DC Motor (1)

CEG3H3

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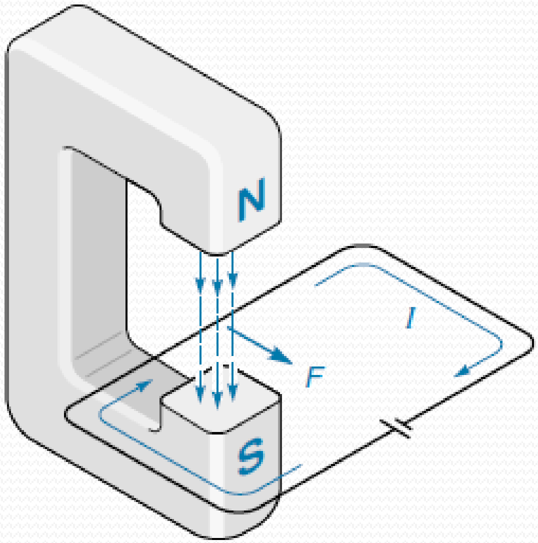
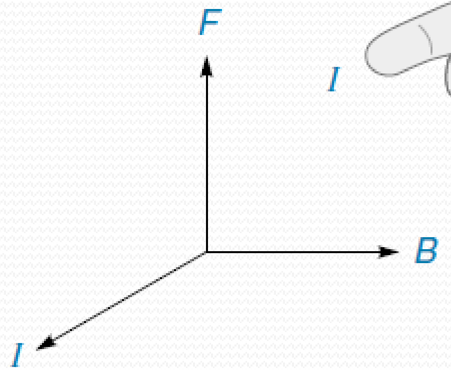
Objectives

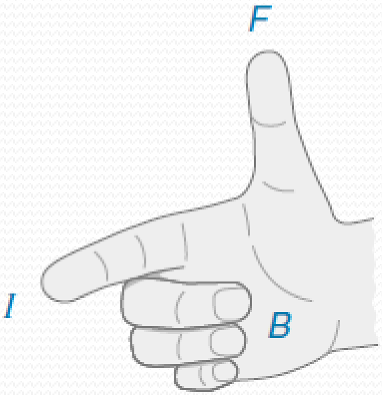
- Explain the theory of operation of electric motors in general and DC motors in particular
- Explain the characteristics of permanent-magnet motors and use the torque-speed curve of a motor to predict its performance

Basic Theory

- A current carrying conductor will experience a force when placed in a magnetic field
- The direction of the force is perpendicular to both the magnetic field and the current







Basic Theory

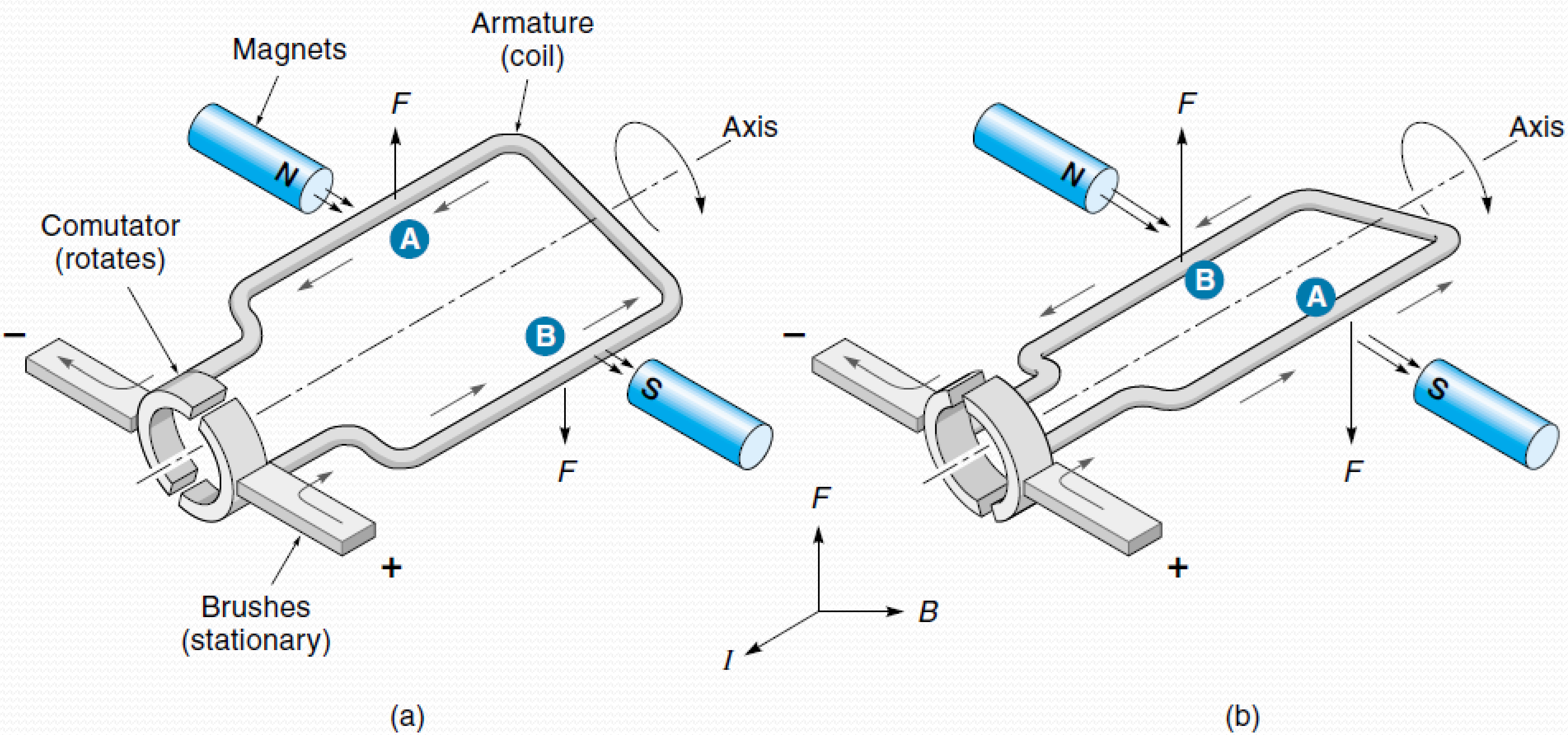
- Force magnitude on the wire can be calculated:

