<u>Module 3</u>

<u>DC MOTOR</u>

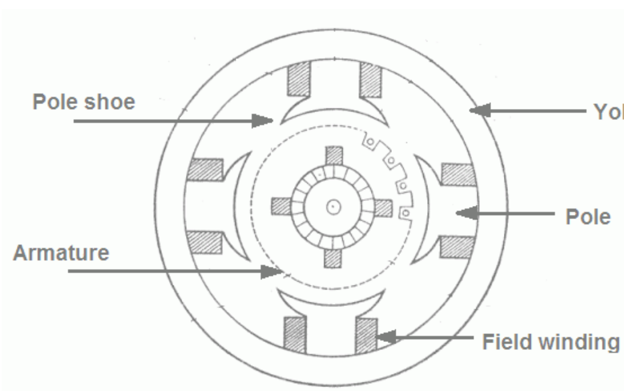
A **DC motor** is any of a class of rotary electrical motors that converts direct current electrical energy into mechanical energy.

Principle of DC Motor

When a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move

The direction of rotation of a this motor is given by Fleming's left hand rule, which states that if the index finger, middle finger, and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of current, then the thumb represents the direction in which force is experienced by the shaft of the **DC motor**.

<u>**CONSTRUCTION** OF DC MOTOR</u>



Construction of a DC Motor

Parts Used in Construction of DC Motor

The main parts used in the construction of a DC motor are the yoke, poles, field winding, commutator, carbon brushes bearings etc.

Yoke

The yoke acts as the outer cover of a DC motor and it is also known as the frame.

The yoke is an iron body, made up of low reluctance magnetic material such as cast iron, silicon steel, rolled steel etc.

Yoke serve two purposes, firstly it provides mechanical protection to the outer parts of the machine secondly

it provides low reluctance path for the magnetic flux.

Poles and Pole Shoe

The pole and pole shoe are fixed on the yoke by bolts.
Poles produce the <u>magnetic flux</u> when the field winding is excited.

Pole shoe is an extended part of a pole.
Due to its shape, the pole area is enlarged and more flux can pass through the air gap to the armature.

Field Winding

The coils around the poles are known as field (or exciting) coils and are connected in series to form the field winding.
Copper wire is used for the construction of field coils..

Armature Core

It is a cylindrical drum and keyed to the rotating shaft.
A large number of slots are made all over its periphery, which accommodates the armature winding.

Armature Winding

The armature winding plays very important role in the construction of a DC motor because the conversion of power takes place in armature winding. On the basis of connections, there are two types of armature windings named:

- Lap winding
- Wave Winding

Commutator

It is a mounted on the shaft.

The commutator connects the rotating armature conductor to the stationary external circuit through carbon brushes.

It converts alternating torque into unidirectional torque produced in the armature.

Carbon Brushes

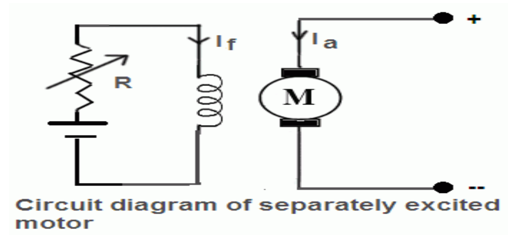
The current is conducted from voltage source to armature by the carbon brushes which are held against the surface of commutator by springs.

They are made of high-grade carbon steel and are rectangular in shape.

Types of DC Motors

- DC shunt motor
- DC series motor
- Compound motors
- Separately excited DC motors
- Permanent magnet DC motors

Separately Excited DC Motor



Circuit diagram of separately excited motor

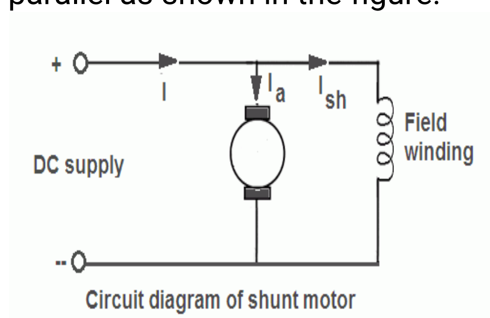
In these motors, the armature and field coils are fed from different supply sources.

