

Direct-Current Machines

- Direct-current (DC) machines are driven from a DC power supply. DC machines are the most versatile of all rotating electrical machines. Their speed may be easily adjusted in very fine increments ranging from standstill to rated speed and even above.
- DC machines can develop rated torque at all speeds from standstill (locked-rotor) to rated speed. DC machines are easier to analyze than their AC counterparts, although their construction is made rather complex by the fact that they need a commutator, which reverses the direction of currents and fluxes to produce a net torque.
- DC motors are used in a wide variety of industrial drives, such as robots, machine tools, oil drilling rigs, mining, automotive systems, etc. On the other hand, DC generators are still in use in some power generating plants,

DC Motors

- When a current-carrying conductor is placed in an external magnetic field vertical to the conductor, the conductor experiences a force vertical to itself and to the external magnetic field.
- The right-hand rule for force on a conductor may be used to find the direction of the force experienced on the conductor. If the right thumb points in the direction of the current in the conductor and the fingers of the right hand point in the direction of the external magnetic field, then the force on the conductor is directed outward from the palm of the right hand.
- Example: 1 ampere is the current passing through two straight parallel conductors 1 metre apart in a vacuum which produces a force of 2×10^{-7} newtons per metre of conductor.

- An electric motor consists of a permanent external field magnet (stator) and a coiled conducting armature (rotor) which is free to rotate within the field magnet. Brushes and a commutator (are different if A.C. or D.C. current is supplied to the armature) connect the armature to an external voltage source.
- The speed of rotation of a motor depends on the value of current flowing through it, the number of coils on the armature, the strength of the field magnet, the permeability of the armature, and the mechanical load connected to the shaft.

Types of DC Motors

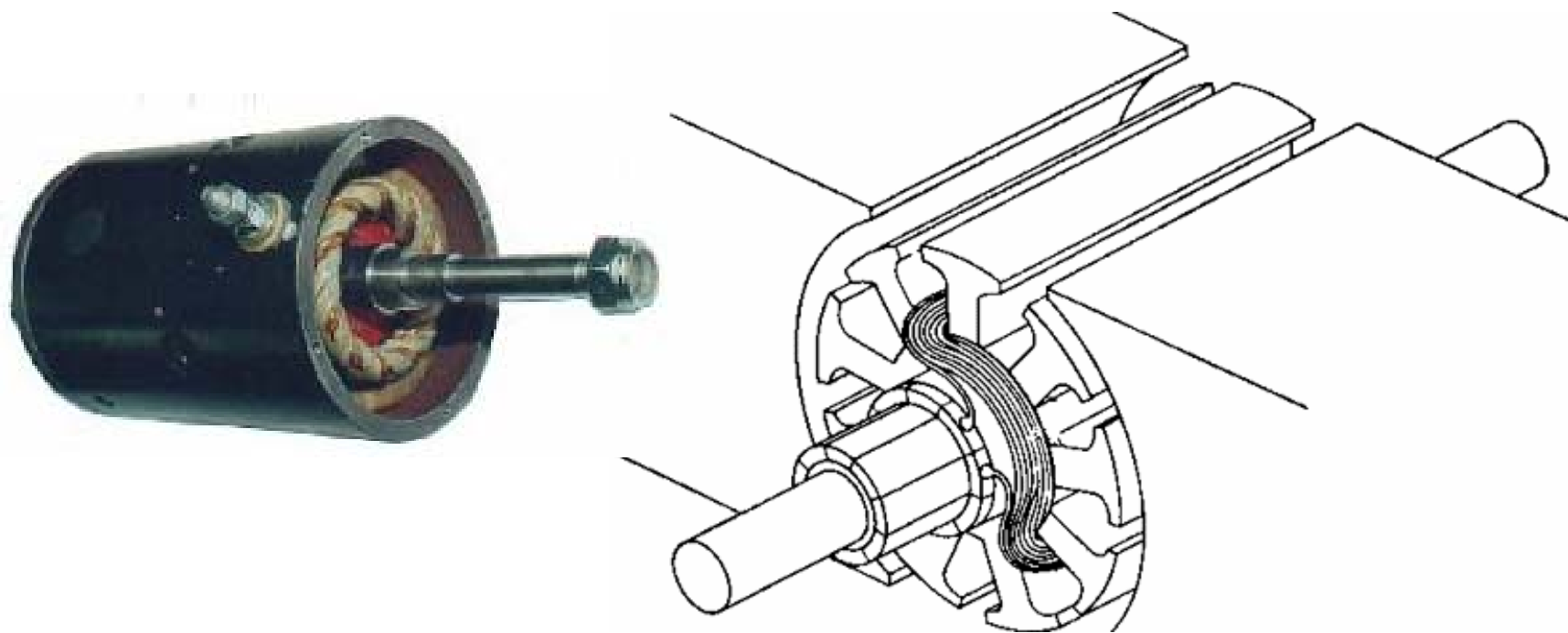
- Stepper Motor: It has very precise speed and position control, high torque at low speed. However, it is expensive and hard to find. Also require a switching control circuit.
- DC Motor: It has wide range of speeds and torques. It is more powerful than permanent magnet motors. However, it requires more current than permanent magnet motors, since field coil must be energized. It is heavier than permanent magnet motors. More difficult to obtain.
- Permanent Magnet Motor: It is small, compact, easy to find, and very inexpensive. However, it is small and cannot vary magnetic field strength.
- Gasoline: It is very high power/weight ratio. It provides very high torque. No batteries are required. However, it is expensive, and loud.

