1. Introduction to Machinery Principles

1.1 Electrical Machines, Transformers, and Daily Life

- An electrical machine is a device that can converter either mechanical energy to electrical energy or electrical energy to mechanical energy
- Generator: Converting mechanical energy to electrical energy
- Motor: Converting electrical energy to mechanical energy
- The transformer converts AC electrical energy from one voltage level to another voltage level
- Why are electric motors and generators so common? The answer is very simple: Electric power is a clean and efficient energy source that is easy to transmit over long distances, and easy to control

1.2 A Note on Units and Notation

- English system of units (inches, feet, pounds, etc.)
- SI: Systeme International (m, kg, etc.)
- IEEE: Institute of Electrical and Electronics Engineers
- Volts, Amperes, Ohms, Watts
- Notation: In this book, vectors, electrical phasors, and other complex values are shown in bold face (e.g., F), while scalars are shown in italic face (e.g., *R*), In addition, a special font is used to represent magnetic quantities such as magnetomotive force (e.g., $\mathscr{F}$).

1.3 Rotational Motion, Newton's Law, and Power Relationships

Angular Position θ/ Angular Velocity ω / Angular Acceleration α/ Torque τ/ Newton's Law of Rotation / Work W Power P

- Almost all electric machines rotate about an axis, call the shaft of the machine
- CW: clockwise ; CCW: counterclockwise

$$v = \frac{dr}{dt} \quad (1-1) \quad ; \quad \omega = \frac{d\theta}{dt} \quad (1-2)$$

ω_m : angular velocity expressed in radians per second

f_m : angular velocity expressed in revolutions per second

n_m : angular velocity expressed in revolutions per minute

$$n_m = 60 f_m \quad (1-3a) \quad ; \quad f_m = \frac{\omega_m}{2\pi} \quad (1-3b)$$

$$a = \frac{dv}{dt} \quad (1-4) \quad ; \quad \alpha = \frac{d\omega}{dt} \quad (1-5)$$

$$\vec{\tau} = \vec{r} \times \vec{F} = rF \sin\theta \quad (1-6)$$

Newton's Law (Newton: 1642-1727)

- 第一運動定律：靜者恆靜、動者恆動
- 第二運動定律：外力等於質量乘以加速度
- 第三運動定律：作用力等於反作用力，方向相反，作用點不同

$$\vec{F} = m\vec{a} \qquad (1-7)$$

$$\vec{F}_x = m\vec{a}_x$$

$$\vec{F}_y = m\vec{a}_y$$

$$\vec{F}_z = m\vec{a}_z$$

$$\vec{\tau} = J\vec{\alpha} \qquad (1-8)$$

$$\vec{\tau}_x = J\vec{\alpha}_x$$

$$\vec{\tau}_y = J\vec{\alpha}_y$$

$$\vec{\tau}_z = J\vec{\alpha}_z$$

Work W (功) , Power P (功率)

$$W = \int \vec{F} \cdot d\vec{r} \qquad (1-9) \Rightarrow W = Fr \qquad same\ direction (1-10)$$

$$W = \int \vec{\tau} \cdot d\vec{\theta} \qquad (1-11) \Rightarrow W = \tau\theta \qquad same\ direction (1-12)$$

$$P = \frac{dW}{dt} \qquad (1-13)$$

$$P = \frac{dW}{dt} = \frac{d}{dt}(Fr) = F\frac{dr}{dt} = Fv \qquad (1-14)$$

$$P = \frac{dW}{dt} = \frac{d}{dt}(\tau\theta) = \tau\frac{d\theta}{dt} = \tau\omega \qquad (1-15)$$

$$P(watts) = 7.04 \times \tau(lb \times ft) n(r/\min)$$

$$= 7.04 \times \tau(0.454kg \times 9.81\frac{m}{\sec^2} \times 0.3048m) n(\frac{2\pi \cdot rad}{60\sec})$$

$$= (7.04 \times 0.142) \times \tau(N \times m) n(\frac{rad}{\sec}) = 1 \times \tau(N \times m) n(\frac{rad}{\sec}) \quad (1-16)$$

單位 馬力 瓦

記: $P(horsepower) = 746 P(watts) = 5252 \times \tau(lb \times ft) n(r/\min) \quad (1-17)$

沒有虛功(only實功)	實功+虛功
$P = IV$	$P(t) = V(t)\cdot i(t)$
$= \frac{V^2}{R}$	實功: R
$= I^2\cdot R$	虛功: L·C. $\begin{cases} V = L\frac{di}{dt} \\ i = C\frac{dV}{dt}. \end{cases}$
$V = IR$	

電機機械 利用磁場有4大公本:

(創造磁場) 1、安培定律: $\oint H\, dl = N\, i$

磁場強度　導体長度　導体圈數　电流

2、法拉第: $e_{ind} = N\cdot\frac{d\phi}{dt} = L\frac{di}{dt}.$ (磁通)

(變压器)　圈数

↳ 時變的磁場感應电压

3、馬達: $\vec{F} = (i\vec{l} \times \vec{B})$

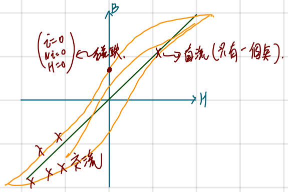
機械　电流　導体　磁通密度

4、發电机: $V = (\vec{v} \times \vec{B})\cdot\vec{l}$

电压　運動速度.

$B = \mu \cdot H$

不是常数(会变化)



面積 → $\oint H\, dB = \int \frac{Ni}{l}\cdot\frac{d\phi}{dA} = \frac{1}{lA}\oint i\cdot e\, dt = \frac{功}{体積}$

1.4 The Magnetic Field

Production of a Magnetic Field / Magnetic Circuits / Magnetic Behavior of Ferromagnetic Materials / Energy Losses in a Ferromagnetic Core

- A current-carrying wire produces a magnetic field in the area around it.
- A time-changing magnetic field induces a voltage in a coil of wire if it passes through that coil. (This is the basis of transformer action.)
- A current-carrying wire in the presence of a magnetic field has a force induced on it. (This is the basis of motor action.)
- A moving wire in the presence of a magnetic field has a voltage induced on it. (This is the basis of generator action.)

Production of a Magnetic Field

Ampere's Law:

$$\oint H \cdot dl = I_{net} \qquad (1-18)$$

$$Hl_c = Ni \qquad (1-19)$$

$$H = \frac{Ni}{l_c} \qquad (1-20)$$

$$B = \mu H \qquad (1-21)$$

$H =$ *magnetic field intensity*

$\mu =$ *magnetic permeability of material*

$B =$ *resulting magnetic flux density produced*

$$\mu_0 = 4\pi \times 10^{-7}\ H/m \qquad (1-22)$$

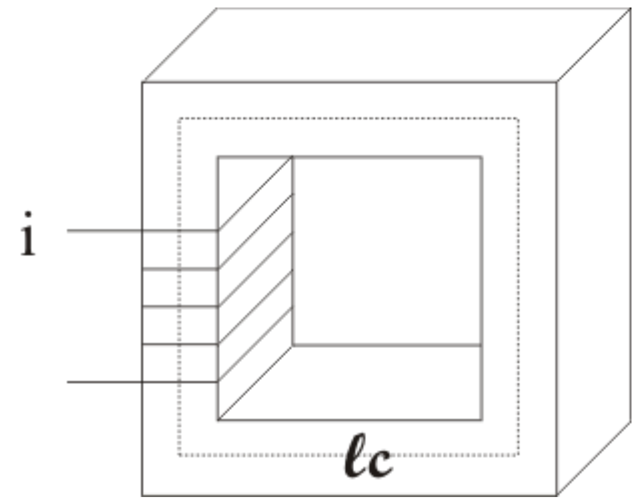
$$\mu = \mu_r \cdot \mu_0 \Rightarrow \mu_r = \frac{\mu}{\mu_0} \qquad (1-23)$$

