Unit-4- Electrical Machines

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Direct Current Machine

A DC machine is an electro-mechanical energy conversion device. When it converts mechanical power (ωT) into DC electrical power (EI), it is known as a DC generator. On the other hand, when it converts DC electrical power into mechanical power it is known as a DC motor.

Construction of DC Machine

The d.c. generators and d.c. motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. generator can be run as a d.c. motor and vice-versa.

The complete assembly of various parts in a scattered form of a DC machine is shown in Fig. 4.1. The essential parts of a DC machine are described below:

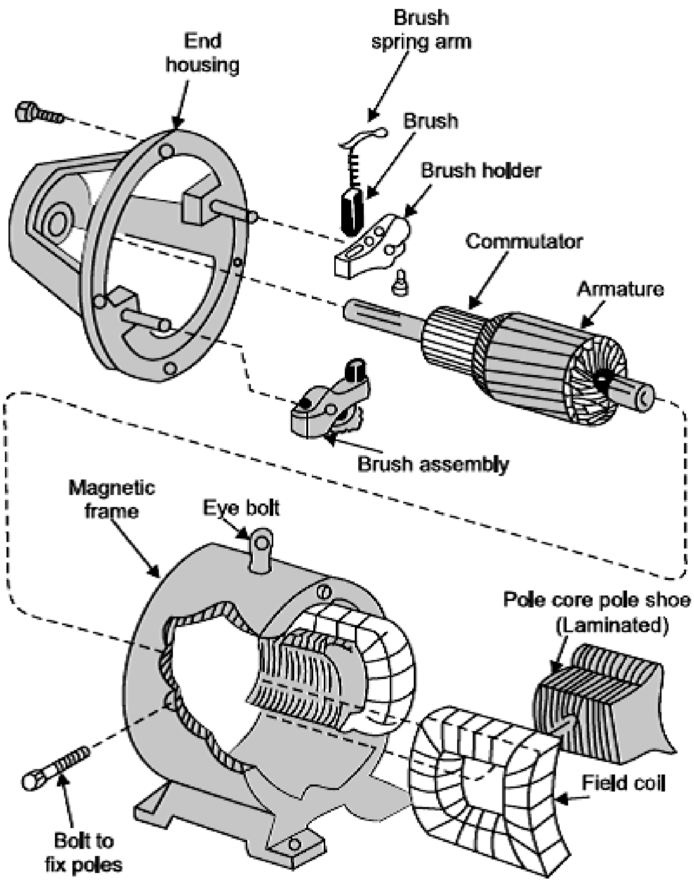


Fig-4.1 Disassembled parts of a DC machine

1. **Magnetic Frame or Yoke**: The outer cylindrical frames to which main poles and inter poles are fixed is called yoke. It also helps to fix the machine on the foundation. It serves two purposes:

(*i*) It provides mechanical protection to the inner parts of the machine.

(*ii*) It provides a low reluctance path for the magnetic flux.

The yoke is made of cast iron for smaller machines and for larger machines, it is made of cast steel or fabricated rolled steel since these materials have better magnetic properties as compared to cast iron.

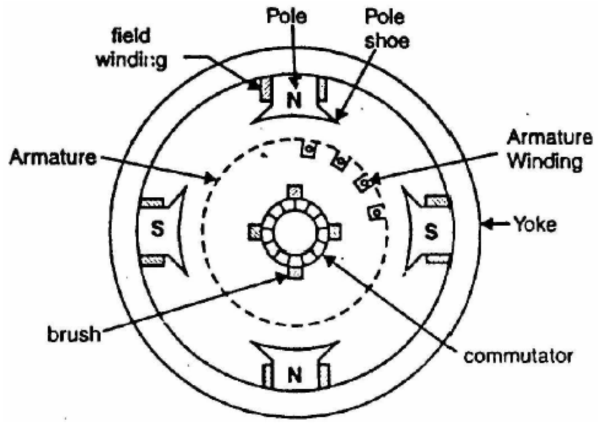


Fig-4.2 Sectional view of DC machine

2. **Pole Core and Pole Shoes**: The pole core and pole shoes are fixed to the magnetic frame or yoke by bolts. They serve the following purposes:
   - *(i)* They support the field or exciting coils.
   - *(ii)* They spread out the magnetic flux over the armature periphery more uniformly.
   - *(iii)* Since pole shoes have larger X-section, the reluctance of magnetic path is reduced.

   Usually, the pole core and pole shoes are made of thin cast steel or wrought iron laminations which are riveted together under hydraulic pressure as shown in Fig-4.3.

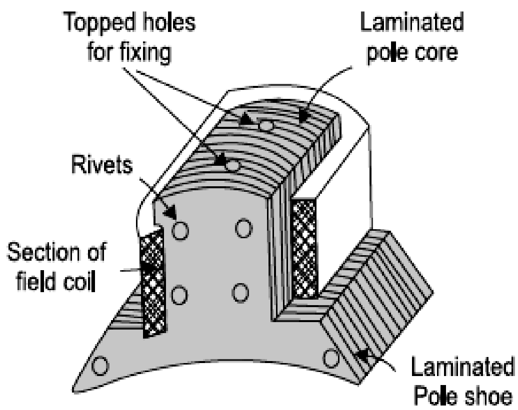


Fig-4.3 Field winding placed around pole core

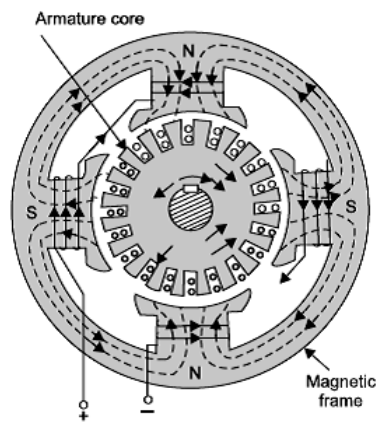


Fig-4.4 Magnetic circuit of DC machine

3. **Field or Exciting Coils**: Enameled copper wire is used for the construction of field or exciting coils. The coils are wound on the former and then placed around the pole core as shown in Fig. 4.3. When direct current is passed through the field winding, it magnetizes the poles which produce the required flux. The field coils of all the poles are connected in series in such a way that when current flows through them, the adjacent poles attain opposite polarity as shown in Fig. 4.4.
4. **Armature Core**: It is cylindrical is shape and keyed to the rotating shaft. At the outer periphery slots are cut, which accommodate the armature winding. The armature core serves the following purposes:
   (i) It houses the conductors in the slots.
   (ii) It provides an easy path for magnetic flux.

