DC Motors

Chapter · May 2019

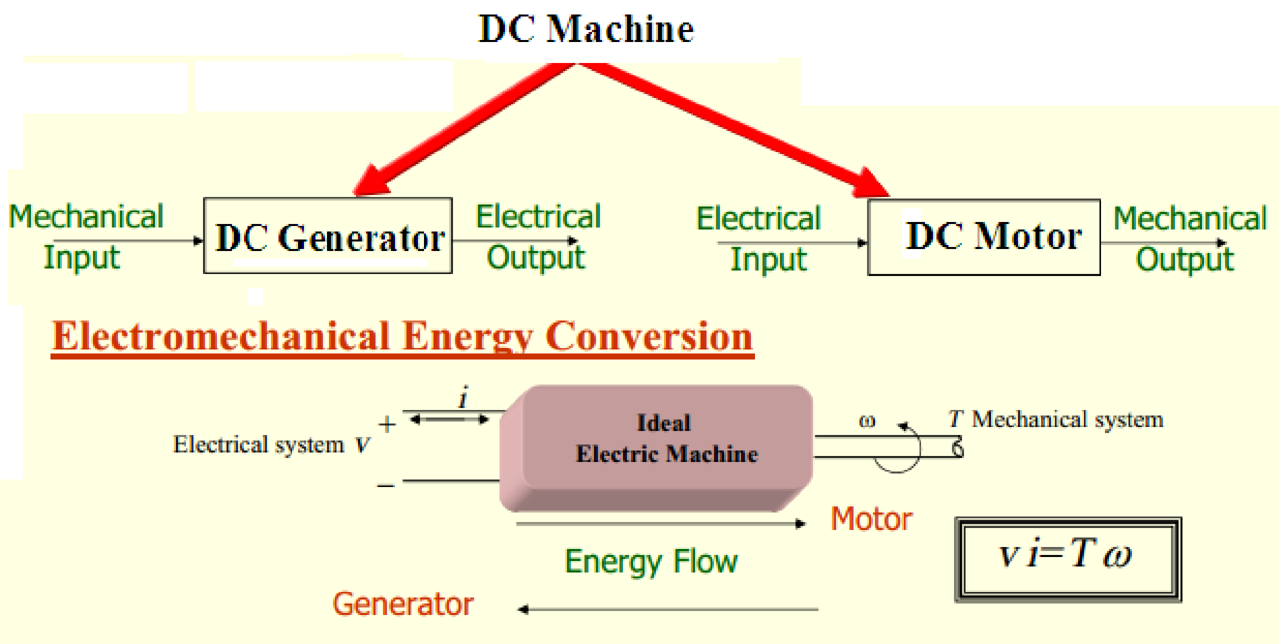
1 author:

Ahmed M. T. Ibraheem Al-Naib
Northern Technical University

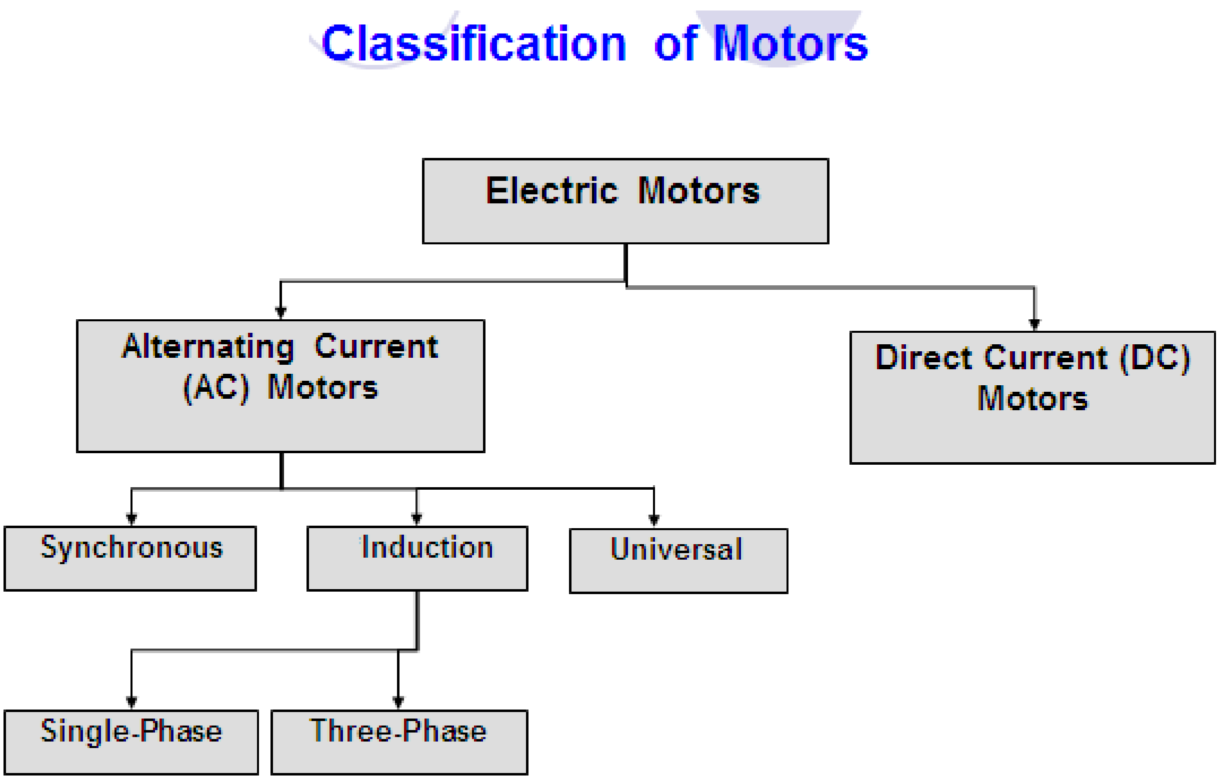
Ahmed M. T. Ibraheem Alnaib, Lecturer.
Dep. of Electrical Power Technology Eng., Technical college / Mosul, Northern Technical University.