$$F = IBL\sin\theta$$

where
F = force on the conductor (in Newtons)
I = current through the conductor (in amperes)
B = magnetic flux density (in gauss)
L = length of the wire (in meters)
θ = angle between magnetic field (B) and current (I)

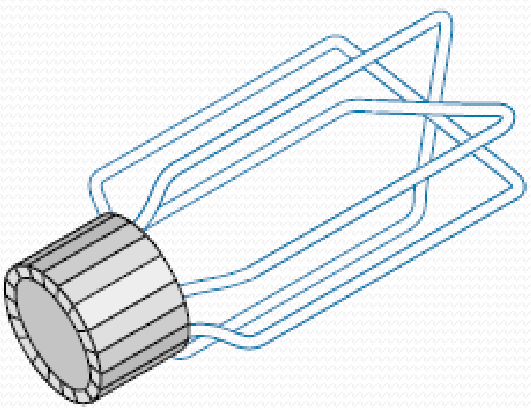
Basic Theory

- Max torque when horizontal, minimum when vertical

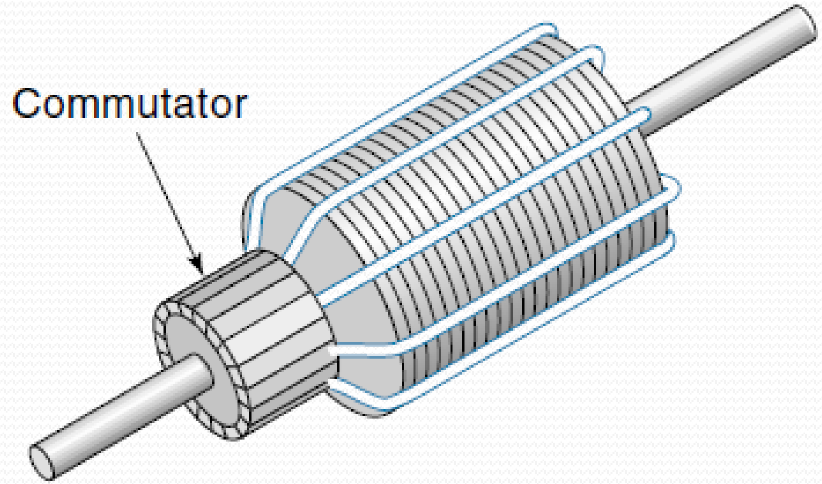


Basic Theory

- Multiple loops in armature analogue with multipiston engine



(a) Simplified armature showing multiple loops



(b) An actual armature (many loops)

Motor Torque

- The motor torque can be expressed:

$$T = K_T I_A \phi$$

where

T = motor torque

K_T = a constant based on the motor construction

I_A = armature current

ϕ = magnetic flux

Electromotive Force (EMF)

- Motor is also capable of converting mechanical energy to electrical energy
- If armature coil were rotated in the magnetic field by some external force, a voltage (called EMF) would appear:

$$\text{EMF} = K_E \phi S$$

where

EMF = voltage generated by the turning motor

K_E = a constant based on the motor construction

ϕ = magnetic flux

S = speed of motor (rpm)

Electromotive Force (EMF)

- EMF voltage is being generated even when the motor is running on its own power, but it has the opposite polarity of the line voltage, called counter-EMF (CEMF)
- Its effect is to cancel out some of the line voltage, so:

$$V_A = V_{In} - \mathrm{CEMF}$$

where

V_A = actual voltage available to the armature

V_{In} = line voltage supplied to the motor

CEMF = voltage generated within the motor

Electromotive Force (EMF)

- You cannot directly measure V_A with a voltmeter because it is an effective voltage inside the armature
- There is evidence that the CEMF exists because the armature current is also reduced:

$$I_A = \frac{V_{In} - \text{CEMF}}{R_A}$$

where

I_A = armature current

V_{In} = line voltage to the motor

R_A = armature resistance

CEMF = voltage generated within the motor

Electromotive Force (EMF)

- Because CEMF increases with motor speed, the faster the motor runs, the less current the motor will draw, and its torque will diminish
- This explains why most DC motors have a finite maximum speed

Electromotive Force (EMF)

- The actual relationship between motor speed and CEMF is derived from previous equation:

$$S = \frac{\text{CEMF}}{K_E \phi}$$

where

S = speed of motor (rpm)

CEMF = voltage generated within the motor

K_E = a motor constant

ϕ = magnetic flux

Example

- A 12 Vdc motor has an armature resistance of 10 Ω and according to its spec sheet generates a CEMF at the rate of 0,3 V/100 rpm. Find the actual armature current at 0 rpm and at 1000 rpm.