   Since armature is a rotating part of the machine, reversal of flux takes place in the core, hence hysteresis losses are produced. To minimize these losses silicon steel material is used for its construction. When it rotates, it cuts the magnetic field and an emf is induced in it. This emf circulates eddy currents which results in eddy current loss in it. To reduce these losses, armature core is laminated, in other words we can say that about 0.3 to 0.5 mm thick stampings are used for its construction. Each lamination or stamping is insulated from the other by varnish layer.
5. **Armature Winding**: The insulated conductors housed in the armature slots are suitably connected. This is known as armature winding. The armature winding acts as the heart of a DC machine. It is a place where one form of power is converted to the other form i.e., in case of generator, mechanical power is converted into electrical power and in case of motor, electrical power is converted into mechanical power. On the basis of connections, there are two types of armature windings named (*i*) Lap winding and (*ii*) Wave winding.
   (i) In lap winding the connections are such that the number of parallel paths is equal to number of poles and the number of brushes is equal to the number parallel paths.
   (ii) In wave winding, the connections are such that the numbers of parallel paths are only two irrespective of the number of poles and the number of brushes is equal to two i.e., number of parallel paths.
6. **Commutator**: It is an important part of a DC machine and serves the following purposes:
   (i) It connects the rotating armature conductors to the stationary external circuit through brushes.
   (ii) It converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit in generator action, whereas, it converts the alternating torque into unidirectional (continuous) torque produced in the armature in motor action.

   The commutator is of cylindrical shape and is made up of wedge-shaped hard drawn copper segments. The segments are insulated from each other by a thin sheet of mica. The segments are held together by means of two V-shaped rings that fit into the V-grooves cut into the segments. Each armature coil is connected to the commutator segment.

7. **Brushes**: The brushes are pressed upon the commutator and form the connecting link between the armature winding and the external circuit. They are usually made of high grade carbon because carbon is conducting material and at the same time in powdered form provides lubricating effect on the commutator surface. The brushes are held in particular position around the commutator by brush holders and rocker.
8. **Brush Rocker**: It holds the spindles of the brush holders. It is fitted on to the stationary frame of the machine with nut and bolts. By adjusting its position, the position of the brushes over the commutator can be adjusted to minimise the sparking at the brushes.
9. **End Housings**: End housings are attached to the ends of the main frame and support bearings. The front housing supports the bearing and the brush assemblies whereas the rear housing usually supports the bearing only.
10. **Bearings**: The bearings may be ball or roller bearings these are fitted in the end housings. Their function is to reduce friction between the rotating and stationary parts of the machine. Mostly high carbon steel is used for the construction of bearings as it is very hard material.
11. **Shaft**: The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating parts like armature core, commutator, cooling fan etc. are keyed to the shaft.

DC Motor:

An electro-mechanical energy conversion device (electrical machine) that converts DC electrical energy or power (EI) into mechanical energy or power (⍰ T) is called a **DC motor**.

Electric motors are used for driving industrial machines, e.g., hammers, presses, drilling machines, lathes, rollers in paper and steel industry, blowers for furnaces, etc., and domestic appliances, e.g., refrigerators, fans, water pumps, toys, mixers, etc.

Working Principle of DC Motors:

The operation of a DC motor is based on the principle that when a current carrying conductor is placed in a magnetic field, a mechanical force is experienced by it. The direction of this force is determined by *Fleming's Left Hand Rule* and its magnitude is given by the relation:

$$F = Bil \text{ newton}$$

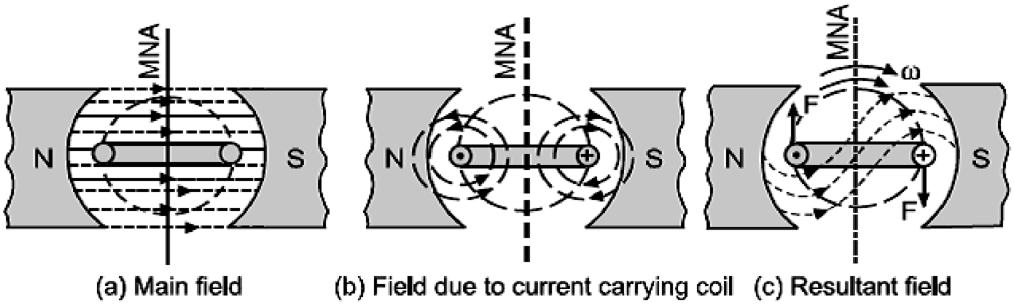


Fig- 4.5 Working principle of a motor

For simplicity, consider only one coil of the armature placed in the magnetic field produced by a bipolar machine, see **Fig. 4.5(a)**. When DC supply is connected to the coil, current flows through it which sets up its own field as shown in **Fig. 4.5 (*b*)**. By the interaction of the two fields (i.e., field produced by the main poles and the coil), a resultant field is set up as shown in **Fig. 4.5(*c*)**. The tendency of this is to come to its original position i.e., in straight line due to which force is exerted on the two coil sides and torque develops which rotates the coil.

In actual machine, a large number of conductors are placed on the armature. All the conductors, placed under the influence of one pole (say, North pole) carry the current in one direction (outward). Whereas, the other conductors placed under the influence of other pole i.e., south pole, carry the current in opposite direction as shown in **Fig. 4.6**. A resultant rotor field is produced. Its direction is marked by the arrow-head *Fr*. This rotor field F_r tries to come in line with the main field F_m and torque (*Te*) develops. Thus, rotor rotates.

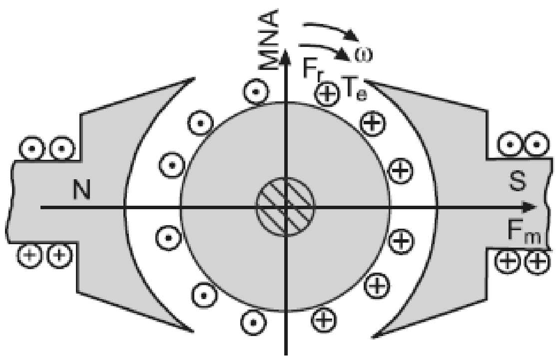


Fig-4.6 Motor Action (Position of main field F_m and rotor field F_r)

It can be seen that to obtain a continuous torque, the direction of flow of current in each conductor or coil side must be reversed when it passes through the **magnetic neutral axis (*MNA*).** This is achieved with the help of a commutator.

The function of a commutator in DC motors is to reverse the direction of flow of current in each armature conductor when it passes through the *M.N.A.* to obtain continuous torque.

Back emf

It has been seen that when current is supplied to the armature conductors, placed in the main magnetic field, torque develops and armature rotates. Simultaneously, the armature conductors cut across the magnetic field and an emf is induced in these conductors.