$$B = \mu H = \frac{\mu N i}{l_c} \qquad (1-24)$$

$$\phi = \int_A B \cdot dA \qquad (1-25a)$$

$$\phi = BA \qquad (1-25b)$$

$$\phi = BA = \frac{\mu N i A}{l_c} \qquad (1-26)$$



Magnetic Circuits

$Ohm's\ Law: V = IR$

$magnetomotive\ \ force\,(mmf)$

$\mathcal{F} = Ni \qquad (1-27)$

$\mathcal{F} = \phi\,\mathcal{R} \qquad (1-28)$

$\rho = 1/\mathcal{R} \qquad (1-29)$

$\phi = \mathcal{F}\rho \qquad (1-30)$

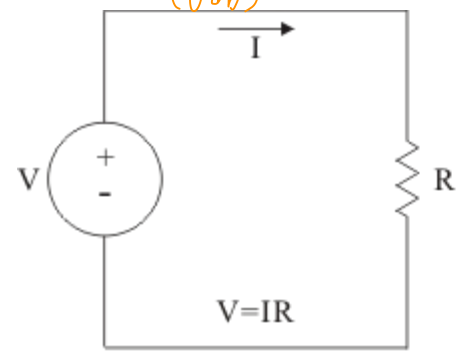
$$\phi = BA = \frac{\mu NiA}{l_c} = Ni(\frac{\mu A}{l_c}) = \mathcal{F}(\frac{\mu A}{l_c}) \qquad (1-31)$$

$$\mathcal{R} = \frac{l_c}{\mu A} \qquad (1-32)$$

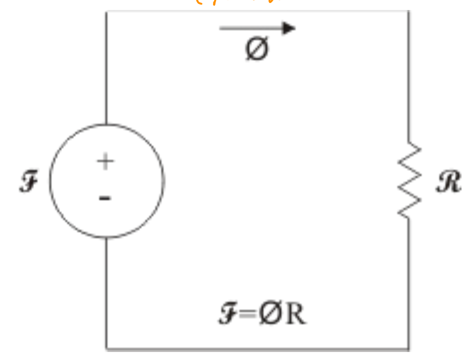
$series: R_{eq} = R_1 + R_2 + R_3 + \cdots \qquad (1-33)$

$$parallel: \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \qquad (1-34)$$

(电路)



(磁路)



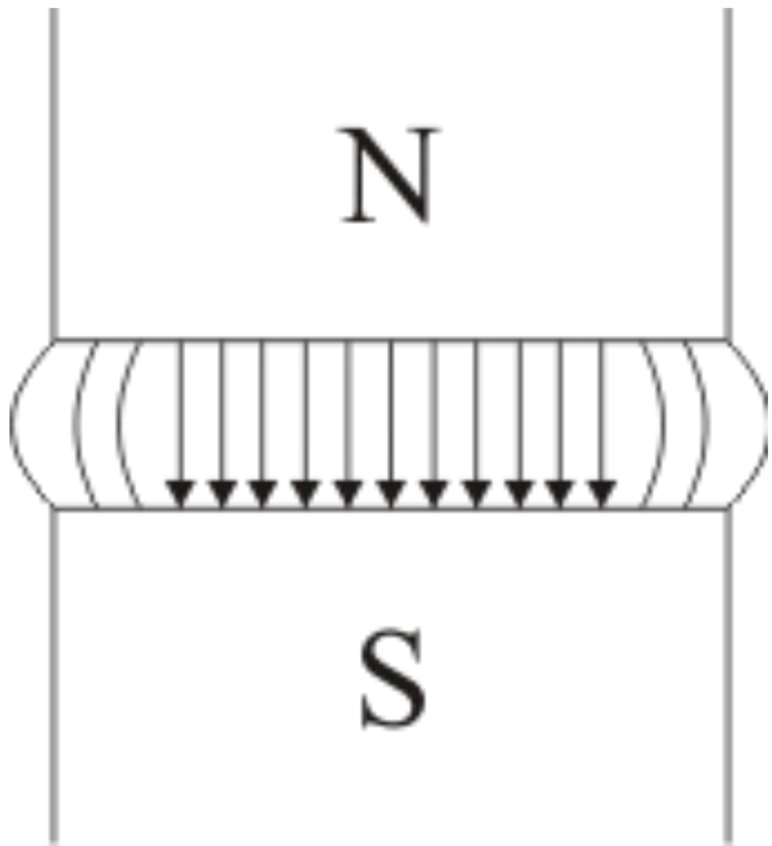
$\boxed{\text{磁路}}$ (非線性 $\xrightarrow{\text{似}}$ 線性)	$\boxed{\text{电路}}$ (線性)
$\mathcal{F} = N \cdot i = \phi R$ $\left(R = \frac{l}{\mu A}\right)$	$V = i \cdot R$ $\left(R = \frac{l}{\mu A}\right)$.
①串联. ②並联.	①串联. ②並联.
	③KVL ④KCL.

導磁≠導电.

Calculations of the flux in a core performed by using the magnetic circuit concepts are always approximations

- The magnetic circuit concept assumes that all flux is confined within a magnetic core. Unfortunately, this is not quite true. The permeability of ferromagnetic core is 2000 to 6000 times that of air, but a small fraction of the flux escapes from the core into the surrounding low-permeability air. This flux outside the core is called leakage flux, and it plays a very important role in electric machine design.
- The calculation of reluctance assumes a certain mean path length and cross-sectional area for the core. These assumptions are not really very good, especially at corners.
- In ferromagnetic materials, the permeability varies with the amount of flux already in the material. This nonlinear effect is described in detail. It adds yet another source of error to magnetic circuit analysis, since the reluctances used in magnetic circuit calculations depend on the permeability of the material.
- If there are air gaps in the flux path in a core, the effective cross-sectional area of the air gap will be large than the cross-sectional area of the iron core on either side. The extra effective area is caused by the “fringing effect” of the magnetic field at the air gap (Figure 1-6).

FIGURE 1-6: The fringing effect of a magnetic field at an air gap. Note the increased cross-sectional area of the air gap compared with the cross-sectional area of the metal



EX1-1: A ferromagnetic core is shown in Fig. 1-7a. Three sides of this core are of uniform width, while the fourth side is somewhat thinner. The depth of the core (into the page) is 10 cm, and the other dimensions are shown in the figure. There is a 200-turn coil wrapped around the left side of the core. Assuming relative permeability μ_r of 2500, how much flux will be produced by a 1-A input current?

$$R_1 = \frac{l_1}{\mu A_1} = \frac{l_1}{\mu_r \mu_0 A_1} \qquad (1-32)$$

$$= \frac{0.45m}{(2500)(4\pi \times 10^{-7})(0.01m^2)} = 14300\, A \cdot turns / Wb$$

