An electric motor operates by a current from some energy source (supply emf) passing through an external magnetic field. A current in a magnetic field experiences a force. The conductor carrying the current is wound into a coil (armature) so that it will experience a torque to cause the rotation.

However, by Faraday’s law, a coil rotating in the magnetic field produces a continually changing magnetic flux. Hence, an emf is induced in the rotating coil.

By Lenz’s law, this emf must be in the opposite sensitive to the supply emf, otherwise the voltage would continually increase leading to an ever increasing current through the coil.

This induced emf is known as the back emf. It has opposite polarity to the supply emf (figure 1).

Consider an ideal motor with no friction or drag forces acting. The net voltage $V_{coil}$ across the coil of the motor is equal to the supply emf $\varepsilon_{supply}$ minus the back emf $\varepsilon_{back}$.

$$V_{coil} = \varepsilon_{supply} - \varepsilon_{back}$$

If there is no load attached to the motor, the coil (armature) will spin faster and faster until the supply emf is equal to back emf. Then, the net voltage across the coil is zero, resulting in the coil current and hence torque acting on the coil to be both zero and so the coil will rotate at a constant angular speed.

$$\varepsilon_{supply} = \varepsilon_{back} \Rightarrow V_{coil} = 0 \Rightarrow I_{coil} = 0 \Rightarrow \tau_{coil} = 0 \Rightarrow \text{armature spins at a constant rate}$$

When the load on the motor increases:
- the armature spins more slowly
- the rate of change of the magnetic flux decreases
- induced emf decreases (back emf decreases)
- coil voltage increases
- coil current increases
If the load becomes too large causing the armature to rotate slowly or stop, then large currents through the coil will cause unwanted heating effects and damage the motor. When motors are turned on, there will be large coil currents unless there is some protection mechanism.

Example
The armature windings of a DC motor has a resistance of 5.0 Ω. The motor is connected to a 240 V power supply. When the motor reaches its full rotation speed the back emf is 188 V. (a) When the motor is just starting, what the motor current? (b) What is the current when the motor is operating at its maximum rotation speed?

Solution

\[ R = 5.0 \, \Omega \quad \varepsilon = 240 \, V \quad \varepsilon_{\text{back}} = 188 \, V \]

Motor starting

\[ \varepsilon_{\text{back}} = 0 \, V \quad I = ? \, A \quad I = \varepsilon / R = (240 / 5) \quad A = 48 \, A \]

Motor max speed

\[ \varepsilon_{\text{back}} = 188 \, V \quad I = ? \, A \]

\[ I = (\varepsilon - \varepsilon_{\text{back}}) / R = (240 - 188) / 5 \quad A = 10 \, A \]

Faster the rotation speed the greater the induced back emf. Currents can be very high on starting. When a motor is jammed \( \rightarrow \) rotation speed much reduced \( \rightarrow \) reduced emf \( \rightarrow \) increased current \( \rightarrow \) motor heats up \( \rightarrow \) motor maybe damaged.
Questions and problems  [p6/p6_problems.pdf]

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