Very accurate speed control can be obtained by these motors.

Moreover, these motors are best suited for the applications where speed variation is required from very low value to high value.

DC Shunt Motor

In the DC shunt motor, the armature and field winding are connected in parallel as shown in the figure.



Circuit diagram of shunt motor

The field winding consists of a large number of turns of fine wire.
The cross-sectional area of the wire used for field winding of shunt motor is always smaller than that of the wire used for the armature winding.

Voltage and Current Relations for DC Shunt Motor

Total current drawn from the voltage source $I = I_a + I_{sh}$

Where I_a = armature current

I_{sh} (field current) = V/R_{sh}

shunt motor is also known as constant flux motors.

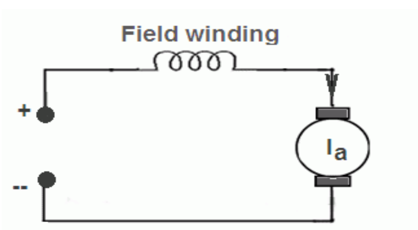
Therefore **flux, $\varphi \propto I_{sh}$ (constant)**

Supply voltage $\mathbf{V = E_b + I_aR_a}$

Where E_b = back EMF

R_a = armature resistance.

DC Series Motor



Circuit diagram of DC series motor

In the DC series motor, the armature and field windings are connected in series with each other.
The field winding of DC series motor consists of few turns of thick wire.

Voltage and Current Relations

As armature and the field winding are in series, therefore,

$I = I_a = I_s$

Where I = total current drawn by the motor

I_a = armature current

I_s = series field current

Total supply voltage V is given by,

$\mathbf{V = E_b + I_a(R_a + R_s)}$

E_b = back EMF

I_a = armature current

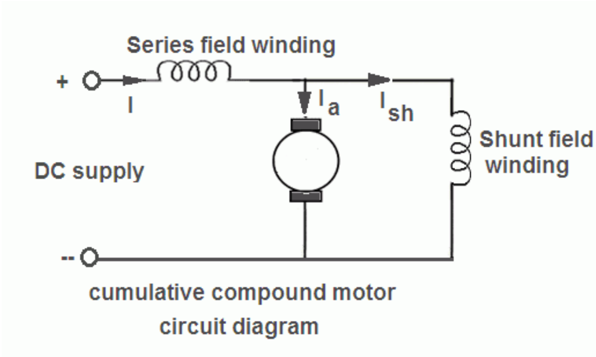
R_a = armature resistance

R_s = series field resistance.

DC Compound Motors

Shunt and series, both the field windings are present in compound motors. In these motors, a part of the field winding is connected across the armature and remaining field winding is connected in series with the armature. These compound motors are further subdivided into two types, namely, cumulative compound and differential compound.

Cumulative Compound Motor



In the cumulative compound motor, shunt and series field winding is connected in such a way that the direction of flow of current is same in both the field windings i.e. series field flux strengthens the field due to shunt field winding.

Differential Compound Motor

In the differential compound motor, shunt and series field winding is connected in such a way that the direction of flow of current is opposite in both the field windings i.e. series field flux weakens the field due to shunt field winding.

Torque equation of a DC motor

When armature conductors of a DC motor carry current in the presence of stator field flux, a mechanical torque is developed between the armature and the stator. Torque is given by the product of the force and the radius at which this force acts.