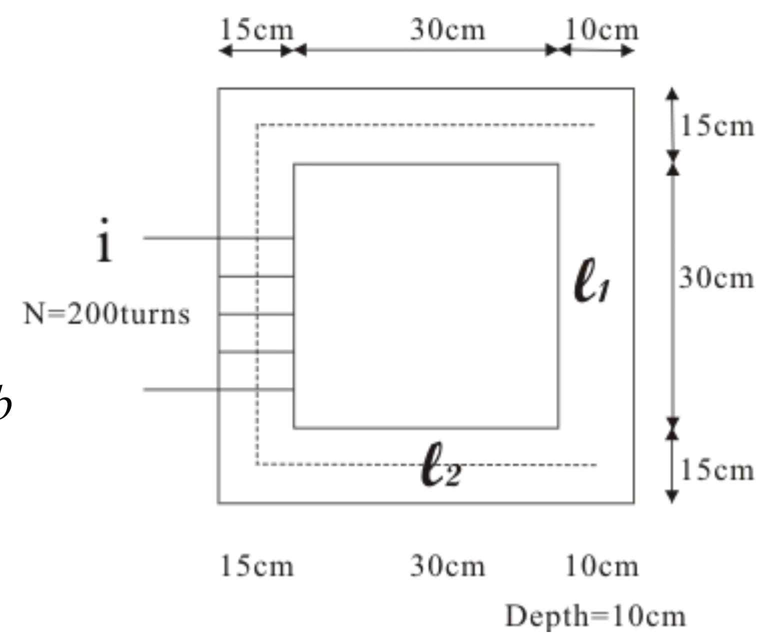
$$R_2 = \frac{l_2}{\mu A_2} = \frac{l_2}{\mu_r \mu_0 A_2} \qquad (1-32)$$

$$= \frac{1.3m}{(2500)(4\pi \times 10^{-7})(0.015m^2)} = 27600\, A \cdot turns / Wb$$

$$R_{eq} = R_1 + R_2 = 41900\, A \cdot turns / Wb$$

$$\mathcal{F} = Ni = (200\ turns)(1.0A) = 200\, A \cdot turns$$

$$\phi = \frac{\mathcal{F}}{R_{eq}} = 0.0048\, Wb$$



EX1-2: Figure 1-8a shows a ferromagnetic core whose mean path length is 40cm. There is a small gap of 0.05cm in the structure of the otherwise whole core. The cross-sectional area of the core is 12cm², the relative permeability of the core is 4000, and the coil of wire on the core has 400 turns. Assume that fringing in the air gap increases the effective cross-sectional area of the air gap by 5 percent. Given this information, find (a) the total reluctance of the flux path (iron plus air gap) and (b) the current required to produce a flux density of 0.5 T in the air gap.

$$(a)\ R_1 = \frac{l_c}{\mu A_c} = \frac{l_c}{\mu_r \mu_0 A_c} \qquad (1-32)$$

$$= \frac{0.4m}{(4000)(4\pi \times 10^{-7})(0.0012m^2)} = 66300 A \cdot turns/Wb$$

$$A_a = 1.05 \times 12cm^2 = 12.6cm^2 = 0.00126m^2$$

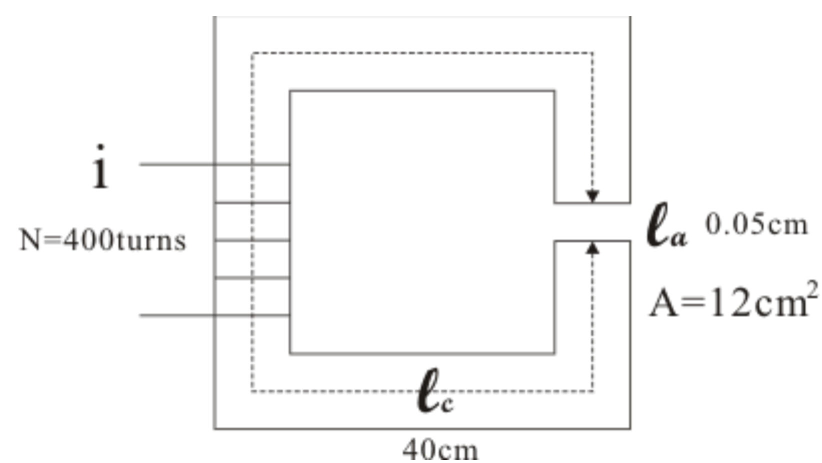
$$R_a = \frac{l_a}{\mu A_a} = \frac{l_a}{\mu_r \mu_0 A_a} \qquad (1-32)$$

$$= \frac{0.0005m}{(1)(4\pi \times 10^{-7})(0.00126m^2)} = 316000 A \cdot turns/Wb$$

$$R_{eq} = R_c + R_a = 382300 A \cdot turns/Wb$$

$$(b)\ \mathcal{F} = Ni = \phi R = BAR$$

$$i = \frac{BAR}{N} = \frac{(0.5T)(0.00126m^2)(382300 A \cdot turns/Wb)}{400 turns} = 0.602 A$$



EX1-3: Figure 1-9a shows a simplified rotor and stator for a dc motor. The mean path length of the stator is 50cm, and its cross-sectional area is 12 cm^2. The mean path length of the rotor is 5cm, and its cross-sectional area also may be assumed to be 12cm^2. Each air gap (including fringing) is 14cm^2. The iron of the core has a relative permeability of 2000, and there are 200turns of wire on the core. If the current in the wire is adjusted to be 1A, what will the resulting flux density in the air gaps be?

$$R_s = \frac{l_s}{\mu_r \mu_0 A_s} \qquad (1-32)$$

$$= \frac{0.5m}{(2000)(4\pi \times 10^{-7})(0.0012m^2)} = 166000 A \cdot turns / Wb$$

$$R_r = \frac{l_r}{\mu_r \mu_0 A_r} \qquad (1-32)$$

$$= \frac{0.05m}{(2000)(4\pi \times 10^{-7})(0.0012m^2)} = 16600 A \cdot turns / Wb$$

$$R_a = \frac{l_a}{\mu_r \mu_0 A_a} \qquad (1-32)$$

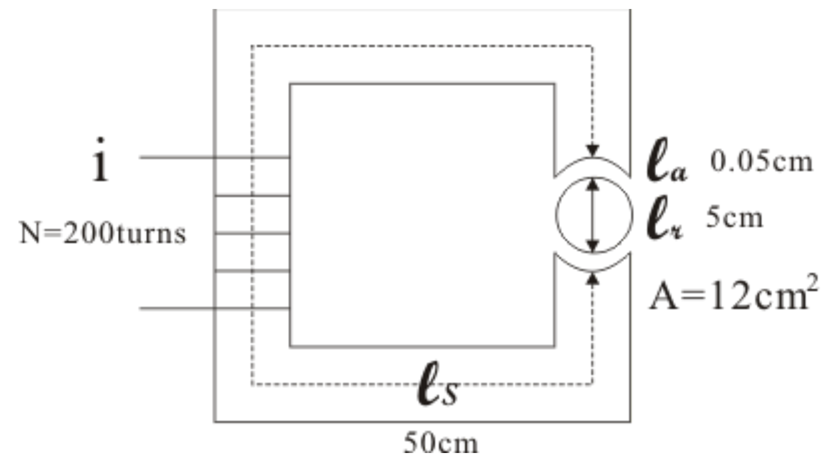
$$= \frac{0.0005m}{(1)(4\pi \times 10^{-7})(0.0014m^2)} = 284000 A \cdot turns / Wb$$

$$R_{eq} = R_s + R_{a1} + R_r + R_{a2} = 751000 A \cdot turns / Wb$$

$$\mathcal{F} = Ni = (200 turns)(1A) = 200 A \cdot turns$$

$$\phi = \frac{\mathcal{F}}{R_{eq}} = \frac{200 A \cdot turns}{751000 A \cdot turns / Wb} = 0.000266 Wb$$