Electrical and Electronic Engineering

Electrical Machine:



Classification of Motors:



DC Motor:

Futures of DC Motors:

1- Most of the electrical machines in service are AC types.

2- DC machine are of considerable industrial importance.

3- DC machine mainly used as DC motors and the DC generators are rarely used.

4- DC motors provides a fine control of the speed which can not be attained by AC motors.

5- DC motors can develop rated torque at all speeds from standstill to rated speed.

6- Developed torque at standstill is many times greater than the torque developed by an AC motor of equal power and speed rating.

Application of DC Machines:

The DC machine can operate as either a motor or a generator; at present its use as a generator is limited because of the widespread use of ac power.

- **Large DC motors** are used in machine tools, printing presses, fans, pumps, cranes, paper mill, traction, textile mills and so forth.
- **Small DC machines** (fractional horsepower rating) are used primarily as control device-such as tachogenerators for speed sensing and servomotors for position and tracking, and used in Robots.

Advantages of DC Machines:

• High starting torque

• Rapid acceleration and deceleration.

• Speed can be easily controlled over wide speed range.

• Used in tough gobs (traction motors, electric trains, electric cars,….)

• Built in wide range of sizes.

Disadvantages of DC Machines:

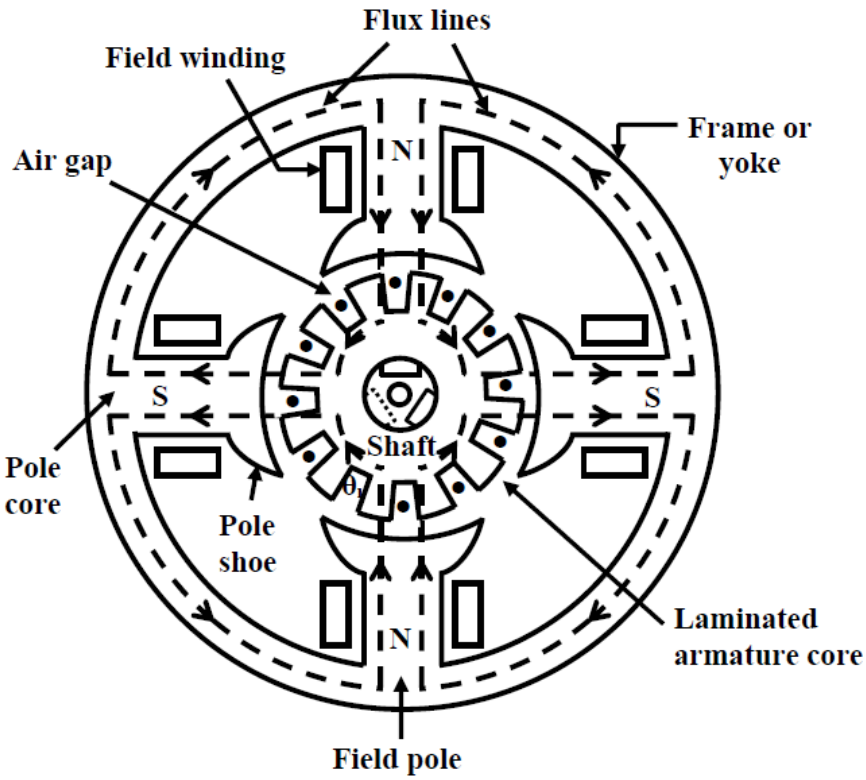
• Needs regular maintenance

• Cannot be used in explosive area.

• High cost.

