1 DC Motor

- The direct current (dc) machine can be used as a motor or as a generator.
- DC Machine is most often used for a motor.
- The major advantages of dc machines are the easy speed and torque regulation.
- However, their application is limited to mills, mines and trains. As examples, trolleys and underground subway cars may use dc motors.
- In the past, automobiles were equipped with dc dynamos to charge their batteries.
1 DC Motor

- Even today the starter is a series dc motor
- However, the recent development of power electronics has reduced the use of dc motors and generators.
- The electronically controlled ac drives are gradually replacing the dc motor drives in factories.
- Nevertheless, a large number of dc motors are still used by industry and several thousand are sold annually.
1 Construction
DC Machine Construction

Figure 1 General arrangement of a dc machine
DC Machines

- The stator of the dc motor has poles, which are excited by dc current to produce magnetic fields.
- In the neutral zone, in the middle between the poles, commutating poles are placed to reduce sparking of the commutator. The commutating poles are supplied by dc current.
- Compensating windings are mounted on the main poles. These short-circuited windings damp rotor oscillations.
DC Machines

- The poles are mounted on an iron core that provides a closed magnetic circuit.
- The motor housing supports the iron core, the brushes and the bearings.
- The rotor has a ring-shaped laminated iron core with slots.
- Coils with several turns are placed in the slots. The distance between the two legs of the coil is about 180 electric degrees.
DC Machines

- The coils are connected in series through the commutator segments.
- The ends of each coil are connected to a commutator segment.
- The commutator consists of insulated copper segments mounted on an insulated tube.
- Two brushes are pressed to the commutator to permit current flow.
- The brushes are placed in the neutral zone, where the magnetic field is close to zero, to reduce arcing.
DC Machines

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- The commutator consists of insulated copper segments mounted on an insulated tube.
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DC Machines

• The *commutator* switches the current from one rotor coil to the adjacent coil,
• The switching requires the interruption of the coil current.
• The sudden interruption of an inductive current generates high voltages.
• The high voltage produces flashover and arcing between the commutator segment and the brush.
DC Machine Construction

Figure 2 Commutator with the rotor coils connections.
Figure 3  Details of the commutator of a dc motor.
DC Machine Construction

Figure 4 DC motor stator with poles visible.
DC Machine Construction

Figure 5 Rotor of a dc motor.
DC Machine Construction

Figure 6 Cutaway view of a dc motor.
2.1 DC Motor Operation
DC Motor Operation

- In a dc motor, the stator poles are supplied by dc excitation current, which produces a dc magnetic field.
- The rotor is supplied by dc current through the brushes, commutator and coils.
- The interaction of the magnetic field and rotor current generates a force that drives the motor.
2.1 DC Motor Operation

- The magnetic field lines enter into the rotor from the north pole (N) and exit toward the south pole (S).
- The poles generate a magnetic field that is perpendicular to the current carrying conductors.
- The interaction between the field and the current produces a Lorentz force,
- The force is perpendicular to both the magnetic field and conductor

(a) Rotor current flow from segment 1 to 2 (slot a to b)

(b) Rotor current flow from segment 2 to 1 (slot b to a)
2.1 DC Motor Operation

- The generated force turns the rotor until the coil reaches the neutral point between the poles.
- At this point, the magnetic field becomes practically zero together with the force.
- However, inertia drives the motor beyond the neutral zone where the direction of the magnetic field reverses.
- To avoid the reversal of the force direction, the commutator changes the current direction, which maintains the counterclockwise rotation.

(a) Rotor current flow from segment 1 to 2 (slot a to b)
(b) Rotor current flow from segment 2 to 1 (slot b to a)
2.1 DC Motor Operation

- Before reaching the neutral zone, the current enters in segment 1 and exits from segment 2,
- Therefore, current enters the coil end at slot a and exits from slot b during this stage.
- After passing the neutral zone, the current enters segment 2 and exits from segment 1,
- This reverses the current direction through the rotor coil, when the coil passes the neutral zone.
- The result of this current reversal is the maintenance of the rotation.

(a) Rotor current flow from segment 1 to 2 (slot a to b)

(b) Rotor current flow from segment 2 to 1 (slot b to a)
2.2 DC Generator Operation
2.2 DC Generator Operation

- The N-S poles produce a dc magnetic field and the rotor coil turns in this field.
- A turbine or other machine drives the rotor.
- The conductors in the slots cut the magnetic flux lines, which induce voltage in the rotor coils.
- The coil has two sides: one is placed in slot a, the other in slot b.
2.2 DC Generator Operation

- In Figure 11A, the conductors in slot a are cutting the field lines entering into the rotor from the north pole,
- The conductors in slot b are cutting the field lines exiting from the rotor to the south pole.
- The cutting of the field lines generates voltage in the conductors.
- The voltages generated in the two sides of the coil are added.