It can be seen that the direction of this induced emf is opposite to the applied voltage. That is why this induced emf is called back emf (E_b). The magnitude of this induced emf is given by the relation;

$$E_b = \frac{PZ\phi N}{60\,A}$$

$$E_b = \frac{ZP}{60\,A}\ \phi N \text{ or } E_b \propto \phi N \qquad \left(\text{since } \frac{ZP}{60\,A} \text{ are constant}\right)$$

$N \propto \frac{E_b}{\phi}$ shows that speed of motor is inversely proportional to magnetic field or flux.

Significance of Back emf

The current flowing through the armature is given by the relation:

$$I_a = \frac{V - E_b}{R_a}$$

Where, I_a = armature current; V = applied voltage;

E_b = back emf and R_a = armature resistance

When mechanical load applied on the motor increases, its speed decreases which reduces the value of E_b. As a result the value $(V - E_b)$ increases which consequently increases I_a. Hence, motor draws extra current from the mains.

Thus, **the back emf** *regulates the input power as per the extra load.*

Torque produced in DC motor:

Assuming the losses to be negligibly small the power developed by the de motor is given by

Electrical Power P = $E_b * I_a = P\phi ZN*I_a/60A$

Mechanical Power P = ω T = $2\pi NT/60$ (as $\omega = 2\pi N/60$ where N=speed in rpm)

Hence $P\phi ZN*I_a/60A = 2\pi NT/60$

or $T = P\phi Z*I_a/2\pi A = K\,\phi\,T_a$

where $K = PZ/2\pi A$ constant for a dc machine.

Hence torque in a de machine is proportional to the product of flux per pole in the air gap and the armature current

Types of DC Motors:

On the basis of the connections of armature and their field winding, DC motors can be classified as;

1. ***Separately excited DC motors***: The conventional diagram of a separately excited DC motor is shown Fig. 4.7.

   $E_b = V - I_a R_a - 2v_b$ (where v_b is voltage drop per brush)

2. ***Self excited DC motors***: These motors can be further classified as;

   (i) Shunt motors: Their conventional diagram is shown in Fig.4.8. The field winding is connected in parallel with the armature. Its voltage equation will be;

   $I_{sh} = V/R_{sh}$

   $I_a = I_L - I_{sh}$

   $E_b = V - I_a R_a - 2v_b$ (where v_b is voltage drop per brush)

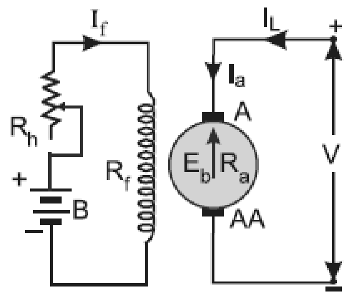


Fig-4.7 Separately excited DC motor

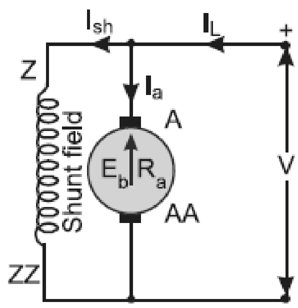


Fig-4.8 DC shunt motor

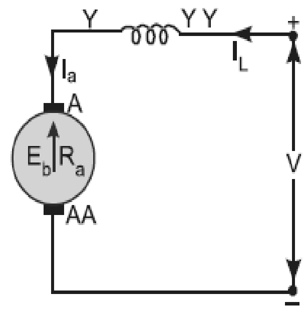


Fig-4.9 DC series motor

   (ii) ***Series motor:*** Its conventional diagram is shown in **Fig. 4.9**. In dc series motor the field winding is connected in series with the armature. Therefore, series field winding carries the armature current. The current passing through the series field winding, armature winding and load will be same.

   Important relations:

   $I_L = I_a = I_{se}$

   $E_b = V - I_a (R_a + R_{se}) - 2v_b$

   (iii) ***Compound motor***: Its conventional diagram (for long shunt) is shown in **Fig. 4.10**

   $I_{sh} = V/R_{sh}$; $Ia = IL - Ish$; $Eb = V - Ia (Ra + Rse) - 2vb$

   The compound motor can be further subdivided as;

   (a) Cumulative compound motors: In these motors, the flux produced by both the windings is in the same direction, i.e.,

   $$\phi_r = \phi_{sh} + \phi_{se}$$

(b) Differential compound motors: In these motors, the flux produced by the series field winding is opposite to the flux produced by the shunt field winding, i.e.,

$$\phi_r = \phi_{sh} - \phi_{se}$$

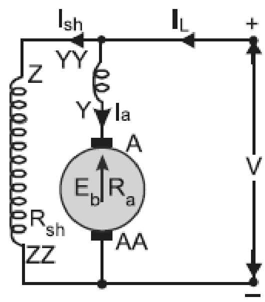


Fig-4.10 DC compound motor

Characteristics of DC Motors:

The performance of a DC motor can be easily judged from its characteristic curves, known as motor *characteristics*. The characteristics of a motor are those curves which show relation between the two quantities. On the basis of these quantities, the following characteristics can be obtained:

1. Speed and Armature current i.e., N – I_a Characteristics: It is the curve drawn between speed *N* and armature current *Ia*. It is also known as *speed characteristics.*

2. Torque and Armature current i.e., T–I_a Characteristics: It is the curve drawn between torque developed in the armature *T* and armature current *Ia*. It is also known as *electrical characteristic.*

3. Speed and Torque i.e., N–T characteristics: It is the curve drawn between speed *N* and torque developed in the armature *T*. It is also known as *mechanical characteristics.*

The following important relations must be kept in mind while discussing the motor characteristics:

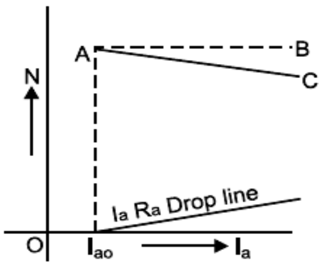
$$E_b \propto N\phi \text{ or } N \propto E_b/\phi \text{ and } T \propto \phi I_a$$

a) Characteristics of *Separately excited DC motors* /DC Shunt Motors:

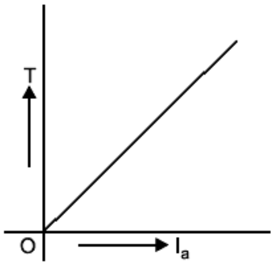
***N-Ia Characteristic*:** The speed N of a. d.c. motor is given by;

$$N \propto E_b/\phi$$

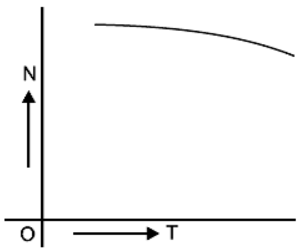
The flux ϕ and back e.m.f. E_b are almost constant under normal conditions. Therefore, speed of a shunt motor will remain constant as the armature current varies (dotted line AB). But, when load is increased, E_b (= V- I_aR_a) and ϕ decrease due to the armature resistance drop and armature reaction respectively. However, E_b decreases slightly more than ϕ so that the speed of the motor decreases slightly with load (line AC).