Construction of DC Machine:

Across-section of a 4-pole DC motor is shown in figure below:



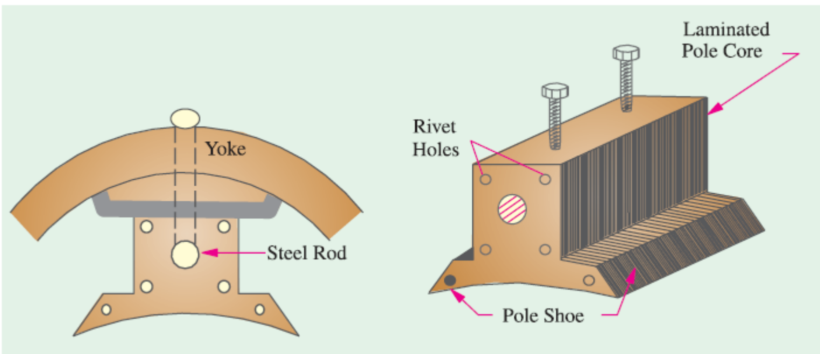
The construction generally consists of:

1- Yoke:

This is the outer part of the DC motor. It provides the mechanical supports for the poles and acts as a protecting cover for the whole machine. It carries the magnetic flux produced by the poles. Yokes are made out of cast iron or cast steel.

2- Field pole:

The field poles are mounted inside the yoke, are made of thin lamination stacked together, it consist of pole cores and pole shoes as shown in figure below.



The pole shoes serve two purposes.

(i) They spread out the flux in the air gap and also being the larger cross section reduced the reluctance of the magnetic path, thus the mean turn length of the wire will reduced thereby its reduce its weight and cost.

(ii) They support the field coils.

3- Field winding:

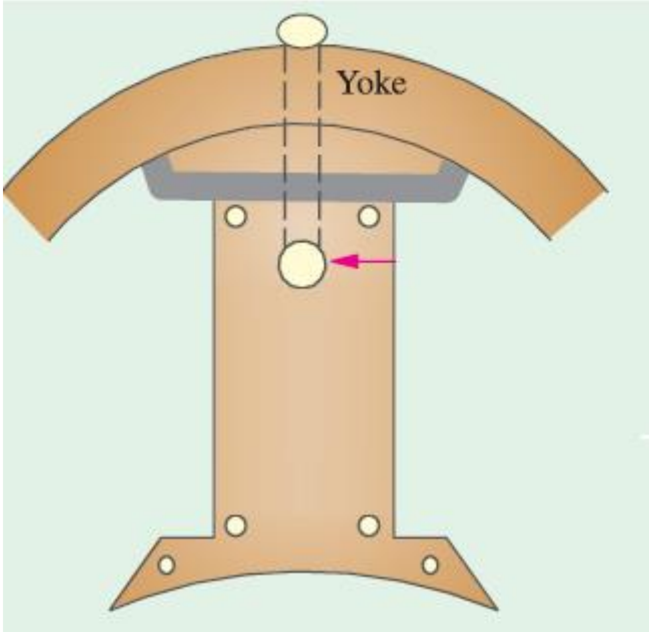
The field coils are wound on the poles. There are two types of field windings:

a- **Shunt field winding**: large number of turns of small section copper conductor is used (fine wire). It is connected in parallel with the armature windings.

b- Series field winding: few turns of heavy cross section conductor is used. . It is connected in series with the armature windings.

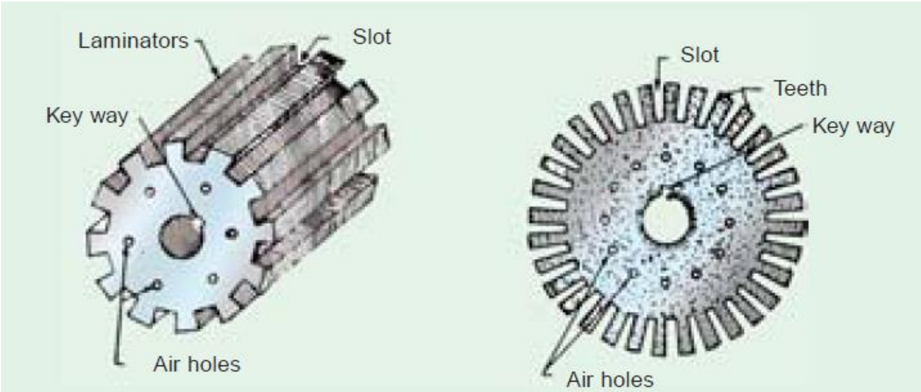
A DC motor may have both field windings wound on the same pole.

- Shunt motor: motor with only shunt field windings.
- Series DC motor: motor with only series field windings.
- Compound DC motor: motor with both field windings (shunt & series).

