current. As a consequence, starting torque is very great, e.g., seven or eight times full load torque, so that a starting resistance may be needed to limit this torque as shown in Fig. 16.8.(b). The resistance is progressively reduced as the motor speeds up.

Speed control :

The speed of a shunt motor can be reduced by using the starting resistances in series with the armature as explained in Fig. 16.8(a). In fact, in this method, an increase in the series resistance decreases the motor speed and vice-versa. However, the author's method of controlling the speed of a shunt motor, is to connect a variable resistance in series with the field as shown in Fig. 16.9.(a) This resistance is used to vary the field current and therefore the strength of the field. Any increase here in the resistance increases the motor speed, (but decreases the maxium load the motor will drive) and vice versa.

For a series or compound motor, speed is controlled by a variable resistance in series with the whole motor [see Fig. 16.8. (b)], or in parallel with the series field [see Fig. 16.9. (b)]. An increase in the resistance decreases the motor speed, and vice versa.

16.7. Electric Braking

Motors can be used to apply a braking torque to the load. Two forms of braking are commonly used: Dynamic and Regenerative. In a dynamic braking, the motor is used as a generator and is made to feed electrical power to a resistance load. This power is dissipated as heat. Regenerative braking uses the motor as a generator but feeds the electrical power back into the power supply.

Dynamic braking is more flexible than regenerative braking but gives the problem of dissipating heat from the resistor. It is less efficient than regenerative braking and is the form of braking adopted on many a.c. winders. Regenerative braking is the form used on d.c. winder drives, the energy removed from bringing the conveyors to rest being returned to the power supply.

16.8. D. C. Winding Engines

Any d.c. motor, used to drive a colliery winding engine, must be suitable for operation in either forward or reverse directions and capable of producing maximum output torque at all speeds, from standstill to full speed.

The connection of field windings on such a motor differ from the previous types and is as follows :—

(a) The coils on the main poles are similar to the shunt type but are connected to a separate constant voltage supply.

(b) The interpoles are connected in series with the armature as in previous types.

(c) A compensating winding is utilised which consists of insulated copper bars let into slots in the faces of the main poles so that they are as close as possible to the armature. The ends of the bar are connected by insulated, formed copper strap to give winding, which is connected in series with the armature. This winding further neutralises the effects of armature reaction described previously. This type of motor

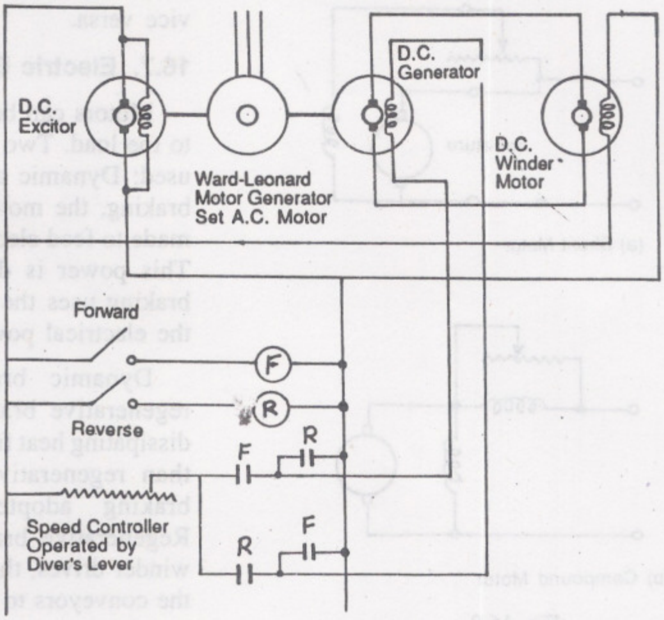


Fig. 16.10

is usually referred to as 'separately excited', and within small limits (due to losses and RI drops) is directly proportional to the value of applied armature voltage (and its polarity), at all output torques from zero to maximum. The output torque, infact, is proportional to the armature current. It will be seen that by supply of the armature current from a variable voltage source the speed of the motor can be controlled. This type of machines lends itself admirably to duties requiring fine speed control during acceleration and retardation in forwards and reverse directions such as in mine winder or rolling mills.