N-I_a Characteristics



T-I_a Characteristic



N-T Characteristics

T-I_a Characteristic: We know that in a d.c. motor $T \propto \phi I_a$.

Since the motor is operating from a constant supply voltage, flux ϕ is constant (neglecting armature reaction).

$$T \propto I_a.$$

Hence T_a-I_a characteristic is a straight line passing through the origin.

N-T Characteristic: The curve is obtained by plotting the values of N and Ta for various armature currents. It may be seen that speed falls somewhat as the load torque increases.

b) Characteristics of Series Motors:

the flux produced by the series field winding is proportional to the armature current before magnetic saturation, but after magnetic saturation flux becomes constant.

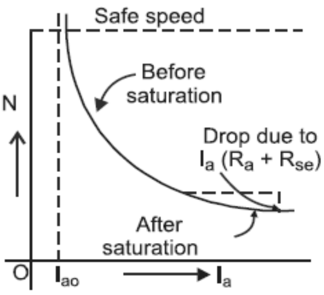
N-I_a Characteristic: The speed N of a series motor is given by; $N \propto E_b/\phi$

where, $E_b = V - I_a (R_a + R_{se})$

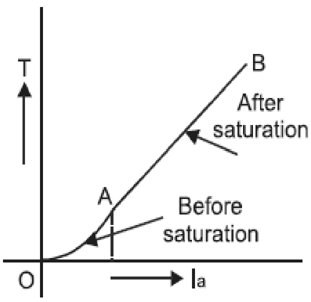
Considering E_b to be constant as drop $I_a(R_a + R_{se})$ is quite small and may be neglected.

$$N \propto 1/\phi \propto 1/I_a \qquad (as\ \phi \propto I_a)$$

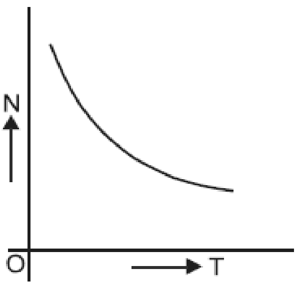
Thus, before magnetic saturation, the $N - I_a$ curve follows the hyperbolic path and the speed decreases abruptly with the increase in load or armature current. After magnetic saturation, flux becomes constant, then $N - I_a$ curve follows a straight line path and speed decreases slightly, shown in N-I_a curve. A *series motor is never started on no-load, because u*nder no-load condition armature current will be very small and hence speed will be dangerously high which may damage the motor due to heavy centrifugal forces.



N-I_a Characteristics



T-I_a Characteristic



N-T Characteristics

T-I_a Characteristic: We know that $T \propto \phi I_a$.

In series motors, before magnetic saturation $\phi \propto I_a$. Hence, before magnetic saturation the electromagnetic torque produced in the armature is proportional to the square of the armature current ($T \propto I_a^2$).

However, after magnetic saturation, the flux ϕ becomes constant and torque proportional to armature current ($T \propto I_a$). The curve (AB) becomes a straight line.

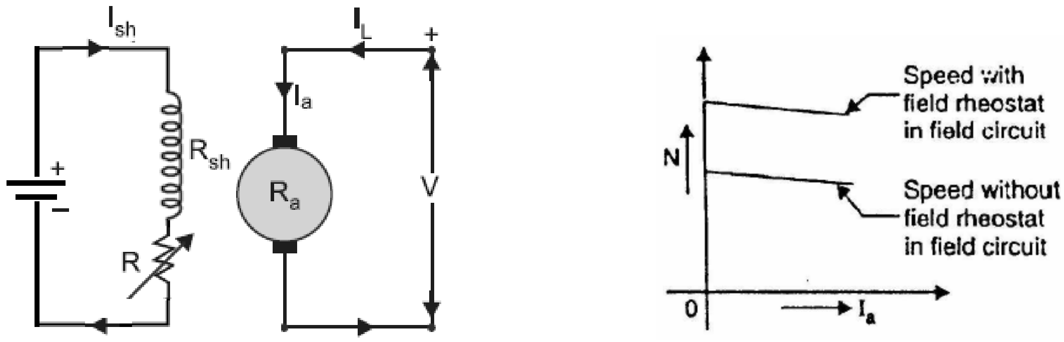
N-T Characteristic: This characteristic is derived from the first two characteristics. At low value of load, I_a is small, torque is small but the speed is very high. As load increases, I_a increases, torque increases but the speed decreases rapidly. Thus for increasing torque, speed decreases rapidly.

Speed Control of DC Motors

The speed of a DC motor is given by the relation $N \propto E_b/\phi$ where $E_b = V - I_a R_a$.
$N \propto V - I_a R_a / \phi$
From the above equation it is clear that the speed of DC motors can be controlled;
1. By varying flux per pole ϕ. This is known as *flux* or *field control method*.
2. By varying the armature drop, i.e., by varying the resistance of armature circuit. This is known as *armature control method*.

Flux control or field control method:

It is based on the fact that by varying the flux ϕ, the motor speed ($N \propto 1/\phi$) can be changed and hence the name flux control method. In this method, a variable resistance is placed in series with field winding as shown in **Fig. 4.11 (a).**



(a) Circuit diagram (b) N-I_a characteristics

Fig-4.11 Field control method

The field rheostat reduces the field current I_{sh} and hence the flux ϕ. Therefore, we can only raise the speed of the motor above the normal speed **Fig. 4.9 (b).**

Advantages

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the field rheostat due to relatively small value of I_{sh}.

(iii) The speed control exercised by this method is independent of load on the machine.

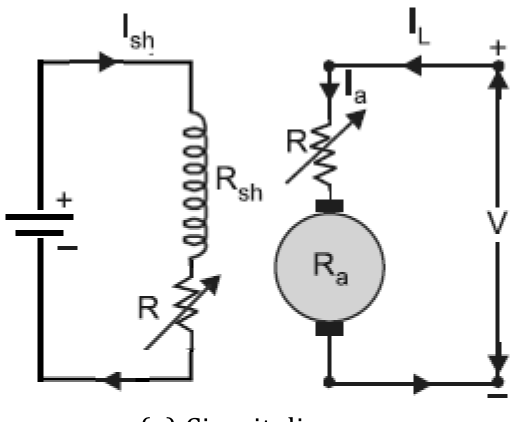
Disadvantages

(i) Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below R_{sh}—the field winding resistance.