(a) Rotor current flow from segment 1 to 2 (slot a to b)

(b) Rotor current flow from segment 2 to 1 (slot b to a)
2.2 DC Generator Operation

- The induced voltage is connected to the generator terminals through the commutator and brushes.
- In Figure 11A, the induced voltage in b is positive, and in a is negative.
- The positive terminal is connected to commutator segment 2 and to the conductors in slot b.
- The negative terminal is connected to segment 1 and to the conductors in slot a.
2.2 DC Generator Operation

• When the coil passes the neutral zone:
  – Conductors in slot a are then moving toward the south pole and cut flux lines exiting from the rotor
  – Conductors in slot b cut the flux lines entering the in slot b.

• This changes the polarity of the induced voltage in the coil.

• The voltage induced in a is now positive, and in b is negative.
2.2 DC Generator Operation

- The simultaneously the commutator reverses its terminals, which assures that the output voltage ($V_{dc}$) polarity is unchanged.

- In Figure 11B
  - the positive terminal is connected to commutator segment 1 and to the conductors in slot a.
  - The negative terminal is connected to segment 2 and to the conductors in slot b.
2.3 DC Machine Equivalent Circuit
Generator
2.3 DC Generator Equivalent circuit

- The magnetic field produced by the stator poles induces a voltage in the rotor (or armature) coils when the generator is rotated.
- This induced voltage is represented by a voltage source.
- The stator coil has resistance, which is connected in series.
- The pole flux is produced by the DC excitation/field current, which is magnetically coupled to the rotor.
- The field circuit has resistance and a source.
- The voltage drop on the brushes represented by a battery.
2.3 DC Generator Equivalent circuit

Figure 12 Equivalent circuit of a separately excited dc generator.
2.3 DC Generator Equivalent circuit

- The magnetic field produced by the stator poles induces a voltage in the rotor (or armature) coils when the generator is rotated.
- The dc field current of the poles generates a magnetic flux.
- The flux is proportional with the field current if the iron core is not saturated:

\[ \Phi_{ag} = K_1 I_f \]
2.3 DC Generator Equivalent circuit

- The rotor conductors cut the field lines that generate voltage in the coils.

\[ E_{ag} = 2 N_r B \ell_g v \]

- The motor speed and flux equations are:

\[ v = \omega \frac{D_g}{2} \quad \Phi_{ag} = B \ell_g D_g \]
2.3 DC Generator Equivalent circuit

• The combination of the three equation results the induced voltage equation:

\[ E_{ag} = 2 N_r B \ell_g v = 2 N_r B \ell_g \left( \omega \frac{D_g}{2} \right) = N_r \left( B \ell_g D_g \right) \omega = N_r \Phi_{ag} \omega \]

• The equation is simplified.

\[ E_{ag} = N_r \Phi_{ag} \omega = N_r K_1 I_f \omega = K_m I_f \omega \]
2.3 DC Generator Equivalent circuit

- When the generator is loaded, the load current produces a voltage drop on the rotor winding resistance.
- In addition, there is a more or less constant 1–3 V voltage drop on the brushes.
- These two voltage drops reduce the terminal voltage of the generator. The terminal voltage is;

\[ E_{ag} = V_{dc} + I_{ag} R_a + V_{brush} \]
Motor
Figure 13    Equivalent circuit of a separately excited dc motor

Equivalent circuit is similar to the generator only the current directions are different
2.3 DC Motor Equivalent circuit

- The operation equations are:
- Armature voltage equation

\[ V_{dc} = E_{am} + I_{am} R_a + V_{brush} \]

The induced voltage and motor speed vs angular frequency

\[ E_{am} = K_m I_f \omega \]
\[ \omega = 2\pi n_m \]
2.3 DC Motor Equivalent circuit

- The operation equations are:
- The combination of the equations results in

\[ K_m \ F \ \omega = E_{am} = V_{dc} - I_{am} R_m \]

The current is calculated from this equation. The output power and torque are:

\[ P_{out} = E_{am} I_{am} \]
\[ T = \frac{P_{out}}{\omega} = K_m I_{am} I_f \]
2.4 DC Machine Excitation Methods
DC Motor Operation

- There are four different methods for supplying the dc current to the motor or generator poles:
  - Separate excitation;
  - Shunt connection
  - Series connection
  - Compound
2.3 DC Motor Equivalent circuit

Figure 14  Equivalent circuit of a shunt dc motor
2.3 DC Motor Equivalent circuit

- Figure 15  Equivalent circuit of a series dc motor
2.3 DC Motor Equivalent circuit

- Figure 16  Equivalent circuit of a compound dc motor