$$B = \frac{\phi}{A} = \frac{0.000266 Wb}{0.0014 m^2} = 0.19T$$

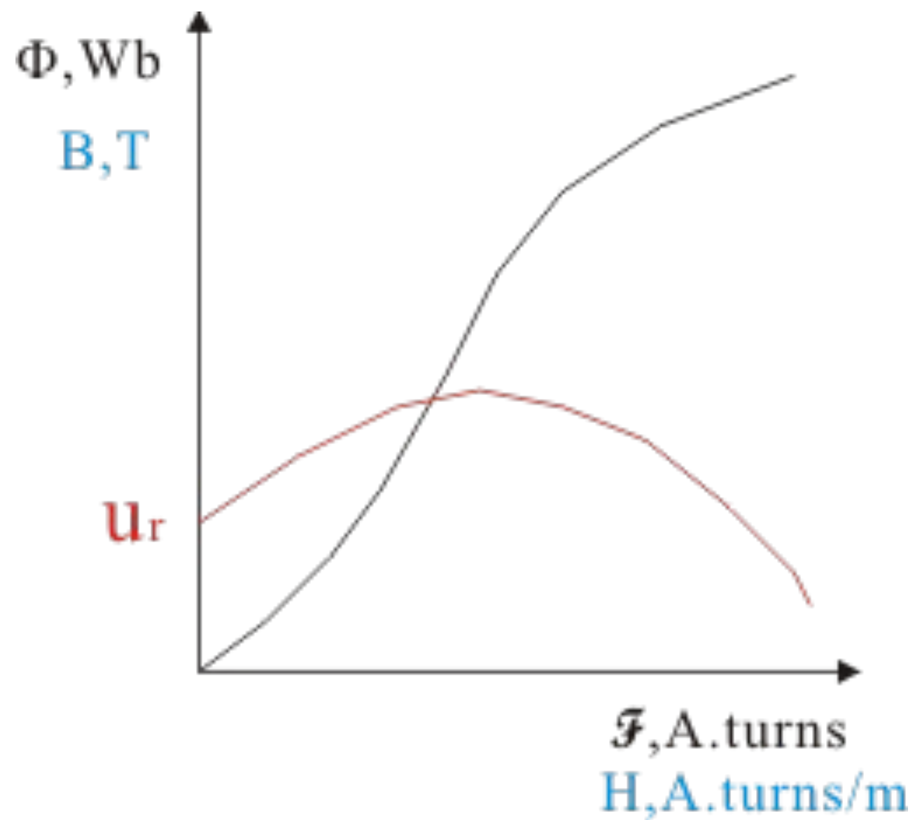


Magnetic Behavior of Ferromagnetic Materials

$$B = \mu H \qquad (1-21)$$

$$H = \frac{Ni}{l_c} = \frac{\mathcal{F}}{l_c} \qquad (1-20)$$

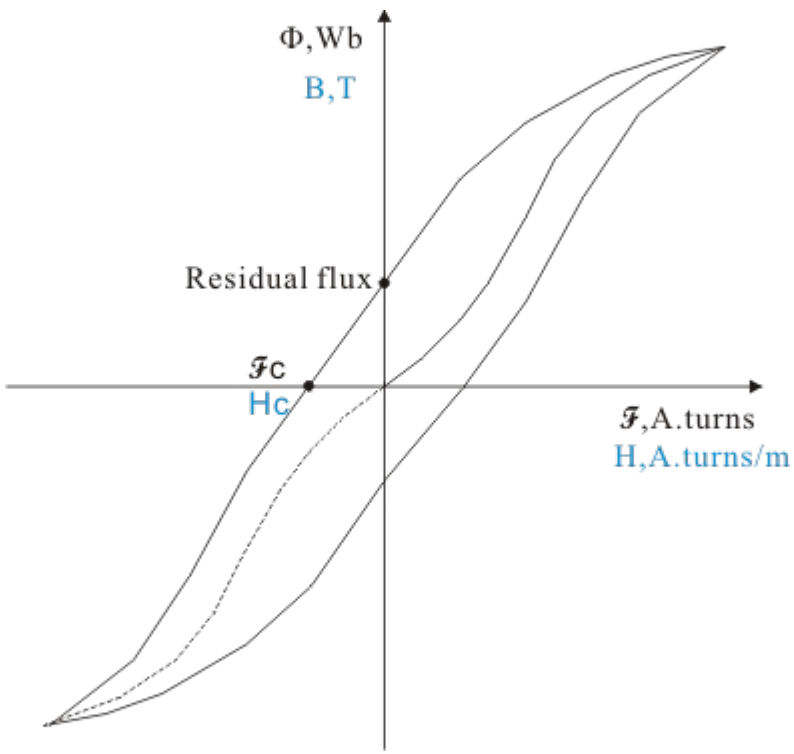
$$\phi = BA \qquad (1-25b)$$



Energy Losses in a Ferromagnetic Core

Eddy current: A time-changing flux induces voltage within a ferromagnetic core and these voltages cause swirls of current to flow within the core, much like the eddies seen at the edges of a river.

$$\oint H \cdot dB = \oint \frac{Ni}{l} \cdot d\frac{\phi}{A} = \oint \frac{i}{l \cdot A} \cdot Nd\phi = \oint \frac{i}{l \cdot A} \cdot Vdt$$



1.5 Faraday's Law — Induced Voltage from a Time-Changing Magnetic Field (Lenz's Law)

对抗

$$e_{ind} = -\frac{d\phi}{dt} \qquad (1-35)$$

$$e_{ind} = -N\frac{d\phi}{dt} \qquad (1-36)$$

$$e_i = \frac{d(\phi_i)}{dt} \qquad (1-37)$$

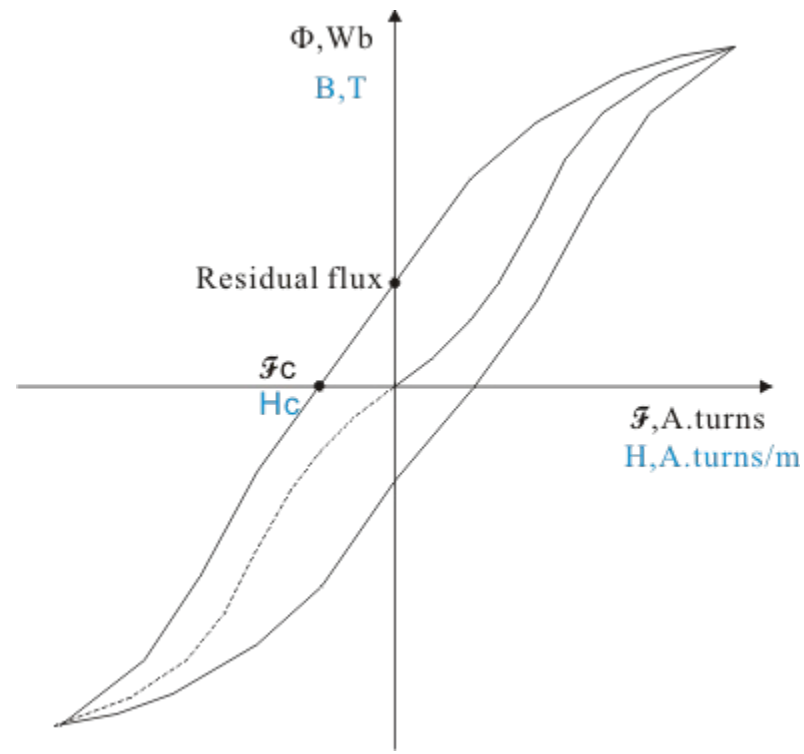
$$e_{ind} = \sum_{i=1}^{N} e_i \qquad (1-38)$$