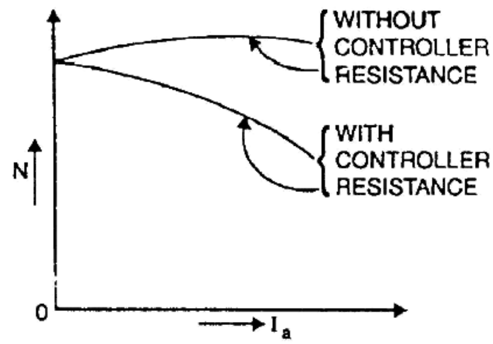
(ii) There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

Armature control method

The flux is constant when applied terminal voltage and shunt field resistance are constant. Therefore, speed of the motor is directly proportional to induced *emf* (i.e., $N \propto E_b$ and $E_b = V - I_a R_a$). The value of E_b depends upon the drop in the armature circuit. When a variable resistance is connected in series with the armature as shown in **Fig. 4.12(*a*)** the induced emf [$Eb = V - 1a\ (Ra + R)$] is reduced and hence the speed. Thus, the motor runs at a speed lower than the normal speed as shown in **Fig-4.12 (b).**



(a) Circuit diagram



(b) N-I_a characteristics

Fig- 4.12 Armature control method

By this method, a wide range of speeds (below normal) can be obtained. Moreover, motor develops any desired torque over its operating range since torque depends only upon the armature current (flux remaining unchanged).

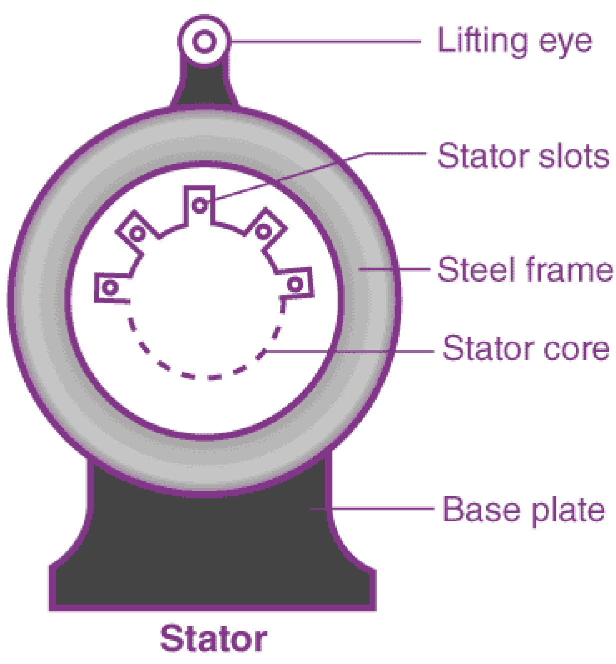
The major disadvantage of this method of speed control is that there is heavy loss of power in the control rheostat. So, the output and efficiency of the motor are reduced.

AC Motor

An AC motor is a motor that converts alternating current into mechanical power. The stator and the rotor are important parts of AC motors. The stator is the stationary part of the motor, and the rotor is the rotating part of the motor. The AC motor may be single-phase or three-phase. Nikola Tesla invented the first AC induction motor in 1887.

Construction of AC Motor

It consists of a Frame or Yoke, stator, rotor, bearings, fan, shaft, and slip rings. The parts of an AC machine is explained below.



Parts of Motor

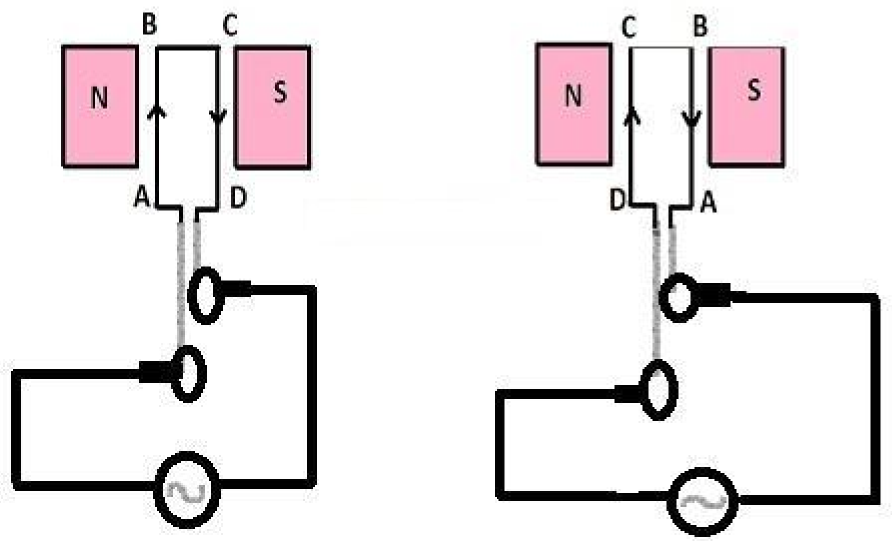
The frame is used as an outer protecting cover that is used to protect against environmental conditions. The frame also acts as an outer periphery such that the inner parts can be easily housed. The stable state section of the equipment is stator on which the stator winding is enclosed. The cross-sectional view of the AC machine is depicted below.

Cross-Sectional View

The rotor is the moving part that either move in clockwise or anti-clockwise depending upon thrust impelled on it. The bearings provide proper friction for the rotor to run smoothly. A fan is employed to remove the unwanted heat that gained during the running of the rotor. It is expelled out through the ventilation that is provided behind the machine. A shaft is provided to deliver the mechanical output as the rotor rotates. The slips rings are employed for a normal Ac machine where rotating armature stationary field winding is employed. In this situation, the slip rings allow the input alternating current to change continuously in the coils.

Working Principle of AC Motor

It works on the principle of Lorentz force equation I,e whenever a current-carrying conductor is placed in the magnetic field it exhibits some force in it. The working of a normal AC machine with the rotating armature and stationary field winding is shown in the figure below.



AC Machine Working Diagram

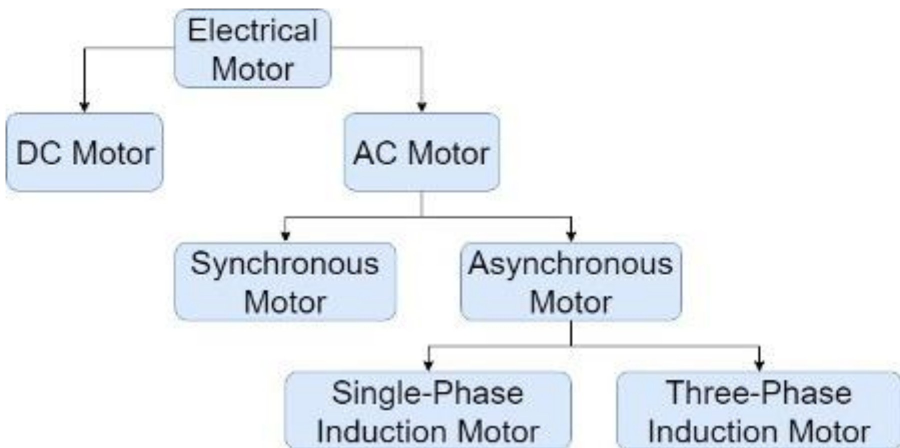
When alternating current supply is fed to the coil of the rotor, it experiences some force due to the law of the Lorentz force equation. Due to this force, torque will be developed in the clockwise direction that enables the rotor to rotate.