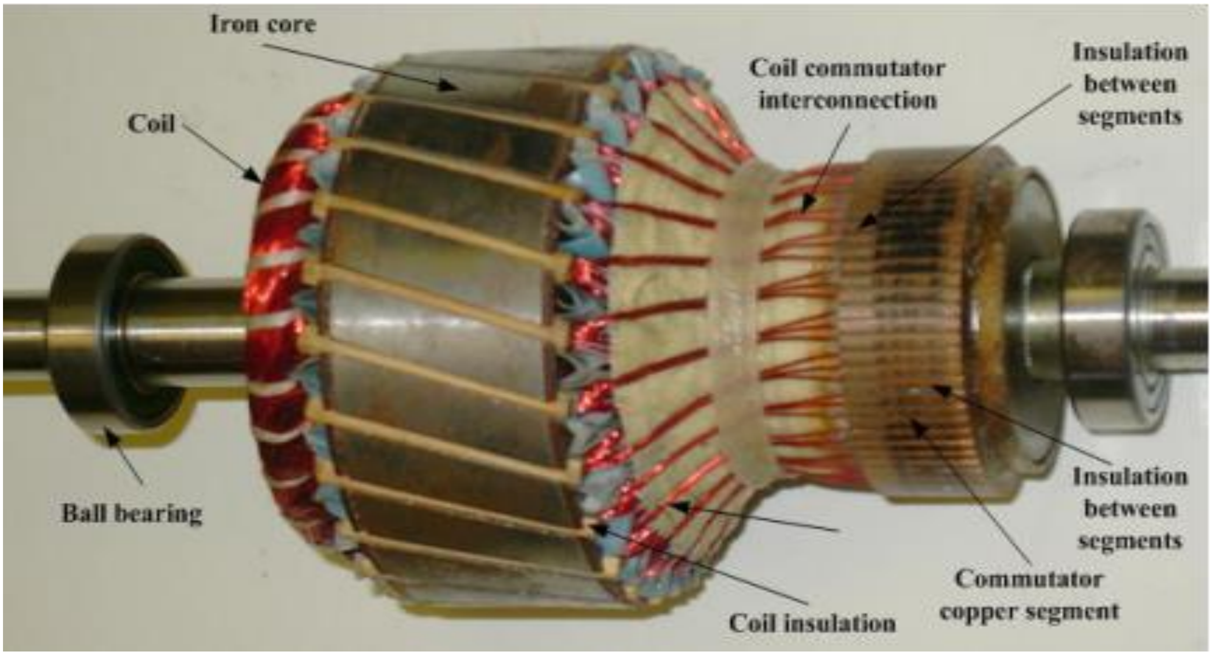
-


4- Armature:

a. **Armature core:** it carries the armature winding, is made of sheet-steel laminations. The laminations are stacked together to form a cylindrical structure as shown in figure below.



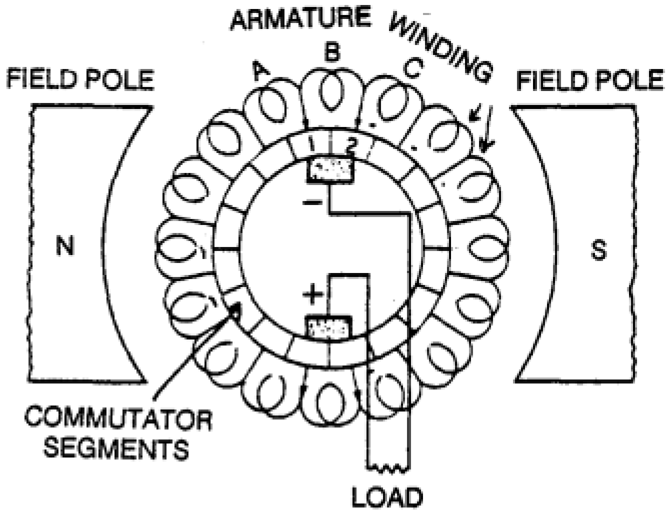
b. **Armature windings:** is the heart of the DC motor in which the torque is developed.



5- Commutatator:

The commutator, whose function is to facilitate the collection of current from the armature, It consists of copper segments tightly fastened together with mica/micanite insulating separators on an insulated base. The whole commutator forms a rigid and solid assembly of insulated copper strips and can rotate at high speeds. Each commutator segment is provided with a 'riser' where the ends of the armature coils get connected.

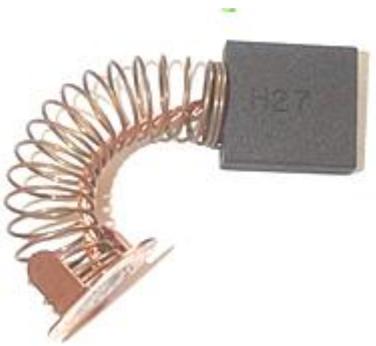
No. of segments = No. of armature windings



Armature and Commutator in a Two-Pole DC Machine.