Solution

For the first case, when the motor isn't turning (0 rpm), the CEMF will be 0 V:

$$I_A = \frac{V_{In} - \text{CEMF}}{R_A} = \frac{12\text{ V} - 0\text{ V}}{10} = 1{,}2\text{ A}$$

Example

For the second case (1000 rpm), determine the CEMF with given rate of 0,3 V/100 rpm:

$$\text{CEMF} = \frac{0{,}3\ \text{V}}{100\ \text{rpm}} \times 1000\ \text{rpm} = 3\ \text{V}$$

Then:

$$I_A = \frac{V_{In} - \text{CEMF}}{R_A} = \frac{12\ \text{V} - 3\ \text{V}}{10} = 0{,}9\ \text{A}$$

Thus, we see that the armature current is reduced in the running motor

Speed Regulation

- Speed regulation is the ability of a DC motor to maintain its speed when the load is applied
- When motor's load is increased

$\rightarrow$ speed tends to decrease

$\rightarrow$ lower speed reduces the CEMF

$\rightarrow$ allows more current into the armature

$\rightarrow$ increased current results in increased torque

$\rightarrow$ prevents motor from slowing further

Speed Regulation

- Speed regulation is usually expressed as a percentage:

$$\% \text{ speed regulation} = \frac{S_{NL} - S_{FL}}{S_{FL}} \times 100$$

where

S_{NL} = no-load speed

S_{FL} = full-load speed

Example

- A motor has a no-load speed of 1150 rpm. When the maximum load for a certain application is applied to the motor, the speed drops to 1000 rpm. Find the speed regulation for this application.

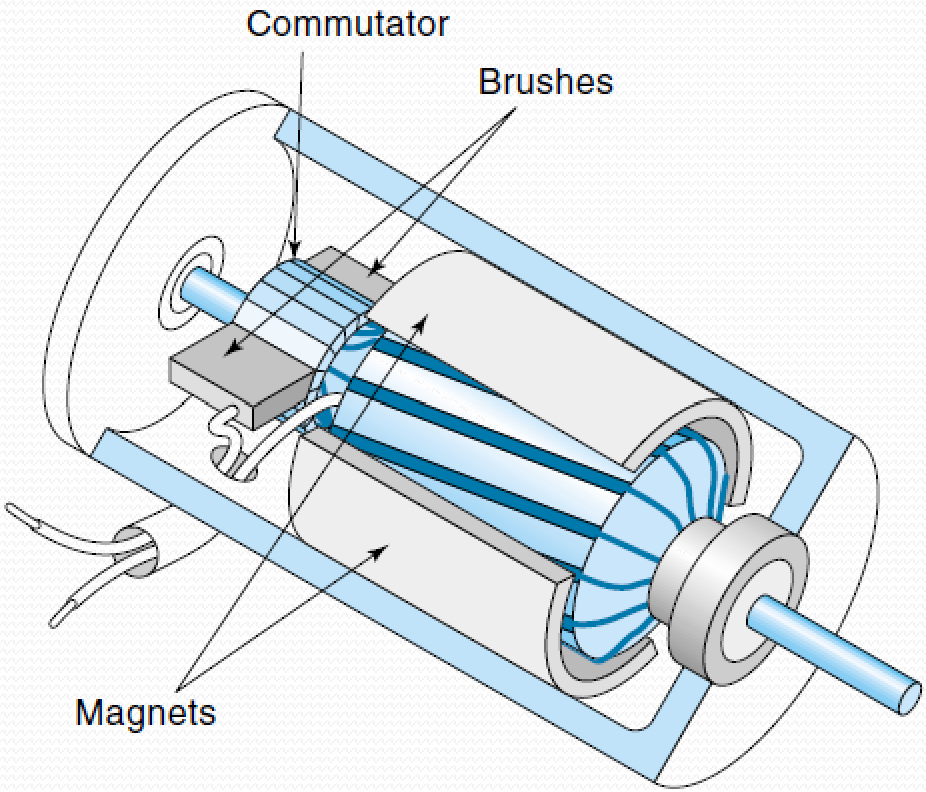
Solution

Applying the speed regulation equation, we get:

$$\frac{S_{\mathrm{NL}} - S_{\mathrm{FL}}}{S_{\mathrm{FL}}} \times 100 = \frac{1150\ \mathrm{rpm} - 1000\ \mathrm{rpm}}{1000\ \mathrm{rpm}} \times 100 = 15\%$$