Basic Parts of the DC Motor

- **Stator:** It is cylindrical. Has an even number of magnetic poles that are established by field windings or by permanent magnets.
- **Rotor:** Also called Armature. It is the rotating part inside the stator. Slots cut lengthwise into the surface of the rotor to carry the armature windings.
- Since the reluctance of air is much higher than that of iron, the flux takes the shortest path from a stator north pole via the rotor to a stator south pole. Therefore the flux in the air gap is vertical to the rotor surface and the rotor conductors.
- Keep in mind that the force will be along the direction of the cross product of current and flux.

An armature made of stacked laminations with one winding in place. The armature is situated between the poles of a permanent magnet. The aim of the armature assembly is to provide a means by which current carrying conductors can be moved through the air gap of an electrical machine. The torque developed by the machine is a consequence of the magnetic forces between stator and rotor poles. This torque

is maximum when the angle γ between the rotor and stator poles is 90° .



Commutation

- To keep the torque angle constant as the rotor spins on its shaft, a mechanical switch, called a commutator, is configured so the current distribution in the rotor winding remains constant, and therefore the rotor poles are consistently at 90° with respect to the fixed stator poles.
- In a DC machine, the magnetizing current is DC. Commutation is the process of converting AC energy in the rotor of a DC machine to DC energy at its terminals. It is the most critical part of the design and operation of any DC machine.
- Commutator consists of radial copper bars separated by an insulating material, usually mica. The number of coils in the armature, the number of poles, and the type of winding determine the number of commutator bars.
- Current is conducted to the armature by carbon *brushes* that are held against the surface of the commutator by springs. Brushes wear with time, must be inspected regularly, and occasionally replaced.

