Lesson 2: Magnetic Circuits-Quantities and Definitions

ET 332a

Dc Motors, Generators and Energy Conversion Devices

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Learning Objectives

After this presentation you will be able to:

- Explain how magnetic flux lines emanate from permanent magnets and produce force
- Define flux density, magnetomotive force, magnetic field intensity, permeability, and reluctance using mathematical equations.
- Identify the parts of a magnetization curve
- Perform calculations using magnetic quantities

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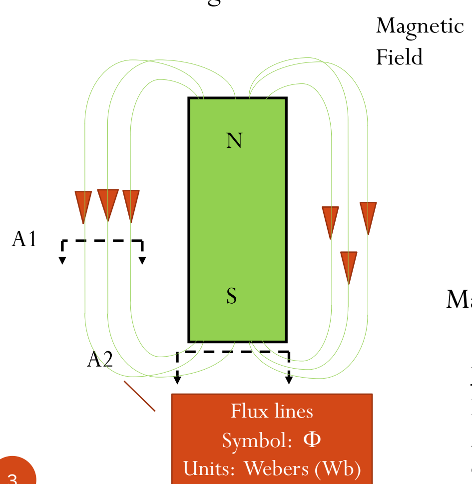
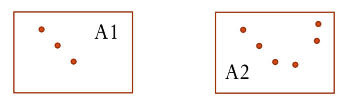
Magnetic Fields and Polarity

Permanent Magnets



Direction convention: From N to S

Flux Density, B
Number of flux lines/ unit area



Mathematically $B = \frac{\Phi}{A}$

<u>Where:</u>
B = flux density (Teslas ,T or Wb/m^2)
A = area (m^2)
Φ= flux (Wb)

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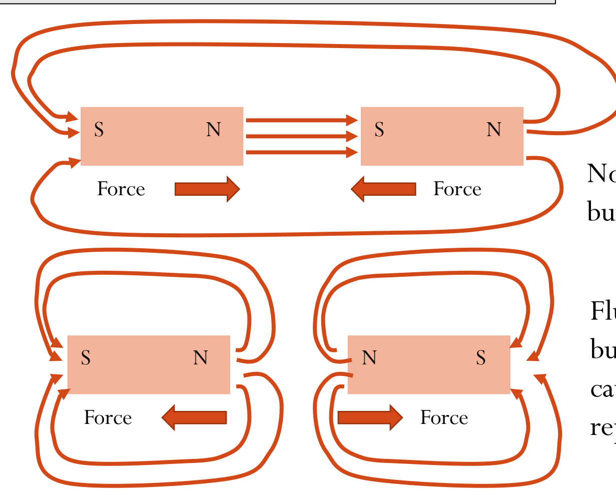
Magnetic Forces

Magnetic field converted to mechanical force

Opposite Poles Attract



No flux bunching

Like Poles Repel

Flux bunching causes repulsion

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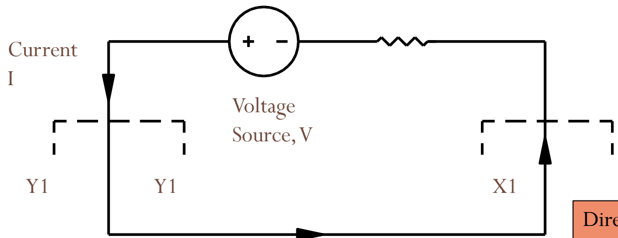
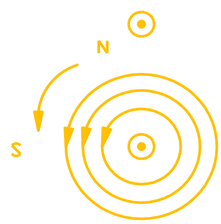
Electromagnetism

Currents flowing in wires produce magnetic flux



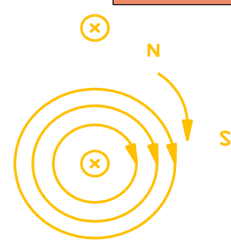
Direction of flux line (Conventional current)

Y1 I into page



Right-hand Rule
Thumb – current
Fingers –direction of flux

X1 I into page



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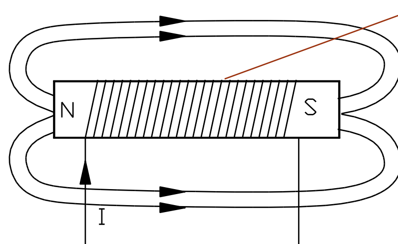
Magnetomotive Force of a Coil

N = number of turns in coil

Given a coil



Magnetomotive Force (MMF) $\mathscr{F}$

Mathematically

$\mathscr{F} = N \square I$

Where $\mathscr{F}$ = MMF (A-t)