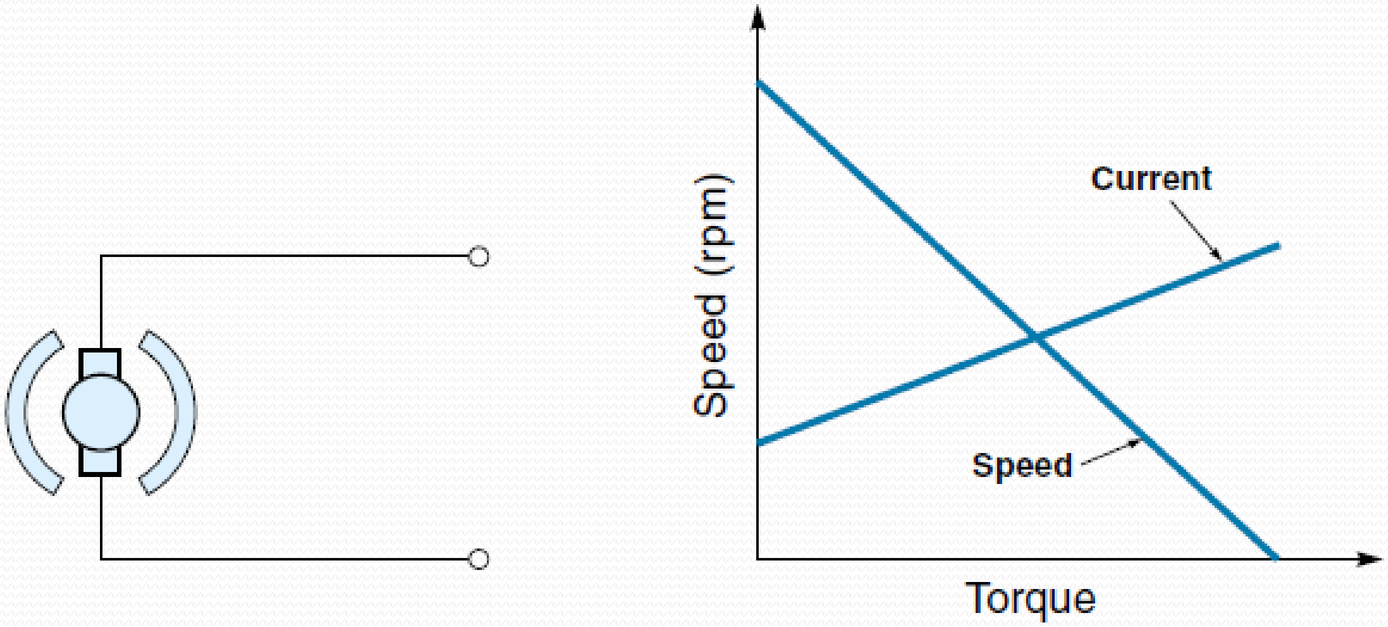
Permanent Magnet DC Motor

- Permanent-magnet (PM) motors use permanent magnets to provide the magnetic flux for the field



Torque and Speed Relationship

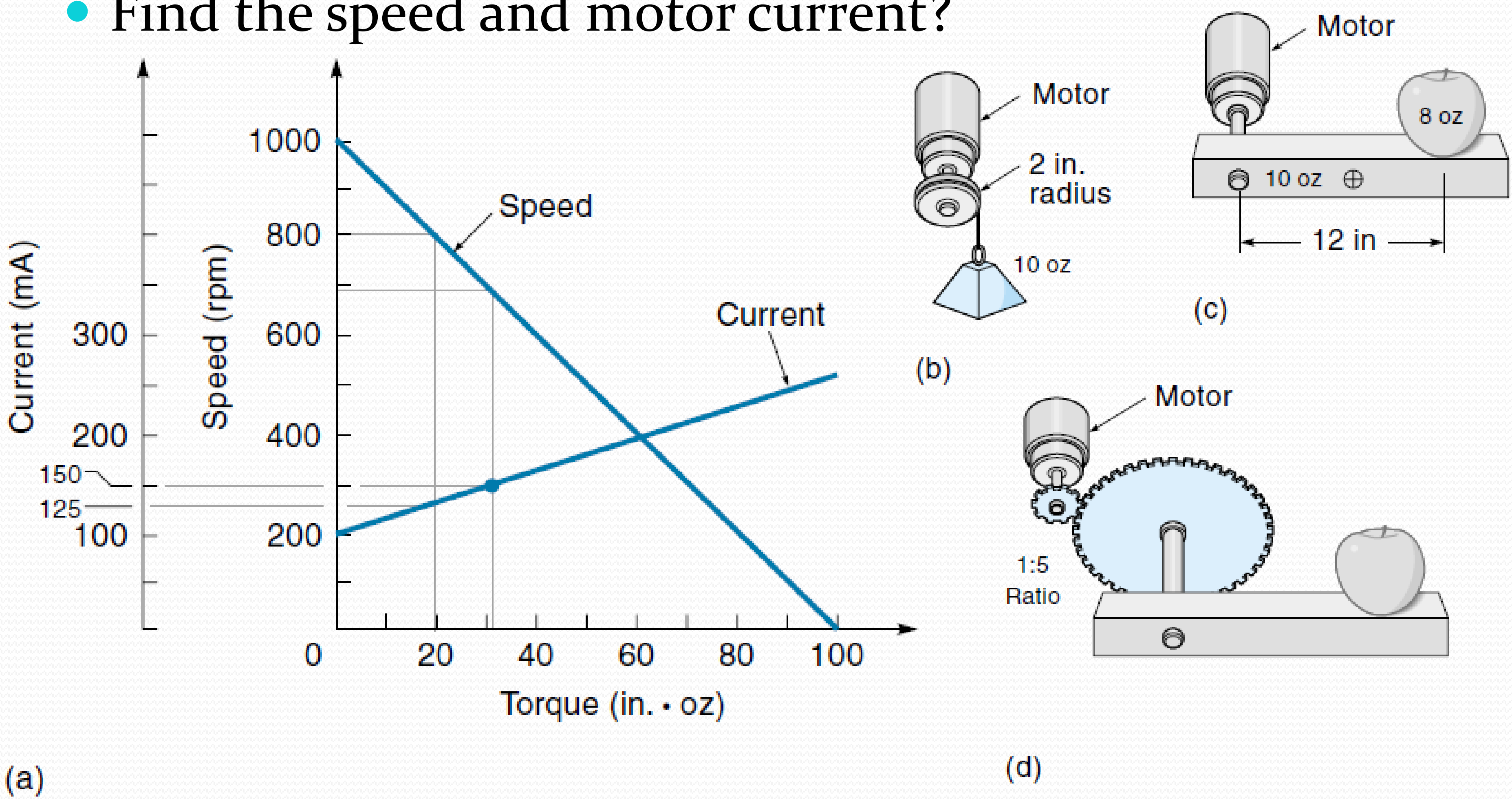
- Its linear torque-speed curve makes PM-DC motor is very desirable for control applications because it simplifies the control equations