6- Brushes:

Are the elements which are connecting the armature windings (through commutator) to the external terminal of the motor. The brush pressure on the commutator should be just right, because low pressure leads to poor contacts which results in excessive sparking and burning the commutator. While high pressure lead overheating the commutator.

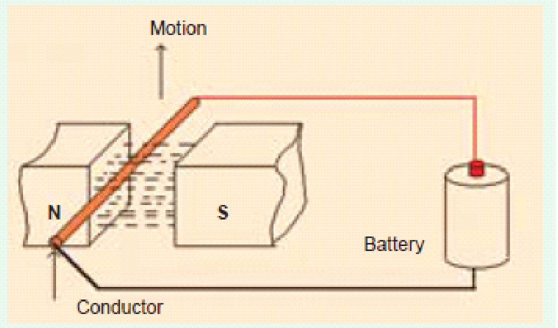


Principle of operation of a DC motor:

In a DC motor:

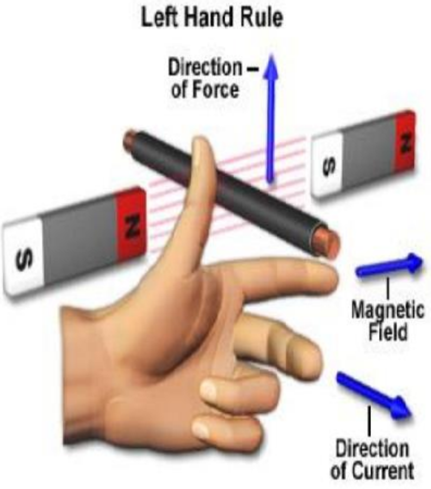
- Field poles are supplied by DC excitation current, which produces a DC magnetic field.
- Armature winding (conductor) is supplied by dc current through the brushes, and commutator.

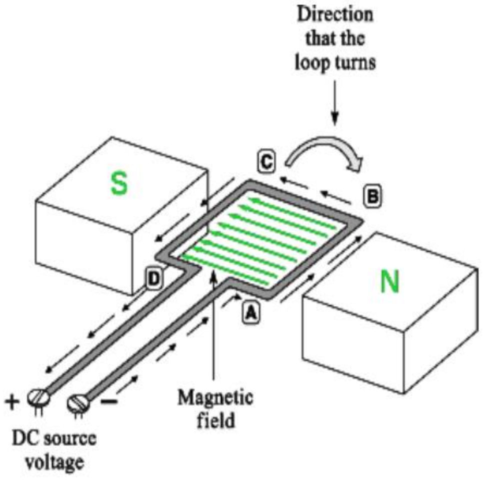
According to the Lorents force equation, **a current-carrying conductor when placed in a magnetic field experiences a force that tend to move it**, as shown in the following figure.



Principle of Motor

All the conductors placed on the periphery of a DC motor are subjected to these forces. These forces cause the armature to rotate in the clockwise direction. Therefore, the armature of a DC motor rotates in the direction of the torque developed by the motor.





BACK e.m.f.:

Due to the rotation of the armature coil (i.e. a conductor) in the magnetic field, the motor works as a DC generator and induced e.m.f acts in the circuit, this opposes the current. This induced e.m.f is called back e.m.f (E_b).

$E_b = K \emptyset\, w_m$

$K = \frac{PZ}{2\pi\, A}$ machine constant

P: No. of poles

Z: Total of armature conductors

A: No. of parallel paths in armature

$A = P$ in case of **Lap** windings

$A = 2$ in case of **Wave** windings

$\emptyset$: Flux/pole in weber

$$w_m = \frac{2\pi N}{60}$$

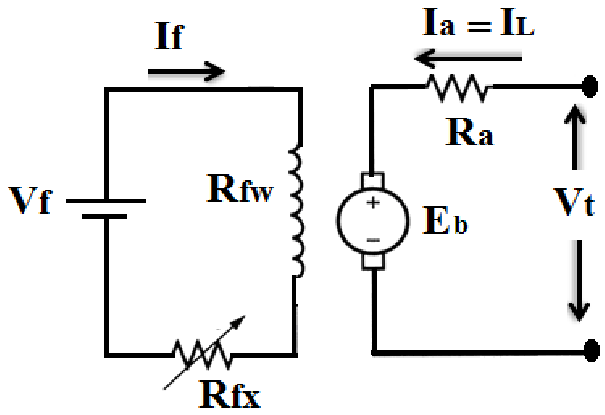
N: Armature speed in revolution per minutes (rpm)

$\therefore E_b = \frac{NPZ\emptyset}{60\ A}$ (E_b is produced by the generator action of the motor)

Types of DC Motors:

1- Separately Excited DC Motor:

A shunt field windings are supplied from a separate constant DC power source (like Battery) for producing the magnetic flux, are represented by resistor R_f. The resistor R_{fc} represents an external variable resistor (sometimes lumped together with the field coil resistance) used to control the amount of current in the field circuit.