N = number of turns in coil (t)

I = current in coil (A)

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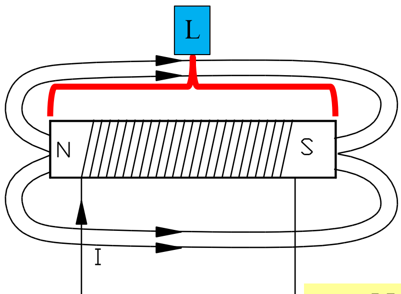
Magnetic Field Intensity of a Coil



Magnetic field intensity, H
(MMF gradient of coil)
Amount of MMF dropped over length

Mathematically $H = \dfrac{N \cdot I}{L} = \dfrac{\mathcal{F}}{L}$

Where: H = Magnetic field intensity (Oersteds, A-t/m)
L = path length (meters)

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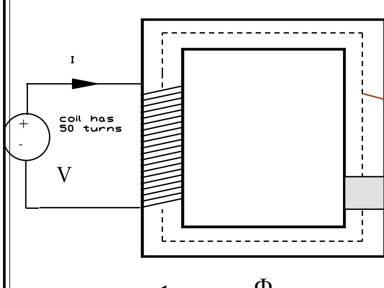
Reluctance of Magnetic Circuits

Reluctance –opposition to flux. Similar to R in dc electric circuit



Ferromagnetic core (iron)

L = mean path length (m)

Core has cross sectional area A (m^2) = LxW

L

W

Magnetic Circuit Relationship $\Phi = \dfrac{\mathcal{F}}{\mathcal{R}} = \dfrac{N \cdot I}{\mathcal{R}}$

So $\mathcal{R} = \dfrac{\mathcal{F}}{\Phi}$

Where: $\mathcal{F}$ = MMF (A-t)
$\mathcal{R}$ = Reluctance (A-t/Wb)
Φ = flux (Wb)
N = coil turns (t)
I = coil current (A)

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Reluctance of Magnetic Circuits

Coil reluctance related to core geometry and material

From previous math relationships

$$\mathfrak{F} = H \cdot L$$

$$\Phi = B \cdot A$$

Substitute into equation from last slide and simplify

$$\mathfrak{R} = \frac{L}{\left(\frac{B}{H}\right) \cdot A}$$

B and H depend on magnetic core material and relationship is usually non-linear

Electric analogy

H → Electric field potential

B → Current density

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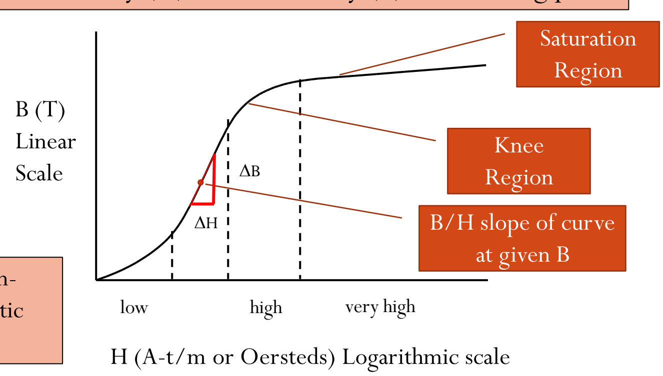
Magnetization Curves (B-H curves)

Plot magnetic field intensity (H) Vs flux density (B) on semi-log plots



Magnetic circuit non-linear due to magnetic saturation

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Magnetization Curves

B-H curves different for each type of material

Free Space

Free space B-H curve is linear, but permeability is very low (hard to magnetize)

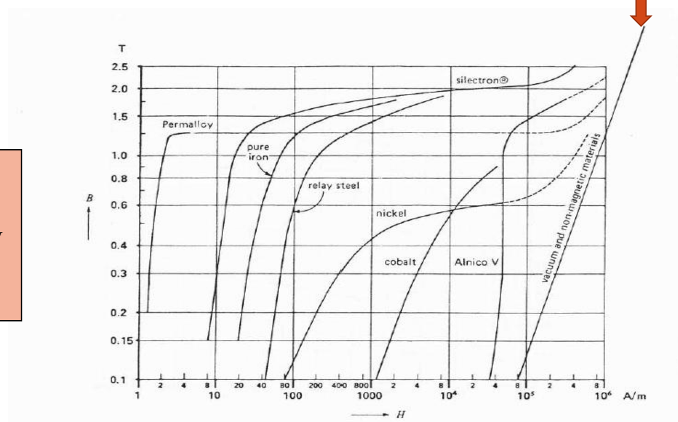

Figure 2.27
Saturation curves of magnetic and nonmagnetic materials. Note that all curves become asymptotic to the *B-H* curve of vacuum where *H* is high.