(a) PM motor symbol (b) PM motor torque-speed curve

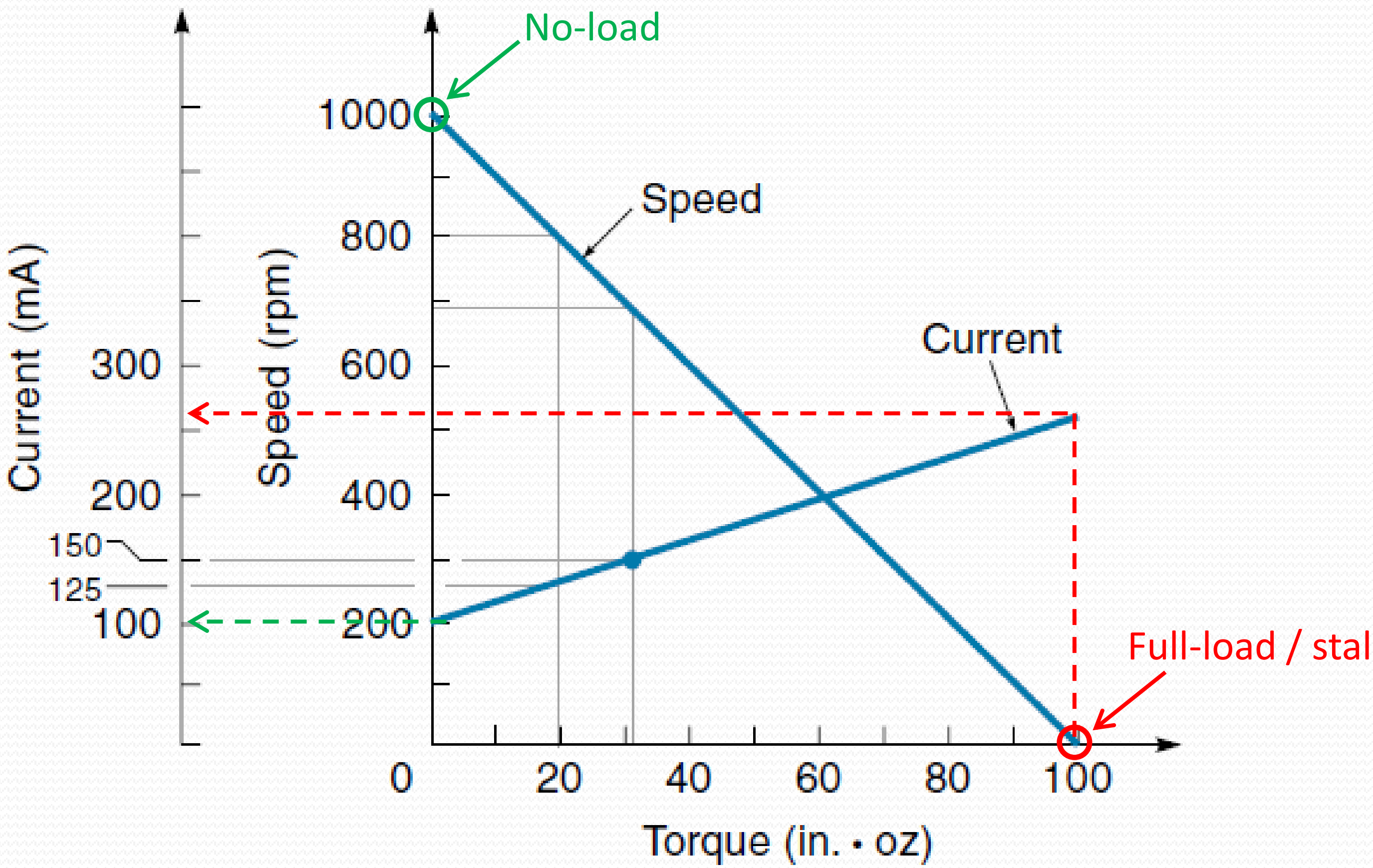
Example

- Find the speed and motor current?