$$= \sum_{i=1}^{N} \frac{d(\phi_i)}{dt} \qquad (1-39)$$

$$= \frac{d}{dt}\left(\sum_{i=1}^{N} \phi_i\right) \qquad (1-40)$$

$$e_{ind} = \frac{d\lambda}{dt} \qquad (1-41)$$

$$\lambda = \sum_{i=1}^{N} \phi_i \qquad (1-42)$$



$$\frac{d \sin \omega t}{d \omega t} \times \frac{d \omega t}{dt}$$

$$= \cos \omega t \times \omega$$

$$= \sin(\omega t + 90^\circ) \times \omega$$

$$= j \sin \omega t \times \omega$$

* $\underset{(rad/s)}{\omega} = 2\pi \underset{(Hz)}{f}$

* $60Hz \Rightarrow \omega = 377\ rad/s.$

  $60kHz \Rightarrow \omega = 377 \times 10^3\ rad/s.$

* $i = C\frac{dv}{dt} = CsV = C(j\omega)V.$

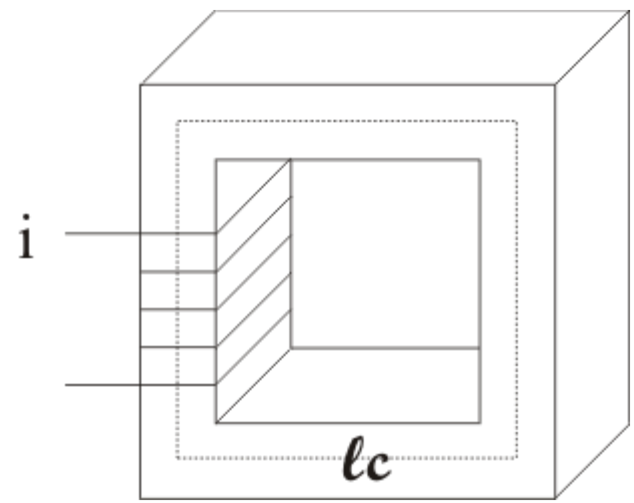
EX1-6: Figure 1-15 shows a coil of wire wrapped around an iron core. If the flux in the core is given by the equation ψ=0.05sin377t Wb If there are 100 turns on the core, what voltage is produced at the terminals of the coil? Of what polarity is the voltage during the time when flux is creasing in the reference direction shown in the figure? Assume that all the magnetic flux stays within the core (i.e., assume that the flux leakage is zero).

$$e_{ind} = N\frac{d\phi}{dt}$$

$$= (100 turns)\frac{d}{dt}(0.05\sin 377t)$$

$$= 1885\cos 377t$$

$$= 1885\sin(377t + 90^0)V$$



1.6 Production of Induced Force on a Wire

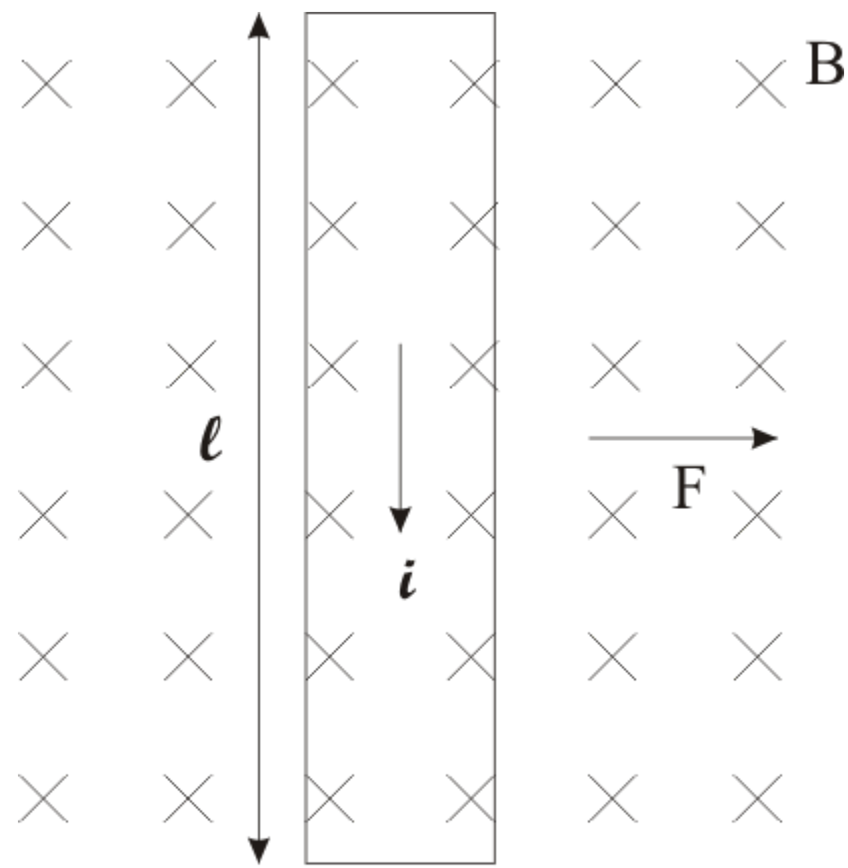
- EX1-7: The magnetic flux density is 0.25T, directed into the page. If the wire is 1.0m long and carries 0.5A of current in the direction from the top of the page to the bottom of the page, what are the magnitude and direction of the force induced on the wire?
- Solution: F=ilBsinθ

=(0.5A)(1.0m)(0.25T)sin90^0

=0.125N, directed to the right

$$\vec{F} = i\vec{l} \times \vec{B} \qquad (1-43)$$

$$F = ilB\sin\theta \qquad (1-44)$$



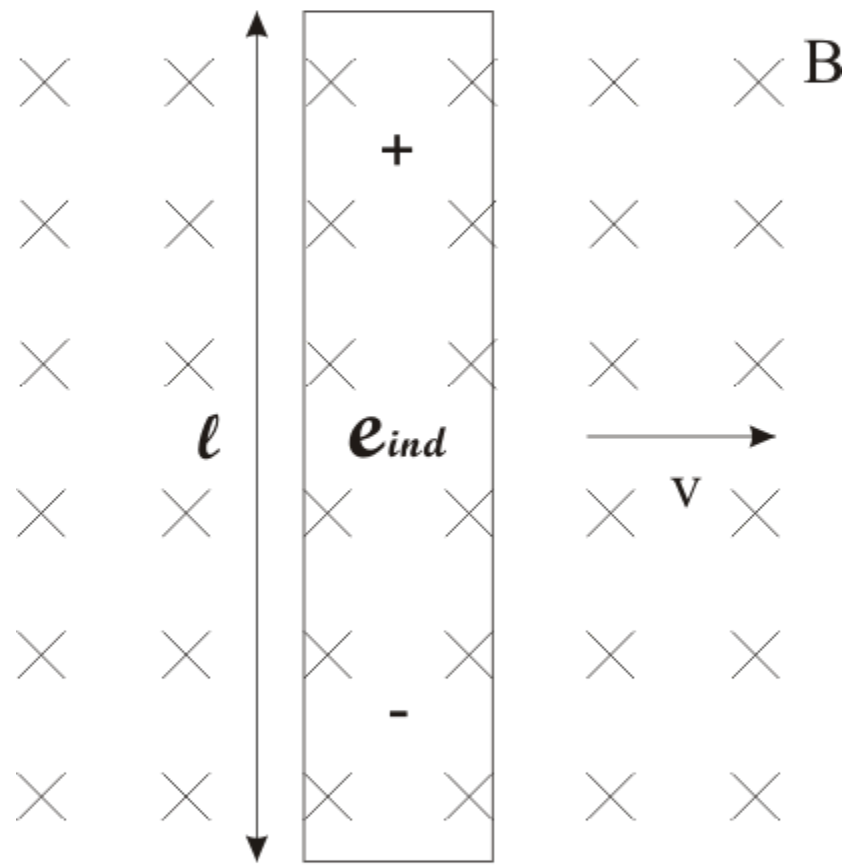
1.7 Induced Voltage on a Conductor Moving in a Magnetic Field

