DC Motors

IDIS - 300
Energy Transformation

Magnetic Field

Mechanical Force (Rotation)  Current
Single-phase appliance motors (Courtesy of General Electric Company).

High-efficiency machine tool motor (Courtesy of Magnetek Motors & Generators).

Drip-drip proof machine with pressed laminated iron frame construction (Courtesy of Reliance Electric Company).
Interaction of Fields

A Strong Magnetic Field Is Produced Here

DIRECTION OF CURRENT

A Weak Magnetic Field Is Produced Here

DIRECTION OF MOTION
Right Hand Rule

- Magnetic Field (left or right)
- Current Flow (in or out)
- Motion of Conductor (up or down)
Value of Mechanical Force

Assuming that the conductor is located at right angles to the magnetic field, the force developed can be expressed as follows:

\[ F = B I L \]

- \( F \) = Force (Newtons)
- \( B \) = Magnetic Flux Density (Tesla)
- \( I \) = Current (Amps)
- \( L \) = Length in meters
Force Generated by Fields
Motor Operation

(A) Current through the loop creates a torque

(B) At this neutral position, there is no torque created, but inertia carries the loop toward (C), shown on the next page
Motor Operation

As the loop continues around, the commutator reverses the current direction so that the magnetic field interacts with the loop to produce a torque that keeps the loop turning in the same direction.

At this neutral position, inertia carries the loop toward position (A), and the cycle is repeated.
Basic Construction
Types of DC Motors

[Diagram showing the components of a DC motor: Electromagnet, Armature, Brush, Field Winding]
Types of DC Motors

- Depending upon the connection of \textit{armature} winding and \textit{field} windings, DC Motors are classified as:
  
  - Series DC Motor
  - Shunt DC Motor
  - Compound DC Motor
Series DC Motor

High Torque – Series Motor

Series motor can handle smooth starting under load conditions. These motors can be used to operate small electric appliances, portable electric tools, cranes, winches, hoists, etc.
Series Motor Limitations

No Load = Infinite Speed!

Limitations:
Some load must ALWAYS be connected to a series motor before you turn it on. The speed of a series motor with no load connected to it increases to the point where the motor speeds may damage its bearings or windings may fly out.

Small motors, such as those used in electric hand drills, have enough internal friction to load themselves.
Shunt DC Motor

**Constant Speed – Shunt Motor**

Shunt motor provides constant speed, even if the load (torque) requirements change during operation.
Counter EMF

CEMF proportional to rpm ???

\[ I_a = \frac{V_{source} - cemf}{R_a} \]
Calculate CEMF

A motor when supplied by a 240 Volts DC electric supply is measured to be using 50 A current. The armature winding (loop) resistance is 0.08Ω. The field current is negligible. How much cemf is being generated?

\[
I_a = \frac{V_{source} - cemf}{R_a}
\]

\[
50 = \frac{240 - cemf}{0.08}
\]

\[
cemf = 236 \text{ volts}
\]
In 18th century England, coal was feeding the industrial revolution and Thomas Newcomen invented a steam driven engine that was used to pump water from coal mines. It was a Scott however, by the name of James Watt, who in 1769 improved the steam engine making it truly workable and practical. In his attempt to sell his new steam engines, the first question coal mine owners asked was "can your engine out work one of my horses?" Watt didn't know since he didn't know how much work a horse could do. To find out, Watt and his partner bought a few average size horses and measured their work. They found that the average horse worked at the rate of 22,000 foot pounds per minute. Watt decided, for some unknown reason, to add 50% to this figure and rate the average horse at 33,000 foot pounds per minute.

What's important is that there is now a system in place for measuring the rate of doing work. And there is a unit of power, horsepower.
Horsepower and Torque

When a source of torque $T$, produces $N$ rotations about an axis, horsepower output can be expressed as:

$$HP = \frac{T \times N}{5250}$$

where:
- $T = \text{output torque in ft-lb}$
- $N = \text{speed in rpm}$

Example:
A 5 hp motor can deliver different amount of torque depending on its speed. How much torque can it deliver at 100 rpm?

$$5 = \frac{T \times 100}{5250}$$
$$T = 262 \text{ ft-lb}$$
Horsepower delivered by Motor

For the motor mentioned earlier, how much horsepower can the motor deliver?