Example

Solution



(a)

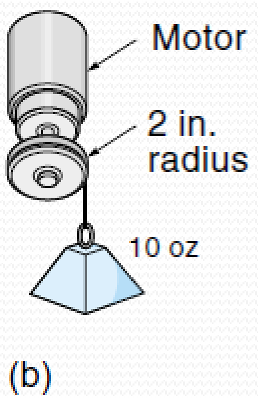
Example

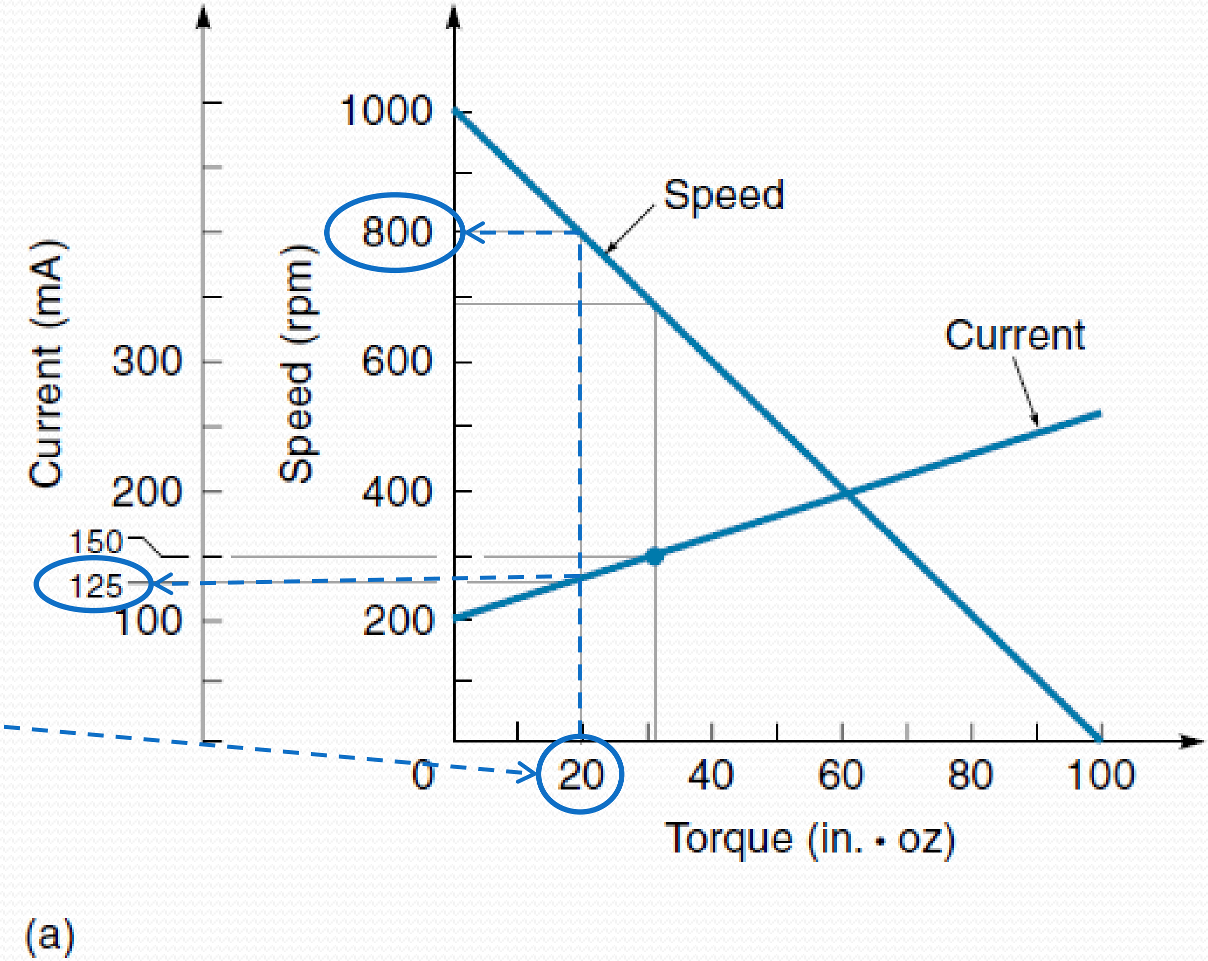
Solution

(a) If voltage is applied to the motor with no load attached to the shaft, the motor would turn at its no-load speed of 1000 rpm and draw 100 mA of current. Then, if the shaft was clamped so it could not turn, the motor would exert the stall torque of 100 inch · oz and draw 260 mA of current.