- Torque T = F × r (N-m) …where, F = force and r = radius of the armature
- Work done by this force in once revolution = Force × distance = F × 2πr (where, 2πr = circumference of the armature)
- Net power developed in the armature = word done / time
  = (force × circumference × no. of revolutions) / time
  = (F × 2πr × N) / 60 (Joules per second) .... eq. 2.1

But, F × r = T and 2πN/60 = angular velocity ω in radians per second. Putting these in the above equation 2.1
Net power developed in the armature
= P = T × ω (Joules per second)

Armature torque (Ta)

- The power developed in the armature can be given as, Pa = Ta × ω = Ta × 2πN/60
- The mechanical power developed in the armature is converted from the electrical power,
  Therefore, mechanical power = electrical power
  That means, Ta × 2πN/60 = Eb.Ia
- We know, Eb = PΦNZ / 60A
- Therefore, Ta × 2πN/60 = (PΦNZ / 60A) × Ia
- Rearranging the above equation,
  Ta = (PZ / 2πA) × Φ.Ia(N-m)

The term (PZ / 2πA) is practically constant for a DC machine. Thus, armature torque is directly proportional to the product of the flux and the armature current i.e. Ta ∝ Φ.Ia

Shaft Torque (Tsh)

Due to iron and friction losses in a dc machine, the total developed armature torque is not available at the shaft of the machine. Some torque is lost, and therefore, shaft torque is always less than the armature torque.

Shaft torque of a DC motor is given as,
Tsh = output in watts / (2πN/60) ....(where, N is speed in RPM)

Speed equqation of a DC Motor

The emf equation of DC motor is given by

$$E = \frac{NP\phi Z}{60A}$$

Here,
N = speed of rotation in rpm.
P = number of poles.
A = number of parallel paths.
Z = total no. conductors in armature.

$$Thus,\ speed\ of\ rotation\ N = \frac{60A}{PZ} X \frac{E}{\phi}$$

$$\Rightarrow N = \frac{E}{k\phi} \quad Where\ k = \frac{PZ}{60A}\ is\ a\ co$$

Hence, speed of a DC motor is directly proportional to emf of rotation (E) and inversely proportional to flux per pole (φ).

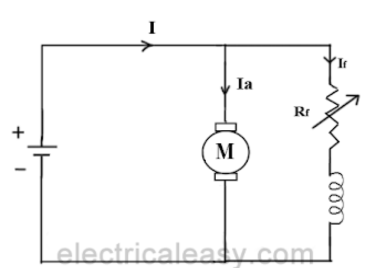
Speed Control of DC Motor

The **speed of a DC motor** (N) is equal to:

$$N = \frac{V - I_a R_a}{k\phi}$$

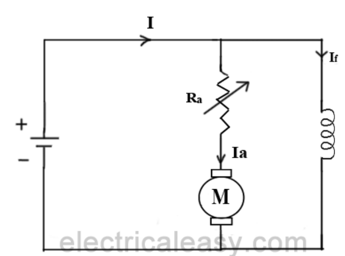
SPEED CONTROL OF SHUNT MOTOR

1. Flux Control Method



- **speed of a dc motor** is inversely proportional to the flux per pole.
- Thus by decreasing the flux, speed can be increased and vice versa.
- To control the flux, a rheostat is added in series with the field winding,
- .Adding more resistance in series with the field winding will increase the speed as it decreases the flux.
- In shunt motors, as field current is relatively very small, I_{sh}^2R loss is small.
- Therefore, this method is quite efficient.

2. Armature Control Method



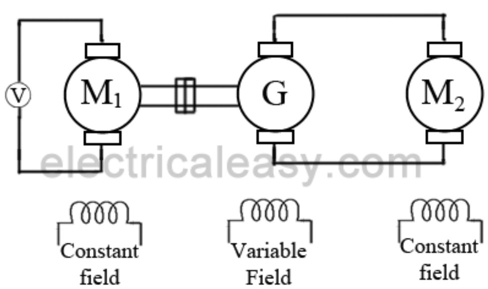
- **Speed of a dc motor** is directly proportional to the back emf E_b and $E_b = V - I_aR_a$.
- That means, when supply voltage V and the armature resistance R_a are kept constant, then the speed is directly proportional to armature current I_a.
- Thus, if we add resistance in series with the armature, I_a decreases and, hence, the speed also decreases.