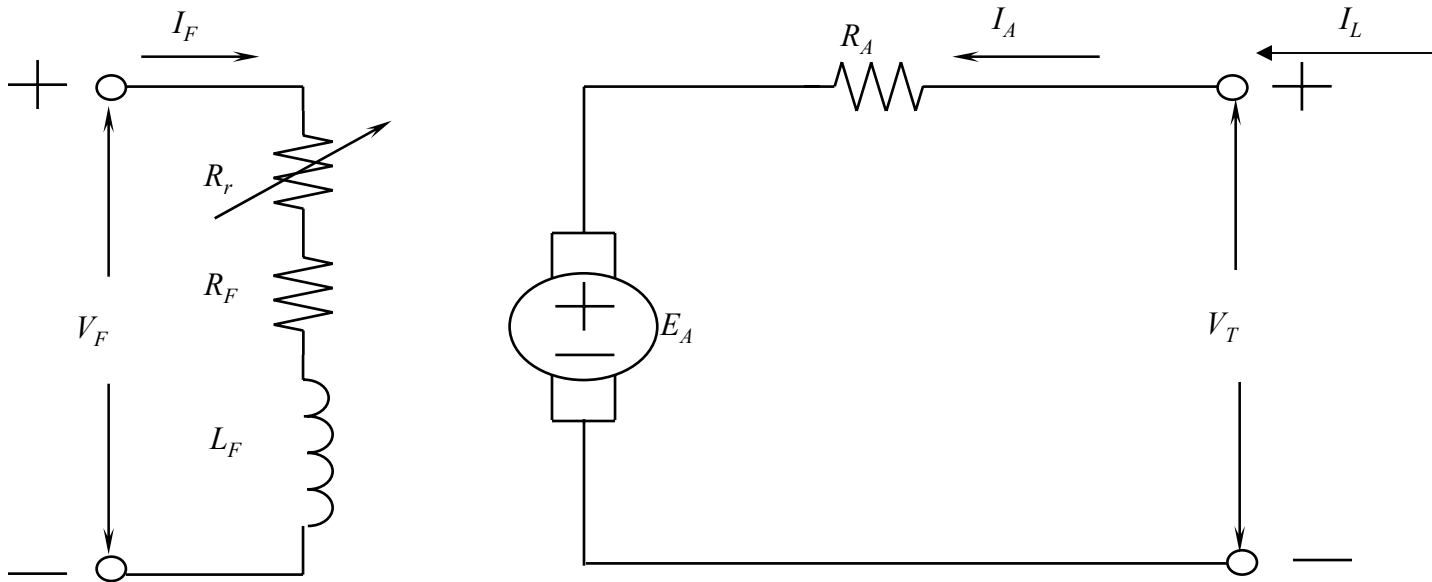
Types of DC Motors

There are five major types of DC motors in general use:

- Separately-excited DC machines
- Shunt DC machines
- Series DC machines
- Compound-connected DC machines
- Permanent magnet DC machines

Separately-Excited Motors

This is a motor whose field circuit is supplied from a separate constant-voltage power supply.



$$I_F = \frac{V_F}{R_F}$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A$$

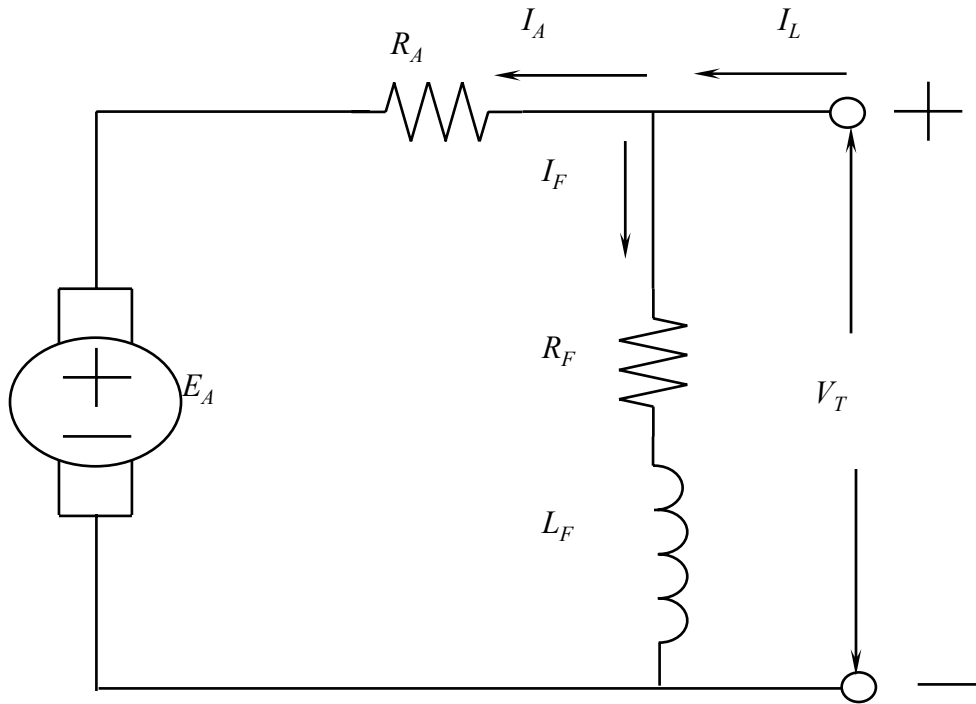
$$E_A = K \phi \omega$$

$$\tau_{\text{ind}} = k \phi \phi_A$$

Shunt Motors

- A shunt motor is connected in the same way as a shunt generator. The field windings are connected in parallel (shunt) with the armature windings.
- When the speed of a dc shunt motor is adjusted, the speed remains relatively constant even under changing load conditions. One reason for this is that the field flux remains constant.
- A constant voltage across the field makes the field independent of variations in the armature circuit. If the load on the motor is increased, the motor tends to slow down. When this happens, the counter emf generated in the armature decreases. This causes a decrease in the opposition to DC current flow through the armature. Armature current increases, causing the motor to speed up. The conditions that established the original speed are re-established, and the original speed is maintained.