The armature windings are represented by back e.m.f E_b and a resistor R_a. are supplied from a DC power source ($\boldsymbol{V_t}$)

$$\boldsymbol{V_f = I_f * R_f}$$

$$\boldsymbol{V_t = E_b + I_a R_a}$$

$$\boldsymbol{E_b = K_a \varphi w_m}$$

$$\boldsymbol{T_a = K_a \varphi I_a}$$

R_{fw}: Resistance of field winding.

R_{fc}: Resistance of control rheostat used in field circuit.

$R_f = R_{fw} + R_{fx}$: total field resistance

R_{a}: Resistance of armature circuit.

2- Self-Excited DC Motor:

A field windings gets its power from the armature terminals of the motor.

a- Shunt DC motor:

A shunt winding gets its power from the armature terminals of the motor. shunt field winding connected across (in parallel with) the armature terminals.

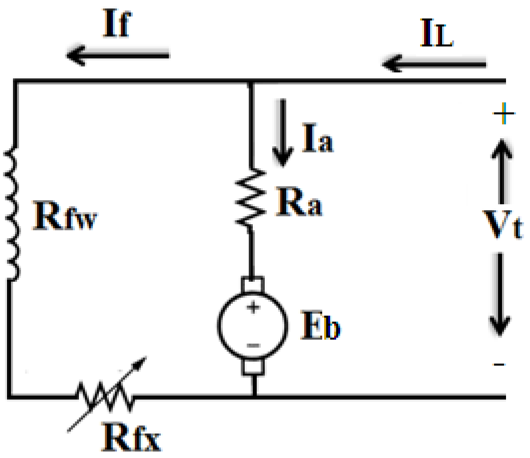
$$V_f = V_t = I_f * R_f$$

$$V_t = E_b + I_a R_a$$

$$E_b = K_a \varphi w_m$$

$$I_L = I_a - I_f$$

$$T_a = K_a \varphi I_a$$



b- Series DC motor:

The series field winding connected in series with the armature windings.

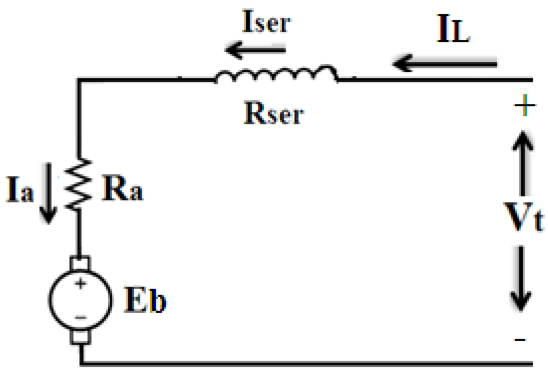
$$I_L = I_{ser} = I_a$$

$$V_t = E_b + I_a(R_a + R_{ser})$$

$$T_a = K_a \varphi I_a$$

$$\varphi = C I_a$$

$$T_a = K_a C I_a{}^2$$



c- Compound DC motor:

Both **shunt** and **series** field windings are connected with the armature windings in short-shunt or long-shunt.

1- Short shunt compound DC Motor:

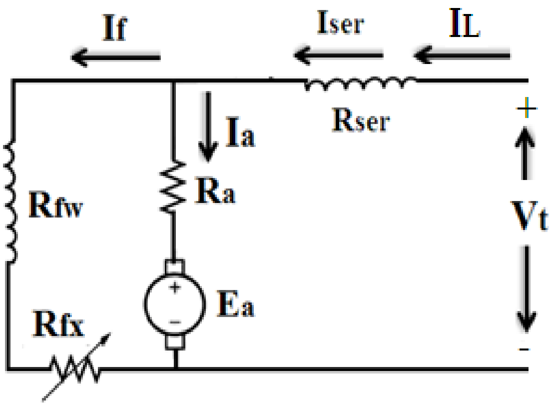
When the shunt field winding is connected directly across the armature terminals, it is called a **short-shunt compound motor.**

$$I_L = I_{ser}$$

$$I_a = I_L - I_f$$

$$I_f = \frac{\mathrm{V_t} + \mathrm{I_{ser}} * \mathrm{R_{ser}}}{\mathrm{R_f}}$$

$$V_t = E_b + (\mathrm{I_a} * \mathrm{R_a}) + (\mathrm{I_{ser}} * \mathrm{R_{ser}})$$



2- Long shunt compound DC motor:

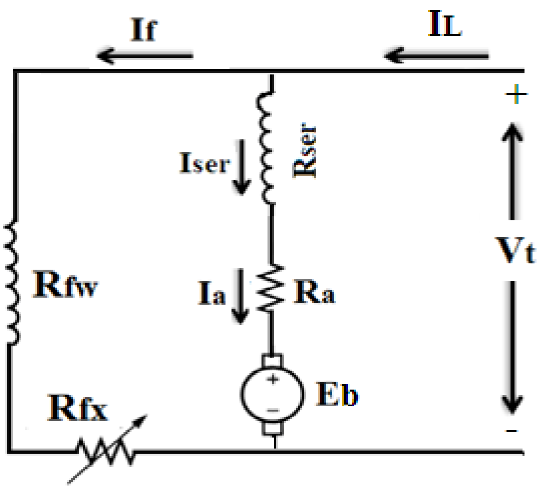
When the shunt field winding is connected across the load, it is called a **long-shunt compound motor.**

$$I_f = \frac{\mathrm{V_t}}{\mathrm{R_f}}$$

$$I_a = I_{ser} = I_L - I_f$$

$$V_t = E_b + (\mathrm{I_a} * \mathrm{R_a}) + (\mathrm{I_{ser}} * \mathrm{R_{ser}})$$

$$V_t = E_b + \mathrm{I_a}(\mathrm{R_a} + \mathrm{R_{ser}})$$



Efficiency(η):

The efficiency of a DC motor is the ratio of its mechanical output power (P_o) to the electrical input power (P_{in}).

$$Efficiency(\eta)\% = \frac{P_o\ (watt)}{P_{in}\ (watt)} * 100$$

P_o : is mechanical output power as mentioned previously, then it in (Horse Power H.P unit) to convert its unit to Watt unit should be multiplied by 476.

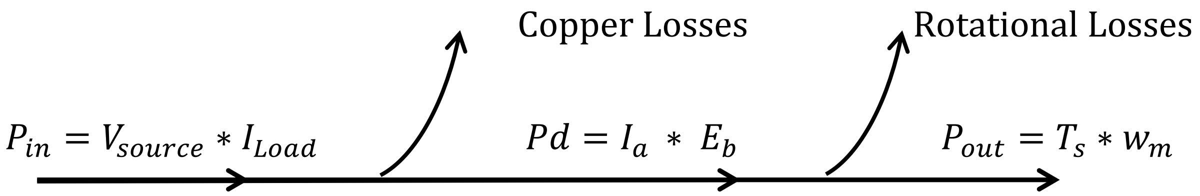
$$\eta\% = \frac{P_o\,(H.P)*746}{P_{in}\,(watt)} * 100$$

$$P_{in} = (P_o\ (H.P) * 746) + Total\ Losses$$

$$\eta\% = \frac{P_o\,(H.P) * 746}{(P_o\,(H.P) * 746) + Total\ Losses} * 100$$

Power-Flow Diagram:

A DC motor is a machine which converts electrical energy (or power) into mechanical energy (or power).



Power-Flow Diagram of a DC Motor

P_{in} = Electrical input power = $V_{source} * I_{Load}$

P_d = Developed power (Electro mechanical power) = $I_a * E_b$

P_o = Output power (Shaft power) = $T_s * w_m$

T_s = Applied shaft torque

Rotational Losses = Mechanical losses + Magnetic losses

P_{cu} = Copper losses

$$P_{in} = P_o + total\ losses$$

Losses in DC Machines:

The various losses occurring in a DC machines can be sub-divided as follows:

1- Copper losses.

Whenever current flows in a wire, a copper loss associated with it, it consists of:

- Armature copper loss = $I_a^2 * R_a$. This loss is about 30 to 40% of full-load losses.
- The loss due to brush contact resistance; It is usually added to the armature copper losses.
- Field copper loss. This loss is about 20 to 30% of full-load losses.
  1. Shunt copper loss = $I_f^2 * R_f$.
  2. Series copper loss = $I_{ser}^2 * R_{ser}$.

2- Magnetic losses (Iron or Core losses):

This loss is about 20 to 30% of full-load losses. It consists of:

- Hysteresis loss.
- Eddy current loss.

3- Mechanical losses:

This loss is about 10 to 20% of full-load losses. It consist of:

These consist of:

- Friction between the bearings and the shaft.
- Friction between the brushes and the commutator.
- Air-friction or winding loss of rotating armature.

Usually, **magnetic** and **mechanical losses** are collectively known as **Rotational Losses.**

Rotational Losses = magnetic losses + mechanical losses

4- Stray losses:

These losses cannot be easily accounted.

- For large machine above (100 H.P); stray losses = 1% of the output power.
- For small machine are neglected.

Example 1: Find the efficiency of DC compound motor (long shunt), 25H.P, 230V, shunt field resistance equal to 115Ω, series field resistance equal to 0.03Ω, armature resistance equal to 0.18 Ω, rotational losses at load equal to 1088W, I_L = 92A.