There are, in fact, two common methods in use for obtaining the variable d.c. voltage for speed control of the d.c. motor, namely–(1) the Ward-Leonard system, and (2) the Rectifier system.

(1) Control by Ward-Leonard System :

In this system the variable voltage is obtained from a motor generator set consisting basically of a relatively constant speed a.c. motor (i.e. slipring induction, or synchronous type) solidly and mechanically coupled to a separately excited d.c. generator. The system is explained schematically in Fig. 16.10. The output terminals of the d.c. generator are coupled electrically to the input terminals of the d.c. motor to form a heavy current armature loop circuit. The speed and direction of the d.c. motor is, therefore, dependent on magnitude and polarity of the d.c. generator field which is suitably controlled by the movement of the winding enginemen's control lever.

In its simple and original form, this control consisted of a series circuit from a constant d.c. voltage supply with a variable resistance rheostat, (operated by the control lever) field current and forward and reverse contactors (also selected by the lever) controlling the direction of current flow. The direction of current flow in the d.c. generator field determine the output voltage polarity and hence the direction of rotation of the d.c. motor. The magnitude of the d.c. generator field current determines the output voltage and hence the speed of the d.c. motor. The constant voltage d.c. supply for the d.c. motor field, d.c.

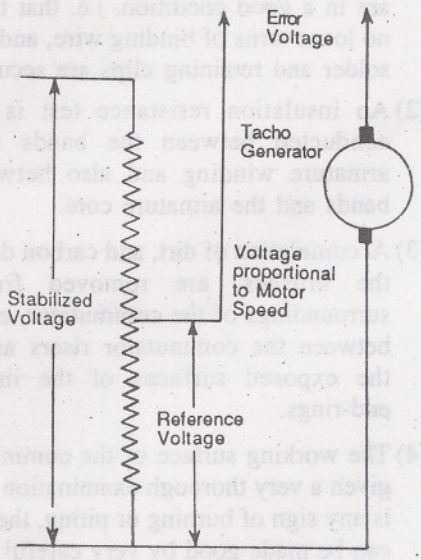


Fig. 16.11

generator field, and control circuits is derived from a separate d.c. exciter which can be part of the motor generator set, or separately driven by an a.c. motor. In this simple control system, however, at any particular value of applied voltage, the motor speed will fall slightly with increase in load and is known as an ''open loop'' system. On most of the Ward Leonard winders installed since late forties the control has been of the closed loop system. With this system there is no variation in speed with load. This is necessary for automatic winding to ensure accurate decking of cages at landings. In closed loop control a comparison is made between the motor speed demanded by the position of the driver's lever and the actual speed of the motor. This is shown in Fig. 16.11. The driver's lever, of course, operaters a potentiometer from which is obtained a reference voltage proportional to movement of the lever and the motor speed required, i.e. 100 per cent reference voltage at full lever throw requiring 100 per cent motor speed, 50 per cent reference voltage at half lever throw requiring 50 per cent speed, or zero reference voltage with lever in neutral requiring motor at standstill. A tacho-generator is driven from the motor to give a voltage output proportional to the actual motor speed. These two voltages are compared and the difference, known as the error voltage, and suitably amplified is used to increase or decrease the generator field current up until there is no error, that is, the motor runs at the speed required by the position of the driver's lever.

(2) Rectifier system :

In this system the d.c. supply to the winder motor is provided from a rectifier. In the past, these were usually of the mercury arc type in which the output voltage is controlled by means of anode grids. The grids can be biased to hold off the instant of anode firing during the positive half cycle and so vary the output voltage from maximum to zero. In the present and modern system, for this type of control, thyristors are used. In this book, we are not going deep into the detail of the principle of this system. However, it is important to note that the current through the rectifier being uni-directional, it is necessary to reverse the winder motor field to make the motor rotate in the reverse direction.