- EX1-8: Figure 1-17 shows a conductor moving with a velocity of 5.0m/s to the right in the presence of a magnetic field. The flux density is 0.5T into the page, and the wire is 1.0m in length, oriented as shown. What are the magnitude and polarity of the resulting induced voltage ?
- Solution: $e_{ind}=(v \times B)\cdot l$

  $=(5.0m/s)(0.5T)(1.0m)$

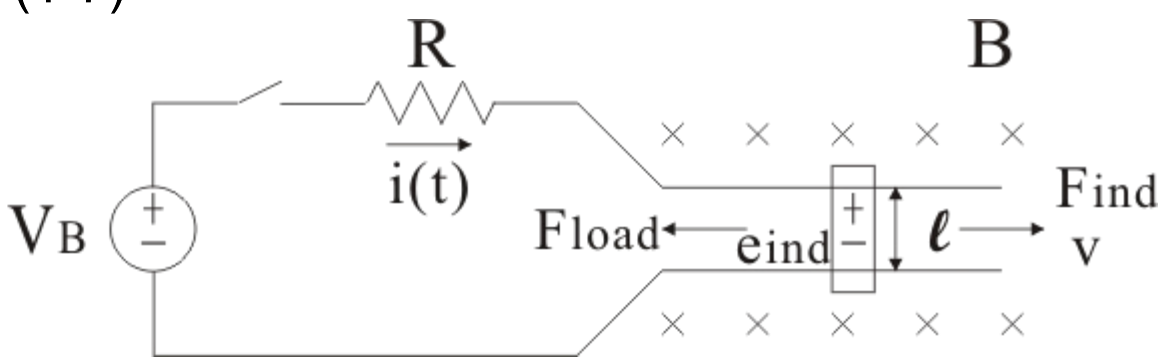
  $=2.5V$

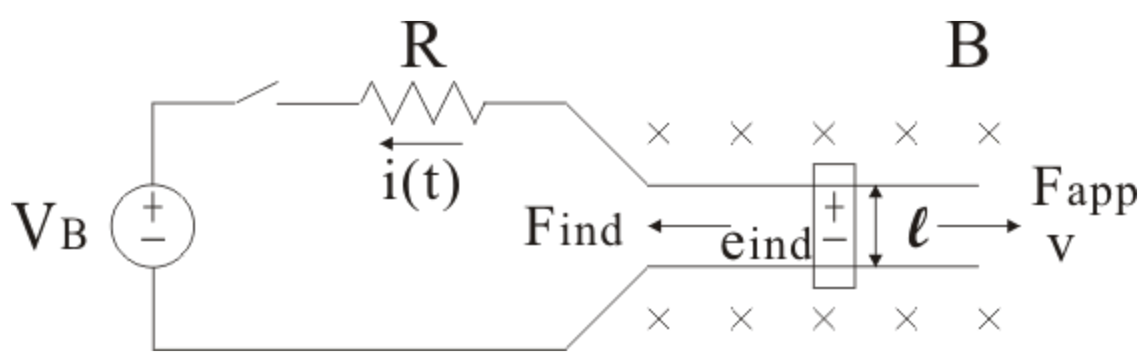
$$e_{ind} = (\vec{v} \times \vec{B}) \cdot \vec{l} \qquad (1-45)$$



1.8 The Linear DC Machine — A Simple Example

1. The equation for the force on a wire in the presence of a magnetic field:
   $F = i(l \times B)$ (1-43)
2. The equation for the voltage induced on a wire moving in a magnetic field:
   $e_{ind} = (v \times B) \cdot l$ (1-45)
3. Kirchhoff's voltage law for this machine:
   $V_B = e_{ind} + iR$ (1-46)
4. Newton's law for the bar across the tracks:
   $F_{net} = ma$ (1-7)





Starting the Linear DC Machine

1. Closing the switch produces a current flow:
   $i = V_B / R$
2. The current flow produces a force on the bar given by:
   $F_{ind} = ilB$ to the right (1-48)
3. The bar accelerates to the right, producing an induced voltage e_{ind} as it speeds up:
   $e_{ind} = vBl$ positive upward (1-49)
4. This induced voltage reduces the current flow:
   $i = (V_B - e_{ind})/R$ (1-47)
5. The induced force is thus decreased ($F=ilB$) until eventually $F=0$. At that point, $e_{ind}=V_B$, $i=0$, and the bar moves at a constant no-load speed
   $v_{ss} = V_B / Bl$ (1-50)

The Linear DC Machine as a Motor

1. A force F_{load} is applied oppsite to the direction of motion, which causes a net force F_{net} opposite to the direction of motion.

   $F=i(l\times B)$ (1-43)

2. The resulting acceleration $a=F_{net}/m$ is negative, so the bar slows down.

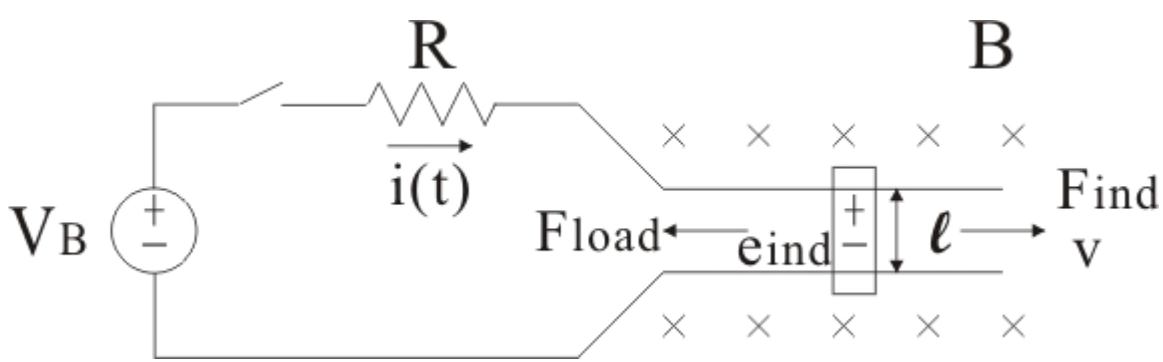
   $F_{net}=ma$ (1-7)

3. The voltage $e_{ind}=vlB$ falls, and so $i=(V_B - e_{ind})/R$ increase.

   $e_{ind}=(v\times B)\cdot l$ (1-45)

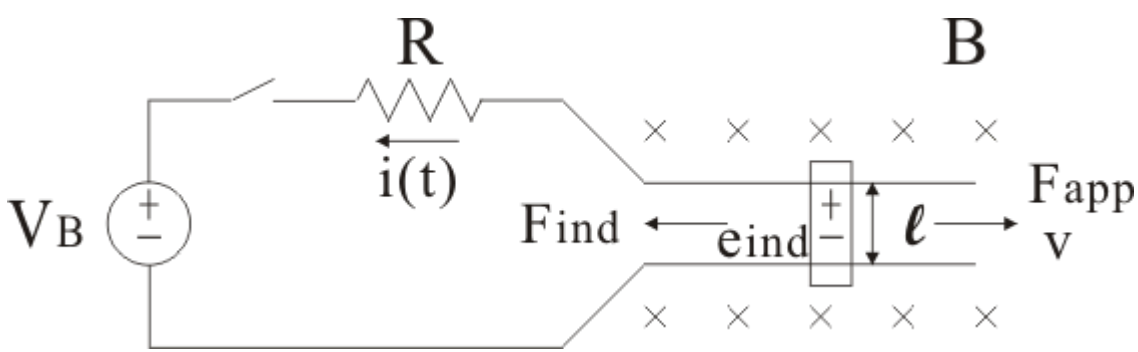
4. The induced force $F_{ind}=ilB$ increases until $F_{ind}=F_{load}$ at a lower speed v.
5. An amount of electric power equal to $e_{ind}i$ is now being converted to mechanical power equal to $F_{ind}v$, and the machine is acting as a motor.

