How Do Things Move Without Contact?

Reference: Heinemann Physics 12 4th Edition Chapters 1 – 3 Pages 1 – 106

Physics with Synno – Move Without Contact – Lesson 9

M.1 Electric Motors

Video: Simple DC Motor Explained
Working Principle of DC Motor (animation of elementary model)

An electric motor is simply a coil inside a magnetic field. When a current flows in the coil it creates a magnetic field of its own. The two magnetic fields interact and cause rotation.

A direct current (D.C.) motor converts electrical energy (using the current through a coil of wire) into mechanical energy (by spinning the coil.)

Current in a wire ⇨ Creates its own magnetic field ⇨ Interacts with another field ⇨ Force on the current carrying wire ⇨ Rotational motion

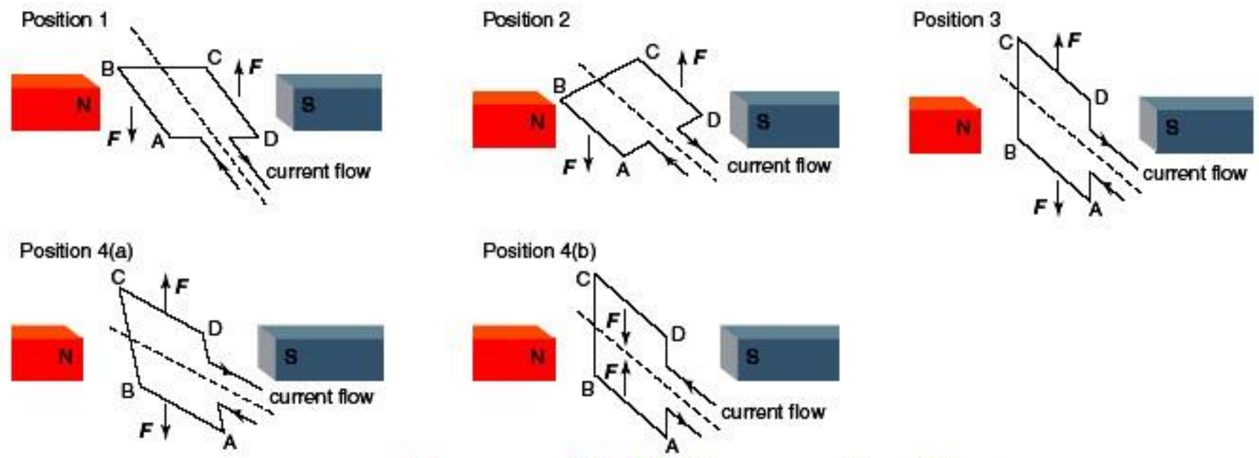


Figure 12.23 Force on a coil in a DC motor

When a coil is in position 1 (current flowing from A to B), the forces will make it rotate (E.2.1). In position 2 the force continues to cause rotation. When the coil is in position 3 the forces act through the axis of rotation, making the torque zero. Momentum will keep the coil moving to position 4(a), but the force acts to return the coil to position 3. Not very useful.

If the motor is to continue rotating the current must be reversed (i.e. flowing from B to A). This is done by the split ring commutator. The forces then act as in position 4(b) and make the coil turn for another 180°. The current is again reversed to complete the rotation. The current needs to be reversed twice in every rotation when the coil is at right angles to the magnetic field. This is done with a commutator.