16.9. Inspection and Maintenance of D. C. Motors

The regular routine maintenance of direct current motors are given below in a systemetic way :

(1) Commutator & Brush :

At a regular interval carbon deposits are cleared from the interior of the brush gear housing and from the surface of the commutator. The commutators are regularly examined for its perfect surface suitable for good electrical contact. The brushes are also examined to ensure that they are still properly bedded to the commutator and to ascertain whether they require renewal. Brushes must be renewed before the copper connector which is embedded in them is exposed on the contact surface, otherwise the brush will damage the commutator. The manufacturers specify the amount of wear permitted before the brush is to be renewed.

If there are signs of heavy sparking at the brushes, e.g. if there are burn marks on the commutator segments, the cause must be found and rectified before the motor is put into service again.

(2) Inspection of Insulation :

The insulation of the field and armature windings are inspected from time to time for any sign of deterioration. The following conditions indicate that attention is required.

(a) Dampness and dirt, which reduce insulation resistance value.

(b) Cracked varnish, which will render the insulation vulnerable to penetration by dirt and moisture.

(c) Looseness of the windings in the armature slots or around the field pole pieces.

(3) Insulation Resistance tests :

Insulation resistance should be checked between :

(a) The field windings and the frame of the motor.

(b) The commutator segments (taking in the armature winding) and the armature core.

c) The brush gear and frame of the machine is tested periodically, usually by an insulation resistance tester, such as a Metro-ohm or a Megger. The readings obtained in successive tests are recorded, so that any tendency to deteriorate can be noticed, and necessary preventive action can be taken immediately.

If the two field windings of a compound wound motor can be electrically disconnected it is usual also to take the insulation resistance between two sets of windings.

(4) Winding Resistance Test :

At a regular interval, the resistance of each winding of the field is measured with a direct reading ohmmetor and it should be compared with the correct value supplied by the manufacturer.

(5) Examination of Armature :

When the armature is removed from the motor during an overhaul, the following inspection is to be carried out without fail :

(1) The armature bands which secure the windings are inspected to ensure that they are in a good condition, i.e. that there are no loose turns of binding wire, and that the solder and retaining clips are secure.

(2) An insulation resistance test is usually conducted between the bands and the armature winding and also between the bands and the armature core.

(3) Accumulation of dirt, and carbon dust from the brushes, are removed from the surroundings of the commutator, e.g. from between the commutator risers and from the exposed surfaces of the insulating end-rings.

(4) The working surface of the commutator is given a very thorough examination, if there is any sign of burning or piting, the surface can be made good by very careful turning. The cause of any sparking or abrasion which has damaged the commutator surface must at the same time be ascertained and rectified.

5) The mica segments of the commutator are examined. If there is any sign of burning or carbonisation, the mica segments must be replaced.

6) The surface of the commutator is examined to ensure that no mica segments are standing out of the copper segments. The mica segments are usually undercut slightly below (say about 1/32 inch to 1/6 inch deep) the level of the copper segments to avoid any possibility of their fouling with the brushes. On most of the machines, however, the micas are finished flush with the copper segments.

7) The soldered connections to the commutator are examined to ensure that the solder has not been thrown and that the joints are not cracked. The throwing of solder indicates loose windings in the armature slots.

The resistance of armature conductors is obtained by testing between each pair of adjacent commutator segments. A sensitive direct reading ohmmeter such as a ducter can be used, but more accurate results are obtained by passing a heavy current through the armature, and measuring the millivolt drop between segments. The resistance between each pair of segments should be the same within a tolerance specified by the maker. Any variation out of tolerance indicates a fault. A high resistance (or millivolt drop) between a pair of segments indicates an open circuit in the winding whereas a low resistance (or millivolt drop) indicates a short circuit. The millivolt drop has to be near to or equal to the results given by the manufacturer.

16.10. Fault–finding Tables :

The tables given below indicate the faults which occur most frequently with d.c. motors. Each table is headed by a defect which is commonly reported like, "Motor will not run" or say, "motor speed below normal" etc., and in the table will be found the most likely causes of that defect. The tables are not exhaustive, they are intended only as a guide to the investigation of a fault.