Equivalent Circuit of a Shunt Motor



$$I_F = \frac{V_T}{R_F}$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

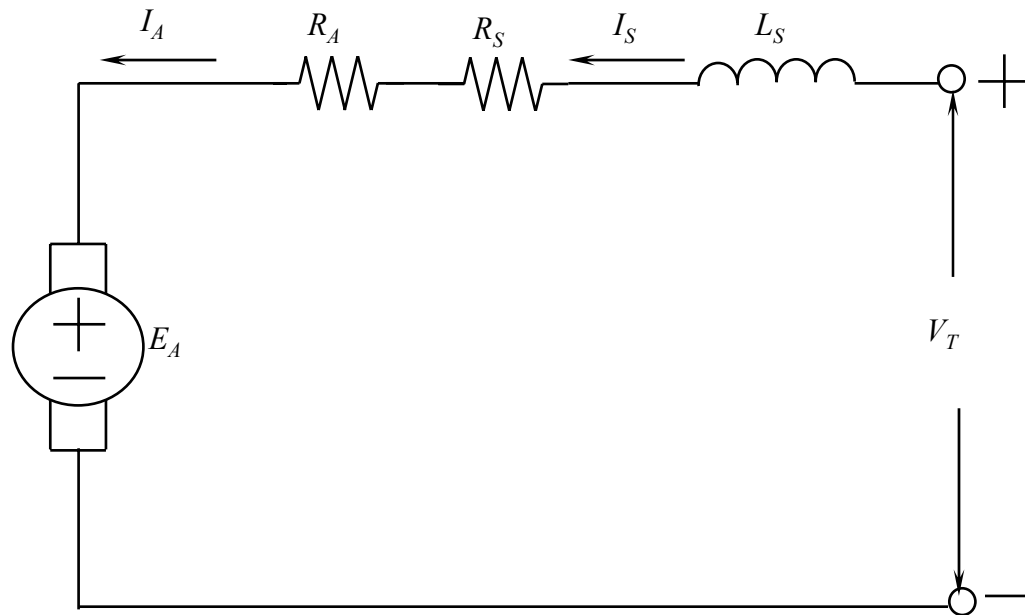
Permanent Magnet DC Motors

- Permanent magnet motors are similar to shunt wound motors. They are built with a conventional armature, they use permanent magnets rather than windings in the field part. DC power is supplied only to the armature part. Since the field is constant, the current draw varies linearly with torque.
- Permanent magnet motors are not expensive to operate since they require no field supply. However, the magnets lose their magnetic properties over time, and this effects less than rated torque production. Few motors have windings built into the field magnets in order to re-magnetize the cores.
- Permanent magnet motors do not endure continuous operation since they overheat rapidly, destroying the permanent magnets.
- Automobiles applications: Power seats, windows, and windshield wipers.

Series Motors

- In a series DC motor, the field is connected in series with the armature. The field is wound with a few turns of large wire, because it must carry full armature current.
- Series motor develops a large amount of turning force (torque), from a standstill. Because of this characteristic, the series DC motor may be used to operate small electric appliances, portable electric tools, cranes, winches, hoists, etc.
- Another characteristic is that the speed varies widely between no load and full load. Series motors cannot be used where a relatively constant speed is required under conditions of varying load.

Equivalent Circuit of a Series Motor



$$I_A = I_S = I_L$$

$$V_T = E_A + I_A (R_A + R_S)$$

$$\tau_{\text{ind}} = K \phi \varphi_A$$

Other Types!

- **The Compound-Wound DC Motor:** employs both a series field and a shunt (parallel) field, as shown in the schematic.
- **Separately Excited Field DC Motors:** In this type of motors, the field winding and the armature windings are separate. The separately excited field has a low current of about 20 compared to series type for example.

Motor Speed

- DC motors are variable-speed motors. The speed of a DC motor is changed by changing the current in the field or in the armature.
- When the field current is decreased, the field flux is reduced, and the counter emf decreases. This permits more armature current. Therefore, the motor speeds up. When the field current is increased, the field flux is increased. Higher counter emf is developed, which opposes the armature current. The armature current then decreases, and the motor slows down.
- When the voltage across the armature is decreased, the armature current is decreased, and the motor again slows down. When the armature voltage and current are both increased, the motor speeds up.

DC Motor Efficiency Calculations

To calculate the efficiency of a DC motor, the following losses must be determined:

Copper losses

Brush drop losses

Mechanical Losses

Core Losses

Stray Losses

DC Generators

- DC generators are DC machines used as generators. There is no real difference between a generator and a motor except for the direction of power flow. There are four major types of DC generators:
 - Separately Excited Generators
 - Shunt Generators
 - Series Generators
 - Cumulatively Compound Generators
 - Differentially Compound Generators