A normal AC machine has its field winding on the stator and armature winding rotor. But due to this the size of the motor increases and also due to commutator and brushes, the efficiency of the machine decreases. So, to avoid these problems, the proper arrangement is made for the housing of stator and rotor windings on the armature. This placement has great advantages compared to the rotating armature type. Almost all the industrial machines used are of stationary armature type. Let us discuss in detail these machines by studying the different types of motors.

Types

There are several varieties of AC machines based on the speed they are classified as a synchronous and asynchronous motor. The asynchronous motor is also known as an induction motor. It is a machine that runs at a constant speed I,e synchronous speed. But an asynchronous motor runs at a speed less than that of synchronous speed. The induction motor is further classified into single-phase, and three-phase induction motors.

The classification of the alternating type of motors is illustrated below.

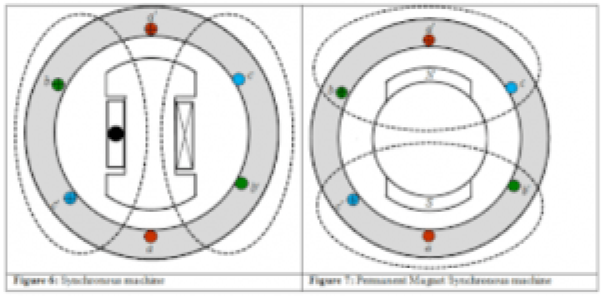


Classification of Motor

Working of Synchronous Motor

The stator winding is given a three-phase power supply such that a rotating magnetic field (RMF) is developed. This RMFrotates in the air gap and tries to interact with the field winding. The field winding is given a DC supply in the synchronous machine. The field winding develops a stationary magnetic field. The rotating magnetic field and the stationary magnetic field interact with each other. Due to the inertia of the rotor, the rotor is unable to achieve unidirectional torque. So, the synchronous motor is not a self-starting machine. To avoid this, an initial rotation is provided.

When an initial rotation is given, the stator and rotor poles get interlocked with each other. Further, the machine develops unidirectional torque that allows the rotor to rotate continuously.



Synchronous Machine

Working of a Single-phase Induction Machine

When a three-phase power supply is given to the stator winding of the machine, RMF will be developed. The RMF interacts with the short-circuited rotor conductors. Due to this, an emf is induced in the rotor bars according to the principle of mutual induction just like a transformer. But the rotor cannot develop the unidirectional torque because the main winding produces a two-directional torque. The flux produced by the main winding develops two fluxes which oppose each other. To produce a unidirectional torque, an auxiliary winding with a capacitor is arranged at a phase displacement of 90 degrees with the main winding. Due to this arrangement, the opposition force is canceled out and an additional force greater the existing force is developed. This makes possible for the rotor to develop unidirectional torque and the rotor runs smoothly. The working of a single-phase induction machine is displayed below.

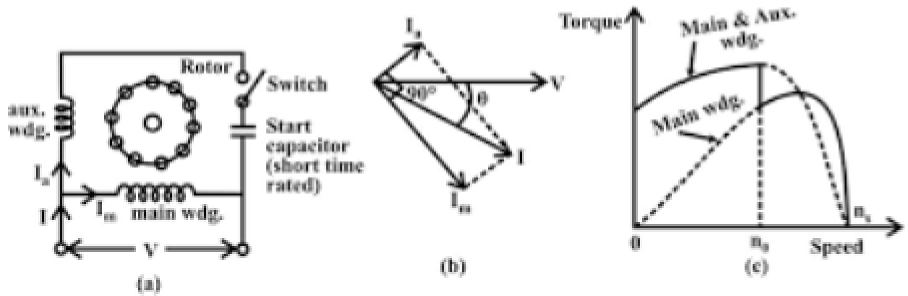


Fig. 34.5: Capacitor-Start Induction Motor
(a) Schematic Diagram
(b) Phasor Diagram
(c) Torque-Speed characteristic

Single Phase Induction Motor

AC motors are a preferred source of supply due to the following reasons:

Longevity

With only a few moving parts, AC motors have the potential to last for years. The durability of AC motors makes them a preferred solution for field applications such as agricultural equipment and commercial applications such as vending machines.

Efficiency

The speed-to-torque characteristics of AC motors allow them to provide excellent performance in many applications without overheating, degeneration or braking. This is why an AC motor is chosen for high-demand applications such as pumps and packaging equipment.

Quiet Operation

Producing less noise, AC motors are ideal for applications in stores, hospitals and restaurants.

Availability

AC motors are available in a wide range of sizes and power outputs. This wide range makes it ideal for many applications.

Applications

- **It is used in mixer grinders, pumps, and household appliances.**
- **Used in industries.**

Classification of Cells or Batteries

Electrochemical batteries are classified into 4 broad categories.

A primary cell or battery is one that cannot easily be recharged after one use, and are discarded following discharge. Most primary cells utilize electrolytes that are contained within absorbent material or a separator (i.e. no free or liquid electrolyte), and are thus termed dry cells.

A **secondary cell** or battery is one that can be electrically recharged after use to their original pre-discharge condition, by passing current through the circuit in the opposite direction to the current during discharge. The following graphic evidences the recharging process.