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Magnetic Permeability

Permeability - Amount of magnetic field intensity required to produce a given flux density for a given material.

Mathematically $\mu = \dfrac{B}{H}$

Where: B = flux density (Wb/m^2)
H = magnetic field intensity (A-t/m)
μ = permeability (Wb/A-t-m)

Characteristics:

- similar to resistivity in conductors
- not a constant for a given material
- larger μ, less H required to produce given B

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Relative Permeability

Relative permeability - Ratio of material's permeability to that of free space

$$\mu_r = \frac{\mu}{\mu_0}$$

Where:

μ_0 = permeability of free space ($4\pi \times 10^{-7}$ Wb/A-t-m)

μ = permeability of material (Wb/A-t-m)

μ_r = relative permeability (dimensionless)

Permeability, μ, found from B-H plots. Experimental results of exciting magnetic material with current and measuring B

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Reluctance formulas In Terms of Permeability

$\mathcal{R}$ depends on:

- type of magnetic material μ
- length of circuit, L
- cross-sectional area of circuit, A

so

$$\mathcal{R} = \frac{L}{\mu \cdot A}$$

$\mu_r \cdot \mu_0 = \mu$ from previous relationship, so

$$\mathcal{R} = \frac{L}{\mu_0 \cdot \mu_r \cdot A}$$

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Calculation Examples

Computing flux density:

A magnetic flux of 0.0046 Wb passes through a core cross sectional dimensions of 10 cm x 17 cm. Find the flux density.

$\Phi = 0.0046$ Wb

$L = 10$ cm $W = 17$ cm

$L = 0.10$ m $W = 0.17$ m

$A = 0.10\text{ m} \cdot 0.17\text{ m} = 0.017\text{ m}^2$

$$B = \frac{\Phi}{A} = \frac{0.0046\text{ Wb}}{0.017\text{ m}^2} = 0.271\text{ Wb/m}^2\ (T)$$ ANSW

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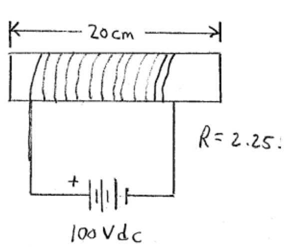
Calculation Examples

Computing MMF and H:

A coil for a solenoid is 20 cm long and made up of 200 turns of wire. This wire has a dc resistance of 2.25 Ω. The solenoid is connected to a 100 V dc source. Find the MMF the coil produces and the magnetic field intensity.



$N = 200$ turns

$\mathcal{F} = NI$

$I = \frac{V}{R} = \frac{100\text{ V}}{2.25\ \Omega} = 44.44\text{ A}$

$\mathcal{F} = (200\ t)(44.44\text{ A})$

$\mathcal{F} = 8888.9$ A-t ANSW

$H = \frac{NI}{L} = \frac{\mathcal{F}}{L}$

$L = 20\text{ cm} = 0.20\text{ m}$

$H = \frac{8888.9\text{ A-t}}{0.20\text{ m}}$

$= 44444$ A-t/m ANSW

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Calculation Examples

Computing Reluctance and Permeability:
A magnetic core made of cast steel must carry a flux density of 1.0T. It has a total length of 1.56 m. and a cross-sectional area of .37 m^2. Find the permeability, the relative permeability and reluctance of the core.

Use B-H curve from text. For a B=1.0T H = 800 A-t/m

$$\mu_{cs} = \frac{1.0\ wb/m^2}{800\ A\text{-}t/m} = 0.00125\ wb/A\text{-}t\text{-}m \quad \text{Answ}$$

$$\mu_r = \frac{\mu_{cs}}{\mu_0} = \frac{0.00125\ wb/A\text{-}t\text{-}m}{4\pi \times 10^{-7}\ wb/A\text{-}t\text{-}m} = 994.7\ (\text{dimensionless})\quad \text{Answ}$$

$$\mathcal{R} = \frac{L}{\mu_{cs} A} = \frac{L}{\mu_r \mu_0 A} \qquad L = 1.52\ m \quad A = 0.37\ m^2$$

use Permeability of cast steel, μ_{cs}

$$\mathcal{R} = \frac{L}{\mu_{cs} A} = \frac{1.52\ m}{0.00125\ wb/A\text{-}t\text{-}m\ (0.37\ m^2)} = 3287\ A\text{-}t/wb \quad \text{Answ}$$

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End Lesson 2 - Magnetic Circuits-Quantities and Definitions

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