Example

Solution





Torque $= F \times d$

$= 10 \text{ oz} \times 2 \text{ inch}$

$= 20 \text{ inch} \cdot \text{oz}$

Example

Solution

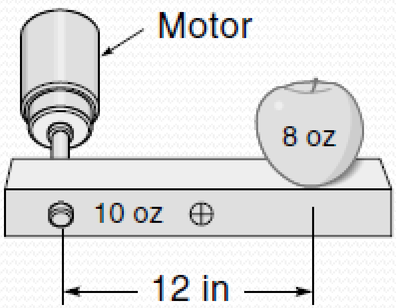
(b) A 10 oz weight is hung from a 2 inch radius pulley. The pulley is on the motor shaft. Torque equals force times distance, so the motor torque required to lift the weight is:

$$2 \text{ inch} \times 10 \text{ oz} = 20 \text{ inch} \cdot \text{oz}$$

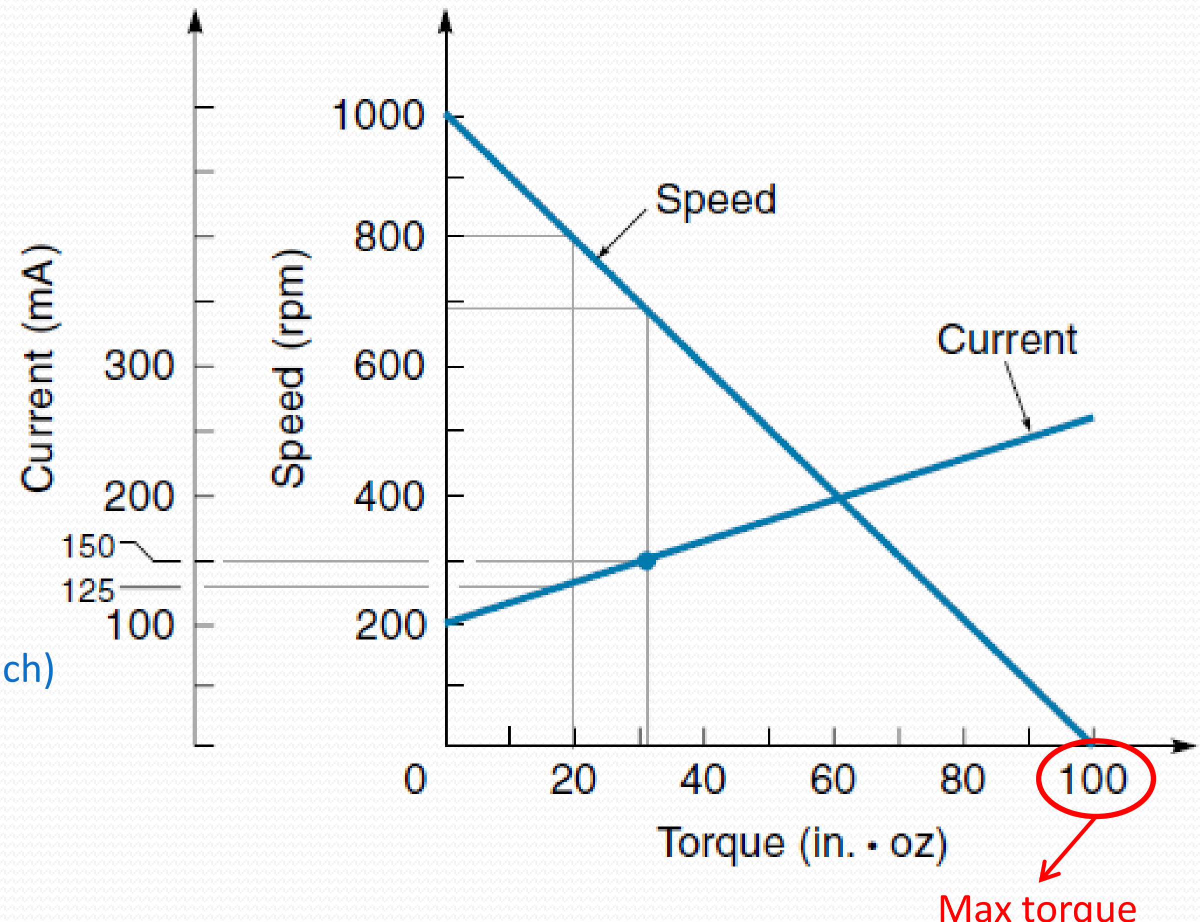
From the graph, we can see that, at a torque of 20 inch · oz, the speed has declined to 800 rpm, and the current is up to 125 mA.