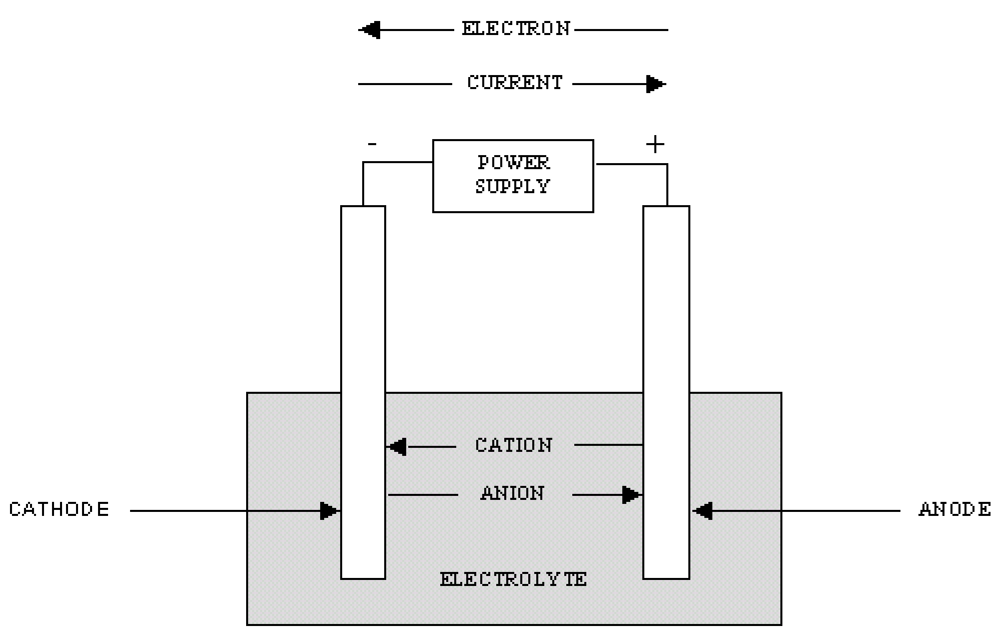


Figure 3: Recharging a Cell

Secondary batteries fall into two sub-categories depending on their intended applications.

- Cells that are utilized as energy storage devices, delivering energy on demand. Such cells are typically connected to primary power sources so as to be fully charged on demand. Examples of these type of secondary cells include emergency no-fail and standby power sources, aircraft systems and stationary energy storage systems for load-leveling.

- Cells that are essentially utilized as primary cells, but are recharged after use rather than being discarded. Examples of these types of secondary cells primarily include portable consumer electronics and electric vehicles.

Primary vs. Secondary – A Comparison

The following table summarizes the ***pros*** and cons of primary and secondary batteries.

Primary	Secondary
Lower initial cost. Higher life-cycle cost ($/kWh). Disposable.	Higher initial cost. Lower life-cycle cost ($/kWh) if charging in convenient and inexpensive. Regular maintenance required.

Disposable.	Periodic recharging required.
Replacement readily available.	Replacements while available, are not produced in the same sheer numbers as primary batteries. May need to be pre-ordered.
Typically lighter and smaller; thus traditionally more suited for portable applications.	Traditionally less suited for portable applications, although recent advances in Lithium battery technology have lead to the development of smaller/lighter secondary batteries.
Longer service per charge and good charge retention.	Relative to primary battery systems, traditional secondary batteries (particularly aqueous secondary batteries) exhibit inferior charge retention.
Not ideally suited for heavy load/high discharge rate performance.	Superior high discharge rate performance at heavy loads
Not ideally suited for load-leveling, emergency backup, hybrid battery, and high cost military applications.	Ideally suited for load-leveling, emergency backup, hybrid battery and high cost military applications
Traditionally limited to specific applications.	The overall inherent versatility of secondary battery systems allows its use and continuing research for a large spectrum of applications.

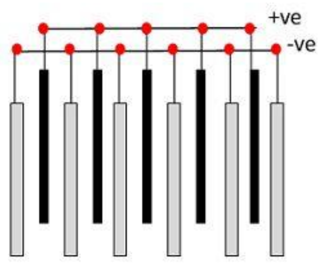
A third battery category is commonly referred to as the **reserve** cell. What differentiates the reserve cell from primary and secondary cells in the fact that a key component of the cell is separated from the remaining components, until just prior to activation. The component most often isolated is the electrolyte. This battery structure is commonly observed in thermal batteries, whereby the electrolyte remains inactive in a solid state until the melting point of the electrolyte is reached, allowing for ionic conduction, thus activating the battery. Reserve batteries effectively eliminate the possibility of self-discharge and minimize chemical deterioration. Most reserve batteries are used only once and then discarded. Reserve batteries are used in timing, temperature and pressure sensitive detonation devices in missiles, torpedoes, and other weapon systems.

Reserve cells are typically classified into the following 4 categories.

- Water activated batteries.
- Electrolyte activated batteries.
- Gas activated batteries.
- Heat activated batteries.

The **fuel cell** represents the fourth category of batteries. Fuel cells are similar to batteries except for the fact that that all active materials are not an integral part of the device (as in a battery). In fuel cells, active materials are fed into batteries from an outside source. The fuel cell differs from a battery in that it possesses the capability to produce electrical energy as long as active materials are fed to the electrodes, but stop operating in the absence of such materials. A well-known application of fuel cells has been in cryogenic fuels used in space vehicles. Use of fuel cell technology for terrestrial applications has been slow to develop, although recent advances have generated a revitalized interest in a variety of systems with applications such as utility power, load-leveling, on-site generators and electric vehicles.

Lead Acid Cell



Definition: The battery which uses sponge lead and lead peroxide for the conversion of the chemical energy into electrical power, such type of battery is called a lead acid battery. The lead acid battery is most commonly used in the power stations and substations because it has higher cell voltage and lower cost

Construction of Lead Acid Cell
The various parts of the lead acid battery are shown below. The container and the plates are the main part of the lead acid battery. The container stores chemical energy which is converted into electrical energy by the help of the plates.

1. Container – The container of the lead acid battery is made of glass, lead lined wood, ebonite, the hard rubber of bituminous compound, ceramic materials or moulded plastics and are seated at the top to avoid the discharge of electrolyte. At the bottom of the container, there are four ribs, on two of them rest the positive plate and the others support the negative plates.
The prism serves as the support for the plates and at the same time protect them from a short-circuit.The material of which the battery containers are made should be resistant to sulfuric acid, should not deform or porous, or contain impurities which damage the electrolyte.

2. Plate – The plate of the lead-acid cell is of diverse design and they all consist some form of a grid which is made up of lead and the active material. The grid is essential for conducting the electric current and for distributing the current equally on the active material. If the current is not uniformly distributed, then the active material will loosen and fall out.

The grids are made up of an alloy of lead and antimony. These are usually made with the transverse rib that crosses the places at a right angle or diagonally. The grid for the positive and negative plates are of the same design, but the grids for the negative plates are made lighter because they are not as essential for the uniform conduction of the current.

The plates of the battery are of two types. They are the formed plates or plante plates and pasted or faure plates.

Plante's plates are used largely for stationary batteries as these are heavier in weight and more costly than the pasted plates. But the plates are more durable and less liable to lose active material by rapid charging and discharging. The plantes plate has low capacity weight-ratio.
Faure process is much suitable for manufacturing of negative plates rather than positive plates. The negative active material is quite tough, and it undergoes a comparatively low change from charging and discharging.