   $P_{conv}=T_{ind}w=F_{ind}v=ilBv=ie_{ind}$ (1-52)



The Linear DC Machine as a Generator

1. A force F_{app} is applied in the direction of motion; F_{net} is in the direction of motion.
   $F_{ind}=ilB$ to the left (1-54)
2. Acceleration $a=F_{net}/m$ is positive, so the bar speeds up.
   $F_{net}=ma$ (1-7)
3. The voltage $e_{ind}=vlB$ increases, and so i increase.
   $i=(e_{ind} - V_B)/R$ (1-53)
4. The induced force $F_{ind}=ilB$ increases until $F_{ind}=F_{app}$ at a higher speed v.
5. A amount of mechanical power equal to $F_{ind}v$ is now being converted to electric power $e_{ind}i$, and the machine is acting as a generator.
   $P_{conv}=T_{ind}w=F_{ind}v=ilBv=ie_{ind}$ (1-52)



EX1-10: The linear dc machine shown in Figure 1-27 has a battery voltage of 120V, an internal resistance of 0.3Ω, and a magnetic flux density of 0.1T.

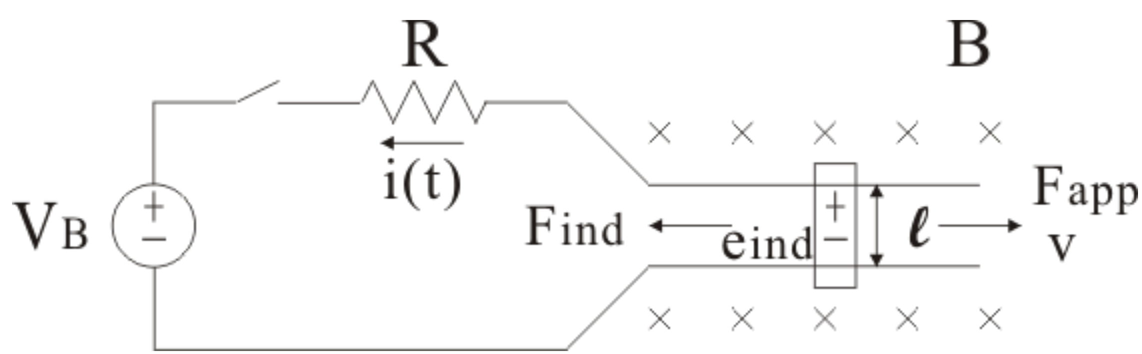
(a) What is this machine's maximum starting current? What is its steady-state velocity at no load ?

(b) Suppose that a 30-N force pointing to the right were applied to the bar. What would the steady-state speed be? How much power would the battery be producing or consuming? Is this machine acting as a motor or as a generator ?

(c) Now suppose a 30-N force point to the left were applied to the bar. What would the new steady-state speed be ? Is this machine a motor or a generator now ?

(d) Assume that a force pointing to the left is applied to the bar. Calculate speed of the bar as a function of the force for values from 0 N to 50 N in 10N-steps. Plot the velocity of the bar versus the applied force.

(e) Assume that the bar is unloaded and that it suddenly runs into a region where the magnetic field is weakened to 0.08T. How fast will the bar go now?



- (a) At starting conditions, the velocity of the bar is 0, so $e_{ind}=0$. Therefore, $i=(V_B - e_{ind})/R=(120V - 0V)/0.3\Omega=400A$

  When the machine reaches steady state, $F_{ind}=0$ and $i=0$. Therefore,

  $v_{ss}=V_B/Bl = 120V/(0.1T)(10m) = 120$ m/s
- (b) $F_{app} = F_{ind} = ilB$, Therefore,

  $i = F_{ind}/lB = 30N/(10m)(0.1T) = 30A$ flowing up through the bar

  The induced voltage e_{ind} on the bar must be

  $e_{ind} = V_B + iR = 120V + (30A)(0.3\Omega)=129V$

  and the final steady-state speed must be

  $v_{ss} = e_{ind}/Bl = 129V/(0.1T)(10m) = 129$ m/s

  The bar is producing P=(129V)(30A)=3870W of power, and the battery is consuming P=(120V)(30A)=3600W. The difference between these two numbers is the 270W of losses in the resistor. This machine is acting as a generator.

- (c) The force is applied to the left, and the induced force is to the right. At steady state,

  $F_{app} = F_{ind} = ilB$

  $i = F_{ind}/lB = 30N/(10m)(0.1T) = 30A$ flowing down through the bar

  The induced voltage e_{ind} on the bar must be

  $e_{ind} = V_B - iR = 120V - (30A)(0.3\Omega) = 111V$

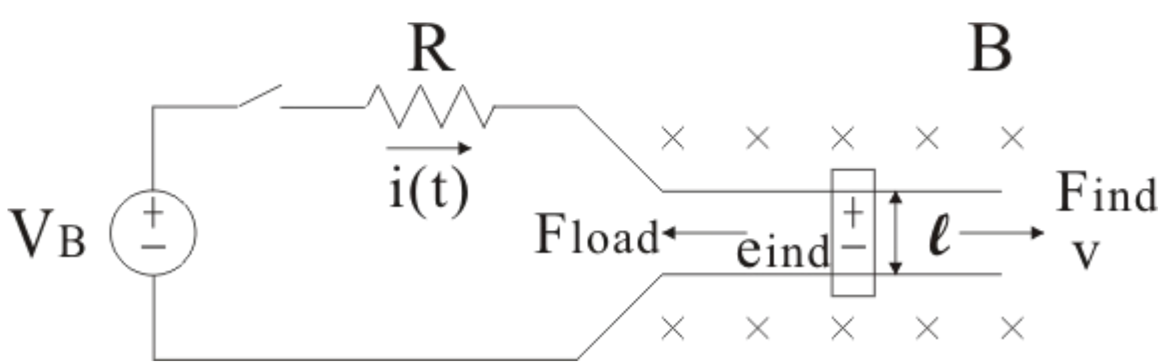
  and the final speed must be

  $v_{ss} = e_{ind}/Bl = 111V/(0.1T)(10m) = 111m/s$

  This machine is now acting as a motor.

