2 Electric Motors - Operating Principles

Electric motors derive their turning motion from the interaction of two magnetic fields. Electric motors consist of a housing together with two or more pole shoes in which an armature is placed (Fig. 2).
The rotating motion is achieved by magnetising the armature, as well as the pole shoes. The armature starts turning due to the interaction of the forces created by the magnetic fields. This works as follows. There is a magnetic field around a current-carrying conductor (wire). If the direction of the current is away from us, the magnetic lines of force will flow to the right.

Electric motor
Armature
Pole shoe
Housing
a Electric motor used in a starter
b Electric motor – key components

Fig. 2 Electric Motor

Armature axis
Armature core
Housing
Pole shoe
Field winding
Armature coil
Collector

If the direction of the current is towards us, the magnetic lines of force will flow to the left (the corkscrew rule, Fig. 3).
The corkscrew rule therefore is as follows:
– Current moving away from us à magnetic field lines point to the right: cross (Fig. 3-a).
– Current moving towards us à magnetic field lines point to the left: dot (Fig. 3-b).
If the current-carrying wire is inserted between two magnets there are **two magnetic fields**. These two magnetic fields will affect one another (Fig. 4):
– to the left of the wire, the two magnetic fields oppose each other; the magnetic field is weakened.
– to the right of the wire, the two magnetic fields reinforce each other; the magnetic field is strengthened.
Because the magnetic field on the left side of the wire is weakened and on the right side it is strengthened, there is a resulting force on the currentcarrying wire. This force, F, is referred to as the **Lorentz force** (Fig. 5).

Fig. 3 Magnetic field surrounding a conductor (corkscrew rule)

a b

Fig. 5 Lorentz force

N
S
F
N
S
F
a b
N
S

Fig. 4 Magnetic fields affect each other

magnetic
lines of force
in opposing
directions
magnetic

lines of force
in the same
direction

The magnitude of the Lorentz force is dependent on:
– the strengths of the magnets
– the current flowing through the wire
– the length of the wire in the magnetic field
The aforementioned principle is used in electric motors.
In Figure 6, a wire frame is placed between two magnets. A current is supplied to the wire frame using carbon brushes and slip rings. Due to the resulting forces, the top portion of the wire frame is pushed to the left and the bottom portion is pushed to the right. The wire frame turns to the left. However, the wire frame will only turn 90º. As soon as the wire frame reaches the horizontal position, there is no longer any torque on the wire frame (Fig. 7).
The continued rotation of the wire frame is opposed due to the fact that the Lorentz forces want to turn the wire frame in the opposite direction (Fig. 7d). The wire frame consequently stops turning.
N
N
S
S
–
+
Slip rings
12
a
12
a
Fig. 6 The wire winding wants to turn to the left
a b
Carbon brushes
Fig. 7 The wire winding remains fixed in a horizontal position
a b c d
N N N N
S S S S

Changing the current’s direction
One possibility to get the wire frame to continue rotating is to reverse the direction of the current. By reversing the direction of the current, the direction of the magnetic field surrounding the wire frame changes. The current must be reversed at the precise point at which the wire frame is positioned perpendicularly to the magnetic field (Fig. 8).
A **collector** is used to reverse the current’s direction. As the wire frame turns, the collector turns with it. As soon as the wire frame passes the horizontal position, it comes into contact with the other carbon brushes (Fig. 9).
The other end of the wire winding then comes into contact with the positive current. This causes the direction of the current flowing through the wire winding to be reversed.
The Armature
Up to now, our examples used only one wire frame (winding). In practice, multiple windings are used. This allows the electric motor to deliver greater torque. The windings are applied to a soft iron core. The entire unit is referred to as an armature (Fig. 10).

Fig. 8 Reversal of current's direction

N N
S S
+ +
– –
+ +
– –
N N
S S
a b

Fig. 9 Collector instead of slip rings Collector

Windings Soft iron

Fig. 10 Armature

By using multiple windings (Fig. 11) and connecting them in series, the electric motor acquires a number of favourable properties, such as:

– high couple (torque)
– smooth rotation of the armature

The current is supplied to the windings via the **carbon brushes**. The armature and the collector turn. The carbon brushes are pushed onto the collector through means of springs. This ensures a proper connection between the collector and the carbon brushes.

The carbon brushes are made of a mixture of carbon and copper. As a result, the carbon brushes have good greasing action and conduct electricity well. Carbon brushes used in starters contain high amounts of copper. Copper ensures that the start-up current is properly conducted. The laminated collector plates are made of a copper alloy.