3. Active Material – The material in a cell which takes active participation in a chemical reaction (absorption or evolution of electrical energy) during charging or discharging is called the active material of the cell. The active elements of the lead acid are

1. **Lead peroxide (PbO_2)** – It forms the positive active material. The PbO_2 are dark chocolate broom in colour.
2. **Sponge lead** – Its form the negative active material. It is grey in colour.
3. **Dilute Sulfuric Acid (H_2SO_4)** – It is used as an electrolyte. It contains 31% of sulfuric acid.

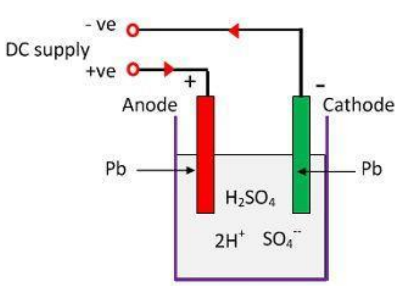
The lead peroxide and sponge lead, which form the negative and positive active materials have the little mechanical strength and therefore can be used alone.

4. Separators – The separators are thin sheets of non-conducting material made up of chemically treated leadwood, porous rubbers, or mats of glass fibre and are placed between the positive and negative to insulate them from each other. Separators are grooved vertically on one side and are smooth on the other side.

5. Battery Terminals – A battery has two terminals the positive and the negative. The positive terminal with a diameter of 17.5 mm at the top is slightly larger than the negative terminal which is 16 mm in diameter.

Working Principle of Lead Acid Cell

When the sulfuric acid dissolves, its molecules break up into positive hydrogen ions ($2H^+$) and sulphate negative ions (SO_4^{--}) and move freely. If the two electrodes are immersed in solutions and connected to DC supply then the hydrogen ions being positively charged and moved towards the electrodes and connected to the negative terminal of the supply. The SO_4^{--} ions being negatively charged moved towards the electrodes connected to the positive terminal of the supply main (i.e., anode).



Charging of Lead Acid Cells

Each hydrogen ion takes one electron from the cathode, and each sulphates ions takes the two negative ions from the anodes and react with water and form sulfuric and hydrogen acid.

The oxygen, which produced from the above equation react with lead oxide and form lead peroxide (PbO_2.) Thus, during charging the lead cathode remain as lead, but lead anode gets converted into lead peroxide, chocolate in colour.
If the DC source of supply is disconnected and if the voltmeter connects between the electrodes, it will show the potential difference between them. If wire connects the electrodes, then current will flow from the positive plate to the negative plate through external circuit i.e. the cell is capable of supplying electrical energy.

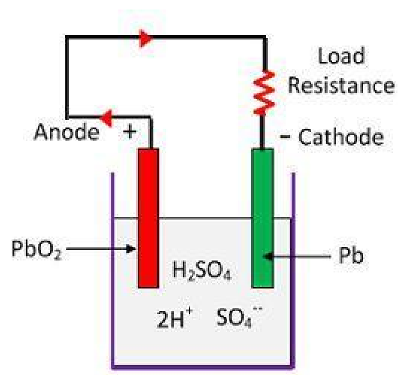
Chemical Action During Discharging

When the cell is full discharge, then the anode is of lead peroxide (PbO_2) and a cathode is of metallic sponge lead (Pb). When the electrodes are connected through a resistance, the cell discharge and electrons flow in a direction opposite to that during charging.
The hydrogen ions move to the anode and reaching the anodes receive one electron from the anode and become hydrogen atom. The hydrogen atom comes in contacts with a PbO_2, so it attacks and forms lead sulphate ($PbSO_4$), whitish in colour and water according to the chemical equation.

$$PbSO_4 + 2H = PbO + H_2O$$

$$PbO + H_2SO_4 = PbSO_4 + 2H_2O$$

$$\overline{PbO_2 + H_2SO_4 + 2H = PbSO_4 + 2H_2O}$$



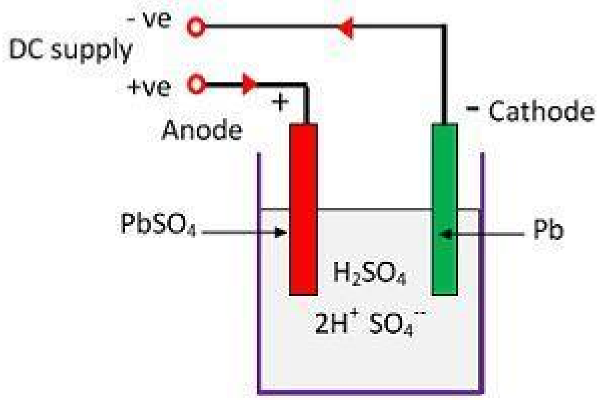
Discharging of Lead Acid Cells

The each sulphate ion (SO_4^{--}) moves towards the cathode and reaching there gives up two electrons becomes radical SO_4, attack the metallic lead cathode and form lead sulphate whitish in colour according to the chemical equation.

Chemical Action During Recharging

For recharging, the anode and cathode are connected to the positive and the negative terminal of the DC supply mains. The molecules of the sulfuric acid break up into ions of $2H^+$ and SO_4^{--}. The hydrogen ions being positively charged moved towards the cathodes and receive two electrons from there and form a hydrogen atom. The hydrogen atom reacts with lead sulphate cathode forming lead and sulfuric acid according to the chemical equation.

$$PbSO_4 + 2H_2O + 2H = PbSO_4 + 2H_2SO_4$$

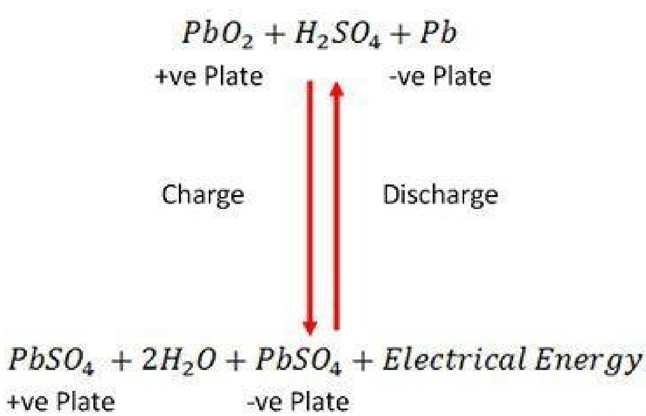


Recharging of Lead Acid Cell

SO_4^{--} ion moves to the anode, gives up its two additional electrons becomes radical SO_4, react with the lead sulphate anode and form leads peroxide and lead sulphuric according to the chemical equation.

$$PbSO_4 + 2H = H_2SO_4 + Pb$$

The charging and discharging are represented by a single reversible equation given below.



The equation should read downward for discharge and upward for recharge.