(a) When Motor does not run :

Possible Symptom of Fault	Causes
1. Armature not free to run.	Possibly a fault in the mechanical drive of the machine. The armature of a series motor may, however, lock against the field windings if the machine has been allowed to race and the armature bands have been burst, or some mechanical jamming has occurred.
2. Terminal connections Broken.	Due to overheat / mishandling, to be immediately rectified.
3. Current path through brushes interrupted.	One or more brushes not making contact with the commutator, or a broken connection to the brushgear.
4. Open circuit in field windings. 5. Short circuit in field winding	Test the resistance of the field windings with low-reading ohm-meter.

(b) Motor switchgear :

Possible Symptom of Fault	Causes
1. Opening-circuit in starting resistor	This fault would prevent the motor starting with resistance in circuit. The operator should not move the starting handle to the "RUN" position if the motor does not start normally.
2. Main contactor or reversing switch not completing circuit.	Examine the contacts for general condition. Ensure that contacts make with adequate pressure.

(c) Low speed of Motor (Below rated speed):

Possible symptom of fault	Causes and / or locating the causes
1. Resistance in starter panel not switched out properly.	Switch may be defective. Check and remove fault.
2. High resistance in armature.	Check soldered joints between the commutator risers and the resistances of the armature conductors.
3. Short circuit in armature.	Carry out a voltage drop test on armature, and / or an induction test.
4. Inadequate contact between brushes and commutator	Examine the brushes to ensure that their contact surface are bedded to the commutator arc, and that they are not damaged, pitted by sparking or covered with a film caused by oxidation.
5. Inadequate brush spring pressure	Measure the pressure of the brush springs with a spring balance. Ensure that the brushes are not worn beyond the point where the brush springs or spring loaded lever can bear on them effectively.

(d) High Speed (above rated speed) :

Symptom	causes, and / or locating causes
1. Compound or interpole winding short circuited, open circuited or reversed.	Examine the connections to these windings. Test their resistance with a low reading ohmmeter.
2. High resistance in shunt winding	Examine the connections to the windings, test its resistance with a low reading ohmmeter. If the motor has a shunt field speed control unit, ensure that the resistance is fully switched out.
3. One or more shunt coils reversed	Check the connections.
4. Short circuit in series field	Measure the resistance of the windings.
5. Brush position disturbed	Check the brush gear for any signs of movements, examine the surface of the commutator for burns pitting and other signs of sparking. This is only for series motor.
6. Machine on light load	

(e) Overheating

Symptom	causes, and / or locating causes
1. Cooling system not effective	The motor may have been working covered by coal dust, or otherwise covered so that air cannot reach the cooling surfaces. If a fan is fitted, ensure that it is working properly and that the air ducts are not blocked by coal dust or any other type of dirt and dust.
2. Continuous working on overload	It must be checked that the motor is driving the rated load. Check for faults in the mechanical drive, couplings, gearbox etc. which may impose excessive load on the motor.
3. Short circuit in field winding	Carry out a voltage drop test on armature or / and induction test.
4. Poor brush contact	Measure the brush spring pressure with a spring balance. Check that the brushes are not worn beyond the point where the brush springs or spring levers are fully effective. Examine the condition of the brush contact surfaces and the commutator working surface.
5. Brush friction	Examine the brush contact surfaces and the commutator working surface, for roughness and abrasion. Ensure that the brush spring pressure is not too great.
6. Excess current caused by tracking between commutator segments	Examine the commutator for deposits of dirt or carbon dust, in the slots between commutator segments or between the risers. And clean at regular intervals of maximum 500 hours operation.

(f) Vibration :

Possible Fault	Remedial Action
1. Commutator should be checked for :	
(a) Mica segments standing out of the copper segments.	Any or all of the defects must be corrected in a well equipped workshop.
(b) Some copper segments out of line.	
(c) Rough or uneven commutator surface.	

Possible Fault	Remedial Action
2. Armature core loose on shaft	Movements of the armature core on its shaft can sometimes be detected by the appearance of rusty powder around the centre of the core, and between the lamination of the cores. The equipment should be attended in a workshop efficiently.
3. Worn or damaged bearings .	Worn bearings are usually noisy when the motor is running and also cause heat loss. Sometimes due to defect in bearing, if not detected early, armature can rub with the field core, and thus damage the whole motor.