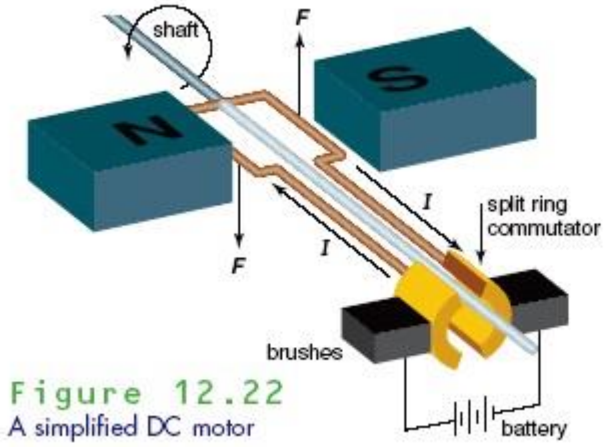
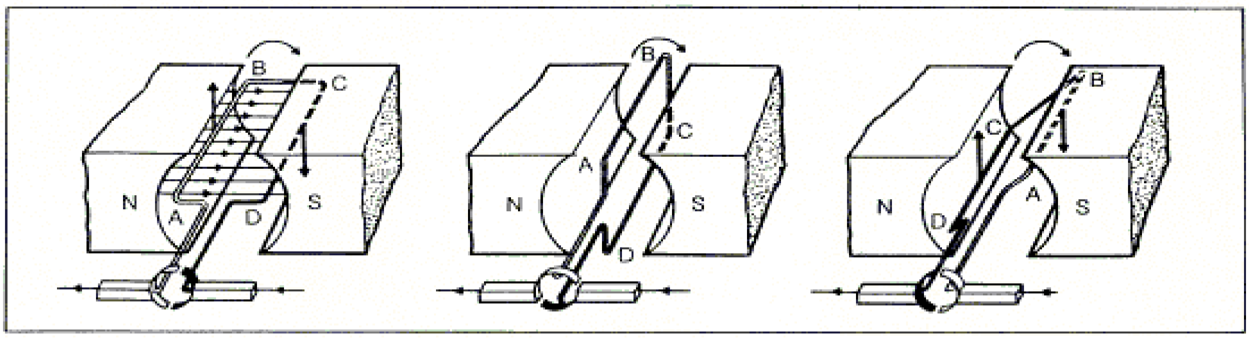


Figure 12.22
A simplified DC motor

Note: A commutator is a device that reverses the direction of the current flowing through an electric circuit.

M.1.1 How the Commutator Works



In the first position, the coil is horizontal.

The D edge of the coil is connected to the right (+) brush at this point, and so current flows from D to A.

This causes the force directions as shown, causing a clockwise rotation.

When the coil becomes vertical as shown in the second position, the split in the commutator is lined up with the brushes, meaning that no current is flowing through the coil.

This means that that there is momentarily no force acting on the coil, and the coil continues to rotate clockwise, due to its momentum.

After passing the vertical position, the D edge of the coil now makes contact with the left (–) brush, so that current now flows from A to D.

This change in current direction means that there is now an upward force on the CD side.

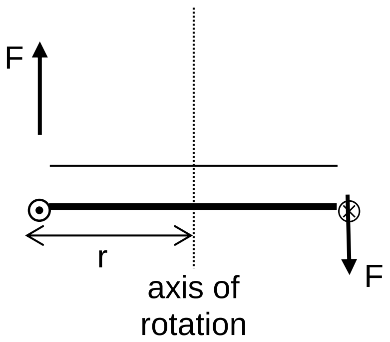
This causes a continued rotation in the clockwise direction.

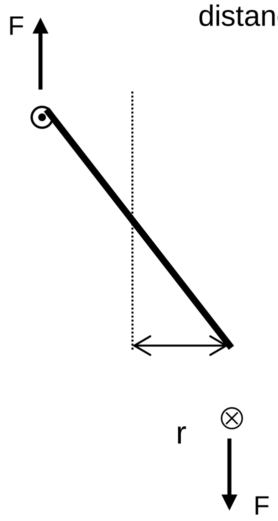
In the middle position above, the current is cut from the circuit. To obtain continuous rotation in a motor, the current in the coil (rotor) is cut just before the plane of the coil is perpendicular to the field, because at this point the forces will act to spread the coil and not to rotate it. The angular momentum of the coil carries it past this position (remember that Newton said that a body will remain in motion unless a force acts on it) and then the current is switched on again but its direction is reversed.

M.1.2 Force and Torque

A coil has a pair of equal and opposite forces acting on its sides. These forces tend to rotate the coil. The turning force F is <u>constant</u> in size (**F** = **ILB**) at all points in the cycle.

We need to distinguish between the force and the spin caused by the force. This is called the torque. The torque depends on the perpendicular distance between the parallel turning forces and the axis of rotation, and so is <u>not constant</u> at all points in the cycle, as shown below.