Greater the resistance in series with the armature, greater the decrease in speed.

3. Voltage Control Method

- **Multiple voltage control**:
  In this method, the shunt field is connected to a fixed exciting voltage and armature is supplied with different voltages.
- Voltage across armature is changed with the help of suitable switchgear.
- The speed is approximately proportional to the voltage across the armature.

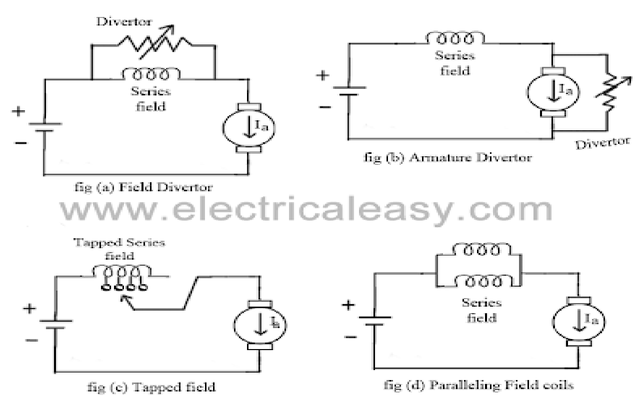
b) **Ward-Leonard System**:



- This system is used where very sensitive **speed control of motor** is required (e.g electric excavators, elevators etc.).
- The arrangement of this system is as shown in the figure at right.
- M_2 is the motor to which speed control is required.
- M_1 may be any AC motor or DC motor with constant speed.
- G is a generator directly coupled to M_1.
- In this method, the output from generator G is fed to the armature of the motor M_2 whose speed is to be controlled.
- The output voltage of generator G can be varied from zero to its maximum value by means of its field regulator and, hence, the armature voltage of the motor M_2 is varied very smoothly.
- Hence, very smooth **speed control of the dc motor** can be obtained by this method

SPEED CONTROL OF SERIES MOTOR

1. Flux Control Method



Field diverter:
- A variable resistance is connected parallel to the series field as shown in fig (a).
- This variable resistor is called as a diverter,
- current through field coil can be decreased.
- Thus, flux can be decreased to the

desired amount and speed can be increased.

Armature diverter:

- For a given constant load torque, if armature current is reduced then the flux must increase,
- This will result in an increase in current taken from the supply and hence flux Ø will increase and subsequently **speed of the motor** will decrease

Tapped field control:

- As shown in fig (c) field coil is tapped dividing number of turns.
- Thus we can select different value of Ø by selecting different number of turns.

Paralleling field coils:

- In this method, several speeds can be obtained by regrouping coils as shown in fig

2. Variable Resistance In Series With Armature

- By introducing resistance in series with the armature, voltage across the armature can be reduced.
- hence, speed reduces in proportion with it.

3**. Series-Parallel Control**

- This system is widely used in electric traction,
- where two or more mechanically coupled series motors are employed.
- For low speeds, the motors are connected in series,
- for higher speeds, the motors are connected in parallel..

Starting of DC Motors

A **starter** is a device to start and accelerate a motor.

- A controller is a device to start the motor, control and reverse the speed of the DC motor and stop the motor.
- While starting the DC motor, it draws the heavy current which damages the motor.
- The starter reduces the heavy current and protects the system from damage.

Need of Starters for DC Motors

- The dc motor has no back emf.
- At the starting of the motor, the armature current is controlled by the resistance of the circuit.
- The resistance of the armature is low, and when the full voltage is applied at the standstill condition of the motor, the armature current becomes very high which damage the parts of the motor.
- Because of the high armature current, the additional resistance is placed in the armature circuit at starting.
- The starting resistance of the machine is cut out of the circuit when the machine gains it speeds.