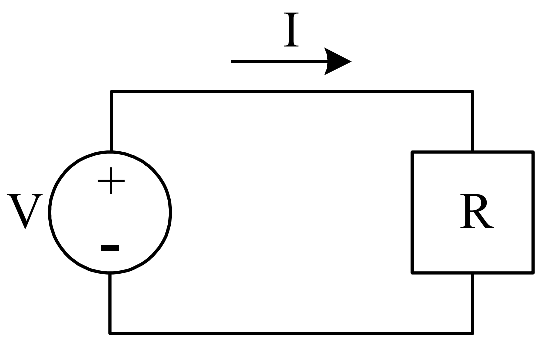
- (d)
- (e) The final speed is

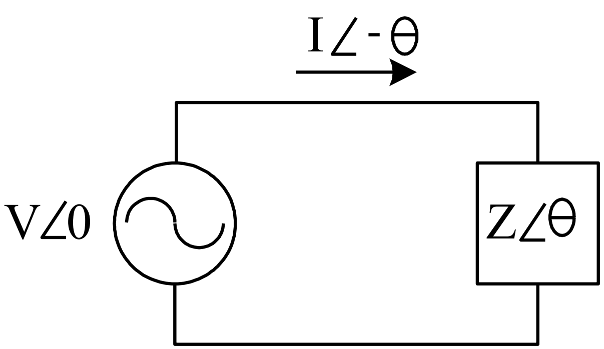
  $v_{ss} = V_B/Bl = 120V/(0.08T)(10m) = 150m/s$



$\boxed{\text{Ex 1-10:}}$

1.9 REAL, REACTIVE, AND APPARENT POWER IN AC CIRCUITS





DC Power

$$P = VI = V^2 / R = I^2 R \qquad (1-55)$$

AC Power

$$v(t) = \sqrt{2}\, V \cos \omega t \qquad (1-56)$$

$$i(t) = \sqrt{2}\, I \cos(\omega t - \theta) \qquad (1-57)$$

$$p(t) = v(t) i(t) = 2VI \cos \omega t \cos(\omega t - \theta) \qquad (1-58)$$

$$p(t) = VI[\cos\theta + \cos(2\omega t - \theta)]$$

$$= VI \cos\theta \cdot (1 + \cos 2\omega t) + VI \sin\theta \cdot \sin 2\omega t \qquad (1-59)$$

The Power Triangle

$$P = VI \cos\theta \qquad (1-60)$$

$$Q = VI \sin\theta \qquad (1-61)$$

$$S = VI \qquad (1-62)$$

Alternative Forms of the Power Equations

$$V = IZ \qquad (1-63)$$

$$P = I^2 Z \cos\theta \qquad (1-64)$$

$$Q = I^2 Z \sin\theta \qquad (1-65)$$

$$S = I^2 Z \qquad (1-66)$$

$$Z = R + jX = |Z|\cos\theta + |Z|\sin\theta$$

$$P = I^2 R \qquad (1-67)$$

$$Q = I^2 X \qquad (1-68)$$

Complex Power

$$S = P + jQ \qquad (1-69)$$

$$S = VI^* \qquad (1-70)$$

$$\begin{aligned} S = VI^* &= (V\angle\alpha)(I\angle-\beta) \\ &= VI\angle(\alpha-\beta) = VI\angle\theta \\ &= VI\cos\theta + jVI\sin\theta \\ &= P + jQ \end{aligned}$$

$$I = \frac{V}{Z} = \frac{V\angle 0^\circ}{|Z|\angle\theta} = \frac{V}{|Z|}\angle-\theta$$

Power Factor

$$PF = \cos\theta \qquad (1-71)$$

EX1-11: Figure 1-34 shows an ac voltage source V=120 $\angle 0^0$ supplying power to a load with impedance Z=20$\angle$-30$^0\Omega$. Calculate the current I supplied to the load, the power factor of the load, and the real, reactive, apparent, and complex power supplied to the loads.

$$I = \frac{V}{Z} = \frac{120\angle 0^0 V}{20\angle -30^0 \Omega} = 6\angle 30^0 A$$

$$PF\ of\ the\ load = \cos\theta = \cos(-30^0) = 0.866 \quad (1-71)$$

$$P = VI\cos\theta \qquad (1-60)$$

$$P = (120V)(6A)\cos(-30^0) = 623.5W$$

$$Q = VI\sin\theta \qquad (1-61)$$

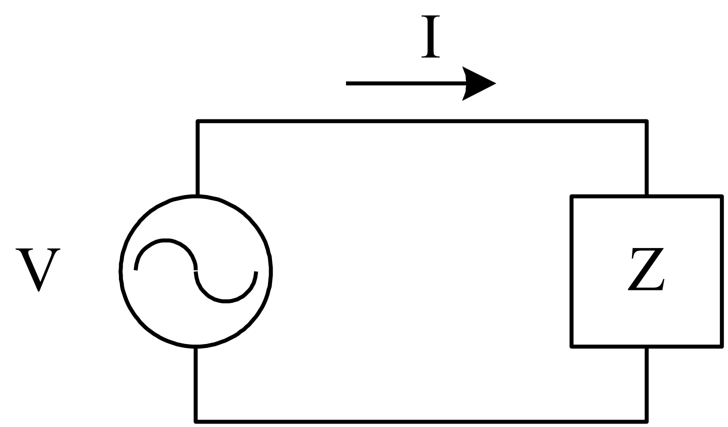
$$Q = (120V)(6A)\sin(-30^0) = -360VAR$$

$$S = VI \qquad (1-62)$$

$$S = (120V)(6A) = 720VA$$

$$S = VI^* = (120\angle 0^0 V)(6\angle +30^0 A)^* = (120\angle 0^0 V)(6\angle -30^0 A)$$

$$= 720\angle -30^0 VA = (623.5 - j360)VA = 623.5W - j360VAR$$



1.10 Summary

- This chapter has reviewed briefly the mechanics of systems rotating about a single axis and introduced the sources and effects of magnetic fields important in the understanding of transformers, motors, and generators.
- Historically, the English system of units has been used to measure the mechanical quantities associated with machines in English-speaking countries. Recently, the SI units have superseded the English system almost everywhere in the world except in the United States, but rapid progress is being made even there. Since SI is becoming almost universal, most(but not all) of the examples in this book use this system of units for mechanical measurements. Electrical quantities are always measured in SI units.
- In the section on mechanics, the concepts of angular position, angular velocity, angular acceleration, torque, Newton's law, work and power were explained for the special case of rotation about a single axis. Some fundamental relationships (such as the power and speed equations) were given in both SI and English units.
- The production of a magnetic field by a current was explained, and the special properties of ferromagnetic materials were explored in detail. The shape of the magnetization curve and the concept of hysteresis were explained in terms of the domain theory of ferromagnetic materials, and eddy current losses were discussed.

- Faraday’s law states that a voltage will be generated in a coil of wire that is proportional to the time rate of change in the flux passing through it. Faraday’s law is the basis of transformer action, which is explored in detail in Chapter3.
- A current-carrying wire present in a magnetic field, if it is oriented properly, will have a force induced on it. This behavior is the basis of motor action in all real machines.
- A wire moving through a magnetic field with the proper orientation will have a voltage induced in it. This behavior is the basis of generator action in all real machines.
- A simple linear dc machine consisting of a bar moving in a magnetic field illustrates many of the features of real motors and generators. When a load is attached to it, it slows down and operates as a motor, converting electric energy into mechanical energy. When a force pulls the bar faster than its no-load steady-state speed, it acts as a generator, converting mechanical energy into electric energy.
- In ac circuits, the real power P is the average power supplied by a source to a load. The reactive power Q is the component of power that is exchanged back and forth between a source and a load. By convention, positive reactive power is consumed by inductive loads (+θ) and negative reactive power is consumed (or positive reactive power is supplied) by capacitive loads (-θ). The apparent power S is the power that “appears” to be supplied to the load if only the magnitudes of the voltage and currents are considered.