Power developed = \((cemf) \cdot (I_a)\)

= \((236) \cdot (50)\) = 11 800 W

Horsepower = \frac{\text{Power developed}}{746}

= \frac{11 800}{746} = 15.8 \text{ hp}
Torque generated by Motor

\[ T = k_t \phi I_a = K_T I_a \]

Where;

\[ T = \text{torque, ft-lb} \]
\[ k_t = \text{constant depending on physical dimensions of motor} \]
\[ \phi = \text{magnetic flux, Wb} \]
\[ I_a = \text{armature current} \]
Exercise:

What is the immediate effect on torque developed by a motor if magnetic field is reduced by 2%. The motor is connected to 220 volt supply, has an armature with 0.2Ω resistance. The motor currently has armature current of 25A. Under this condition torque developed by motor is;

\[ T_1 = k_t \phi I_{a1} = 25 K_T \]

and cemf is:

\[ I_{a1} = \frac{V_{source} - cemf_1}{R_a} \]

\[ 25 = \frac{220 - cemf_1}{0.2} \]

\[ cemf_1 = 215 \text{ volts} \]

If flux is reduced by 2%, so will cemf, thus \( cemf_2 = (0.98)(215) = 210.7 \) volts, and

\[ I_{a2} = \frac{V_{source} - cemf_2}{R_a} = \frac{220 - 210.7}{0.2} = 46.5 \ A, \text{ and thus new torque developed will be} \]

\[ T_2 = k_t \phi I_a = k_t (0.98)\phi(46.5) = 45.6k_t\phi = 45.6K_T \]

The torque increase is \( T_2 / T_1 = 1.82 \text{ times} \)
Speed of DC Motor

\[ I_a = \frac{V - cemf}{R_a} \quad \rightarrow \quad I_a R_a = V - cemf \quad \rightarrow \quad I_a R_a = V - K_T \omega \quad \rightarrow \quad V = I_a R_a + K_T \omega \]

Where;

- \( \omega \) is speed of motor in radians/sec *
- \( K_T \) is constant
- \( V \) is voltage of electric supply
- \( I_a \) is armature current drawn by motor
- \( R_a \) is armature resistance

* 1 rad/sec = 9.602 rpm
Calculating the speed of CD-ROM

Connect the CD-ROM to a 3 Volt supply. The motor spins up, drawing just enough current to prove sufficient torque. Using ammeter current is measured to be 0.022 Amps.

\[ V = I_a R_a + K_T \omega \]
\[ 3 = 0.022 \times R_a + K_T \times \omega \] \hspace{1cm} \ldots (1)

**Finding \( K_T \):** From the motor specifications: Under test conditions at rated voltage of 3V motor delivers torque of 0.0024 N-m while drawing armature current of 0.265 Amps. Thus the value of \( K_T \) is \( 0.0024/0.265 = 0.0091 \) Nm/Amp. (Using \( T = k_i \phi I_a = K_T I_a \) )

**Finding \( R_a \):** The motor resistance is \( R_a = V/I_a = 3/0.265 = 11.3 \) Ohms.

Thus from \((1)\)

\[ \omega = (3-(0.022 \times 11.3))/0.0091 \]
\[ = 302 \text{ rad/sec.} \]
\[ = 2900 \text{ RPM} \]

\[ *1 \text{ rad/sec} = 9.602 \text{ rpm} \]
Counter EMF and Speed

- Speed of motor depends on current flowing in the loop.
  \[ \uparrow \text{Current} \text{ means } \uparrow \text{Speed} \]

- Current in the loop depends on emf (total).
  \[ \uparrow \text{Emf (total)} \text{ means } \uparrow \text{Current} \]

- Amount of cemf depends on speed of loop.
  \[ \uparrow \text{Speed} \text{ means } \uparrow \text{Cemf} \]

**Speed Regulation:**

Mechanical Load \( \uparrow \), speed \( \downarrow \), cemf \( \downarrow \), emf (total)* \( \uparrow \), loop current \( \uparrow \) speed \( \uparrow \)

* \[ \text{emf}_{\text{total}} = \text{emf}_{\text{source}} - \text{cemf} \]