Example

Solution



(c)



(a)

Torque $= F \times d$

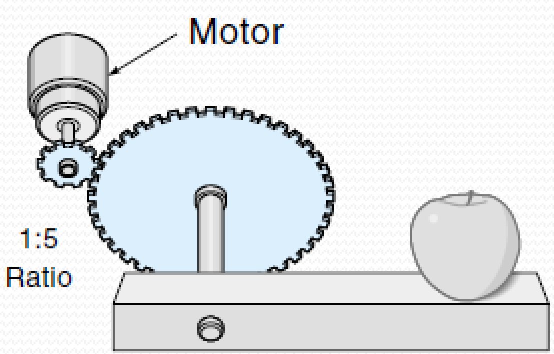
$= (10\text{ oz} \times 6\text{ inch}) + (8\text{ oz} \times 12\text{ inch})$

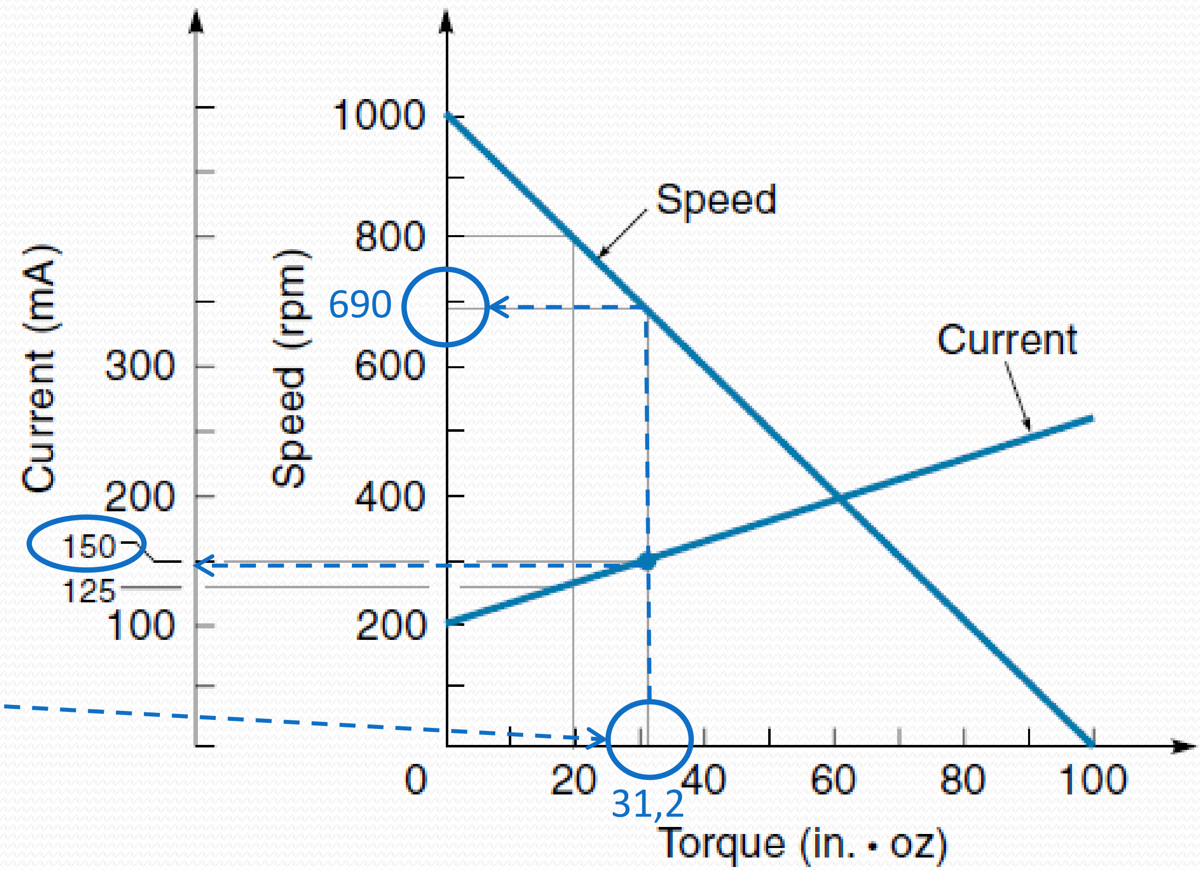
$= 60\text{ inch} \cdot \text{oz} + 96\text{ inch} \cdot \text{oz}$

$= 156\text{ inch} \cdot \text{oz}$

Example

Solution





(d) Torque $= \dfrac{156 \text{ inch} \cdot \text{oz}}{5}$

$= 31{,}2 \text{ inch} \cdot \text{oz}$

(a)

Example

Solution

(c) The motor is attached to a 12 inch arm (weighing 10 oz). On the end of the arm rests an 8 oz apple. Note the arm is considered to be a point mass of 10 oz at its center of gravity, which is 6 inch from the motor shaft. The total load on the motor is calculated:

$$(6 \text{ inch} \times 10 \text{ oz}) + (12 \text{ inch} \times 8 \text{ oz}) = 156 \text{ inch} \cdot \text{oz}$$

From the graph, we see that 156 inch · oz exceeds the stall torque of 100 inch · oz, so the motor will not be able to lift this load at all.

Example

Solution

(d) One solution to the problem would be to insert a gear train, say, 5 : 1 between the motor and load. Now the torque required of the motor is only one fifth:

$$\frac{156\,\text{inch}\cdot\text{oz}}{5} = 31{,}2\,\text{inch}\cdot\text{oz}$$

which is within the torque range of the motor, so we see from the graph it will rotate at 690 rpm and require a current of 150 mA.

Objectives Completed

- ✓ Explain the theory of operation of electric motors in general and DC motors in particular
- ✓ Explain the characteristics of permanent-magnet motors and use the torque-speed curve of a motor to predict its performance