The armature current of a motor is given by

$$I_a = \frac{V - E}{R_a} \quad \dots\dots\dots \quad (1)$$

- Thus, I_a depends upon E and R_a, if V is kept constant.

- When the motor is first switched ON, the armature is stationary.

- Hence, the back EMF E_b is also zero. The initial starting armature current I_{as} is given by the equation shown below.

$$I_{as} = \frac{V - 0}{R_a} = \frac{V}{R_a} \dots\dots\dots\dots($$

- Since, the armature resistance of a motor is very small, generally less than one ohm.
- Therefore, the starting armature current I_{as} would be very large.

WORKING OF STARTERS

The starter handle is now moved from stud to stud, and this builds up the speed of the motor until it reaches the **RUN** position.

- The Studs are the contact point of the resistance.
- In the RUN position, three main points are considered. They are as follows.

- The motor attains the full speed.

- The supply is direct across both the windings of the motor.

- The resistance R is completely cut out.

The handle H is held in RUN position by an electromagnet energised by a **no volt trip coil (NVC)**.

This no volt trip coil is connected in series with the field winding of the motor.

In the event of switching OFF, or when the supply voltage falls below a predetermined value, or the complete failure of supply while the motor is running, NVC is deenergised. The handle is released and pulled back to the OFF position by the action of the spring. The current to the motor is cut off, and the motor is not restarted without a resistance R in the armature circuit. The no voltage coil also provides protection against an open circuit in the field windings.

The other protective device incorporated in the starter is the overload protection.

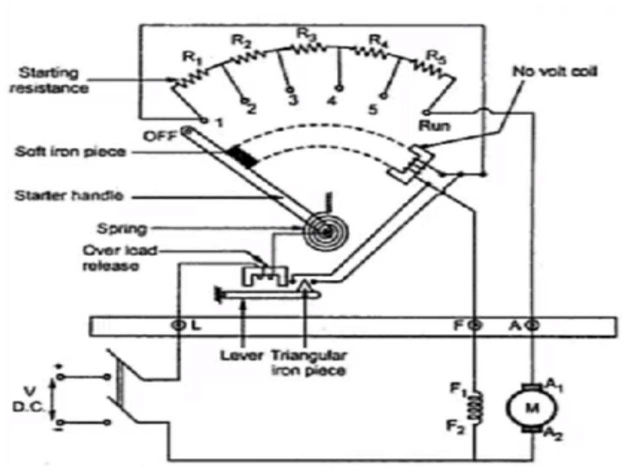
The **Over Load Trip Coil (OLC)** and the **No Voltage Coil (NVC**) provide the overload protection of the motor.

The overload coil is made up of a small electromagnet, current

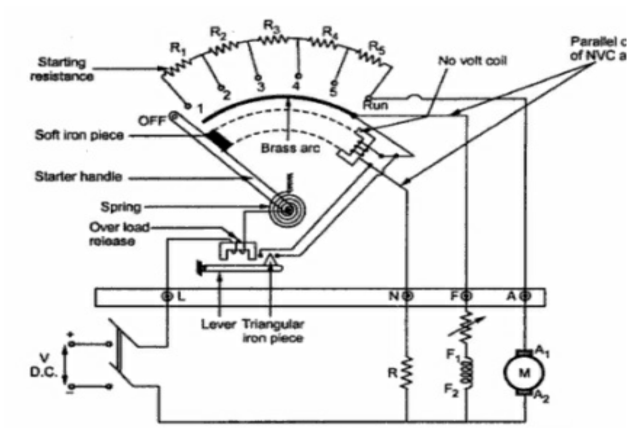
When the motor is overloaded, that is the armature current exceeds the normal rated value, P is attracted by the electromagnet of the OLC and closes the contact aa thus, the No Voltage Coil is short-circuited,

As a result, the handle H is released, which returns to the OFF position, and the motor supply is cut off.

3 POINT STARTER



4 POINT STARTER



Four Point Starter

2 POINT STARTER