Sol:

Example 2: Find the efficiency of DC compound motor (long shunt); armature current (101.3 A), rotate at (1800 rpm), total no. of armature conductor (476), flux/pole (0.015 wb), no. of parallel path (p=2), shunt field resistance (150Ω), series field resistance (0.04Ω), armature resistance (0.1Ω), rotational losses at load (1827W).

Example 3: A 300V DC shunt motor, shunt resistance (150 Ω), armature resistance (0.2 Ω), the source supplied current equal to 36 A, core losses (210 W), running at 1500 r.p.m. , friction losses (100 W).

Find: 1- back e.m.f. , 2- efficiency, 3- developed torque, 4- shaft torque.

Example 4: A 240 V short shunt compound DC motor, series resistance (0.09 Ω), shunt resistance (80 Ω), armature resistance (0.11 Ω), the source supplied current equal to 15 A, core losses (210 W), running at 1500 r.p.m. , friction losses (100 W).

Find: 1- back e.m.f. , 2- efficiency, 3- developed torque, 4- shaft torque.

Speed Control of DC Motor:

1- Speed control of separately excited DC motor:

We know that back e.m.f. is produced by the generator action of the motor. Hence back e.m.f. $E_b = \frac{NPZ\emptyset}{60\,A}$.

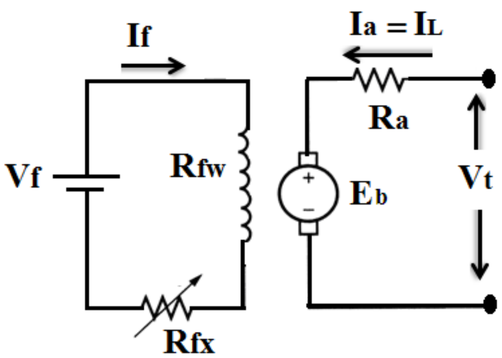
Let V_t be the applied voltage and I_a and R_a is the armature circuit current and resistance respectively.

Then

$$E_b = V_t - I_a R_a$$

$$E_b = \frac{NPZ\emptyset}{60\,A} = V_t - I_a R_a$$

$$N = \frac{(V_t - I_a R_a) * 60A}{PZ\emptyset}$$



Or N $\propto (V - I_a R_a) / \phi$ since P Z & A are constants for a particular motor.

From this formula it follows that the speed of a D.C. motor can be regulated by:

(i) Armature Control: Adjusting the terminal voltage (V_t) applied to the armature

This method implies changing the voltage applied to the armature of the motor without changing the voltage applied to its field. Therefore, the motor must be separately excited to use armature voltage control.

$N \, \alpha \, \frac{V_t}{\emptyset}$ Since I_a R_a drop is very small as compared to the applied voltage V_t

$N \, \alpha \, V_t$, if applied voltage $\emptyset$ is constant

(ii) Field control: Adjusting the field resistance R_F (and thus the field flux)

N $\propto 1/\phi$, if applied voltage V_t is constant

Hence speed is inversely proportional to flux / per pole if the applied voltage is constant. Then the speed can be increased by decrease the flux and vice versa. The flux of DC motor can be changed by changing the field current (I_f), with help of external field resistance (R_{fx}).

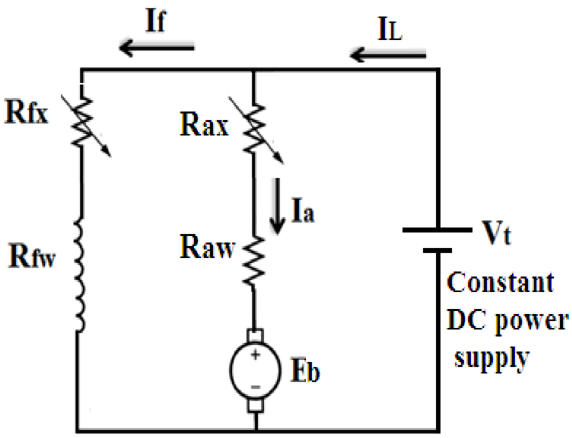
$\emptyset \, \alpha \, I_f$ $\quad$ *then* $\quad$ $N \, \alpha \, \frac{1}{I_f}$

2- Speed control of shunt DC motor:

Here the speed control is similar to the speed control of separately excited DC motor.

$N \, \alpha \, V_t$, if applied voltage $\emptyset$ is constant

$N \propto \frac{1}{\emptyset} \propto \frac{1}{I_f}$, if applied voltage V_t is constant



But the difference is that:

- The armature terminal voltage is adjusted by the external armature resistance (R_{ax}). Because terminal voltage cannot be varied should be constant (if it varied caused to I_f to be varied also).

- The field current (I_f) is controlled by an external field resistance (R_{fx}).