The turning moment or torque (τ) of a force **F** acting at a perpendicular distance **r** from the axis of rotation of a rigid body is defined as

$$\tau = \mathbf{F} \times r$$

In both positions, the size of the force is equal.

However, as the coil rotates closer to a vertical position, the line of action of the force moves closer to the axis of rotation (reducing r)
Hence, the torque decreases

M.1.3 Torque

The unit for τ is Nm

$\tau = \mathbf{F} \times r$ and $\mathbf{F} = n\,\mathbf{B}IL$

Hence $\tau = n \times B \times I \times L \times r$

Torque is directly proportional to the speed of the motor. Hence, the speed of an electric motor can be increased by:

1. Increasing the length of the conductor in the magnetic field. (**L or n**)
   This is most effectively done by using a large number of turns in the coil. However, this can make the motor heavy.
2. Increasing the size of the current that flows through the coil. (**I**)
   This may cause overheating, and is limited by the resistance of the wire used in the coil.
3. Increasing the magnetic field strength of the permanent magnets. (**B**)
   This is limited by the quality of the materials used in the manufacture of the stator. It is not a very efficient way of increasing the torque.
4. Increasing the lever arm of the torque. (**r**)
   This means making the motor bigger physically. This is often inconvenient.

Example.

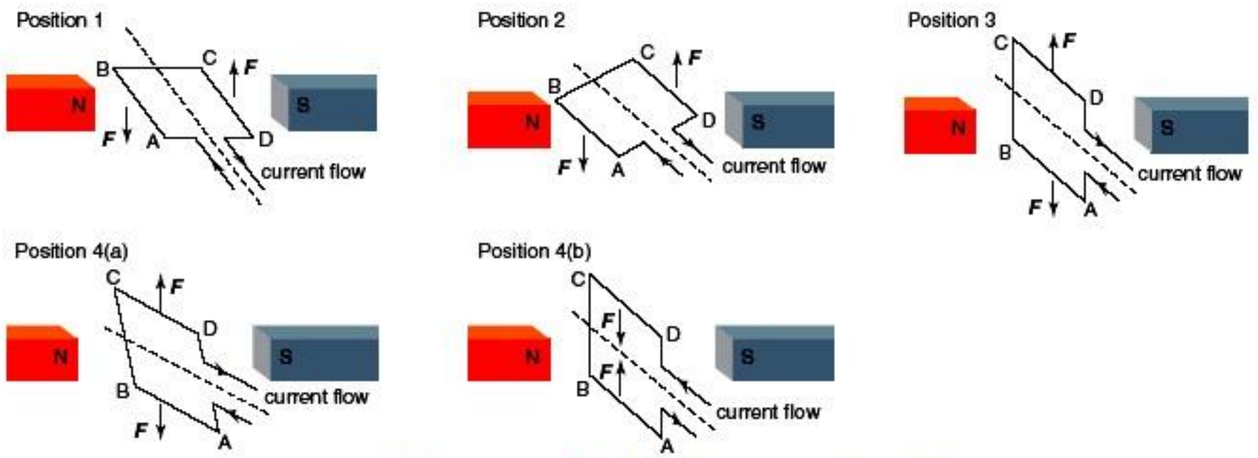


Figure 12.23 Force on a coil in a DC motor

The coil shown in Figure 12.23 is a square of side length 4 cm and consists of 20 turns of wire and carries a current of 5 A in a field of 0.8 T.

a) What are the forces on each side?

b) What is the torque on the coil?

Solution

a) The magnitude of the force on the coil is given by

$F = nIlB$, where n = 20 turns, I = 5 A, L = 0.04 m and B = 0.8 T.

So:

$F = 20 \times 5 \times 0.04 \times 0.8$

$= 3.2$ N

b) The torque on one arm of the coil is given by $\tau = r\,F$, where r is 2 cm (0.02 m) and F is 3.2 N.

The total torque will be twice this as both arms contribute the same torque

So:

$\tau = 2 \times 0.02 \times 3.2$

$= 0.128$ N m

Text Questions: Page 92 All Questions