Lesson 3: Solving Magnetic Circuits

ET 332a
Dc Motors, Generators and Energy Conversion Devices

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Learning Objectives

After this presentation you will be able to:

- Explain the dc circuit analogy to magnetic circuits
- Represent a magnetic circuit using reluctances and MMF sources.
- Combine series and parallel reluctance values to find total reluctance
- Perform calculations to find flux distributions using dc circuit analogy.

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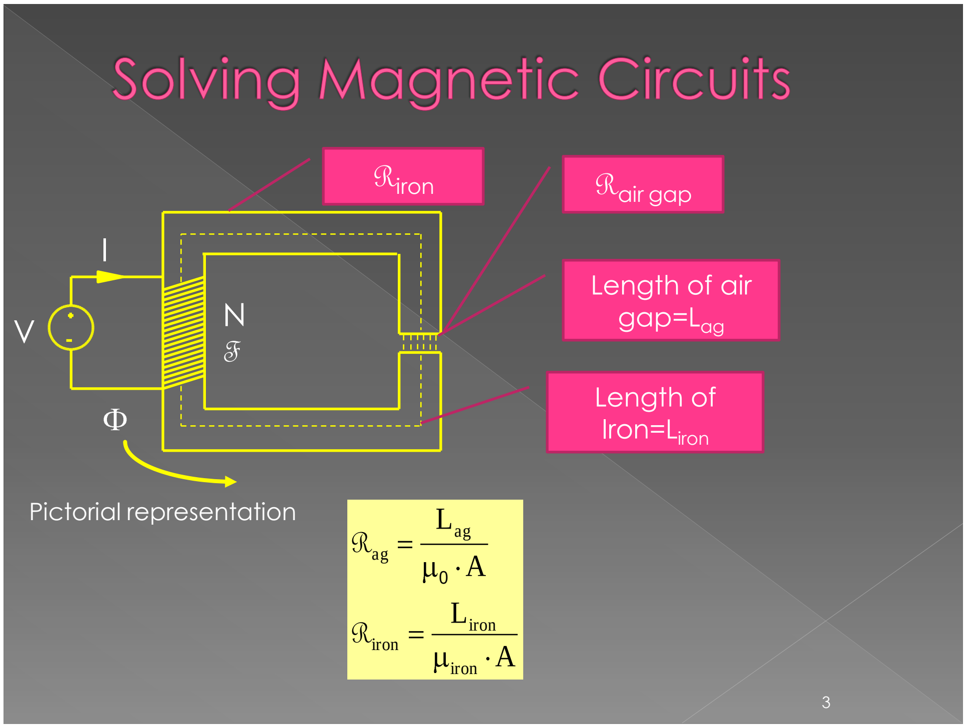
Solving Magnetic Circuits
$\mathcal{R}_{iron}$
$\mathcal{R}_{air\ gap}$
Length of air gap=L_{ag}
Length of Iron=L_{iron}
I
V
N
$\mathcal{F}$
Φ
Pictorial representation
$\mathcal{R}_{ag} = \frac{L_{ag}}{\mu_0 \cdot A}$
$\mathcal{R}_{iron} = \frac{L_{iron}}{\mu_{iron} \cdot A}$
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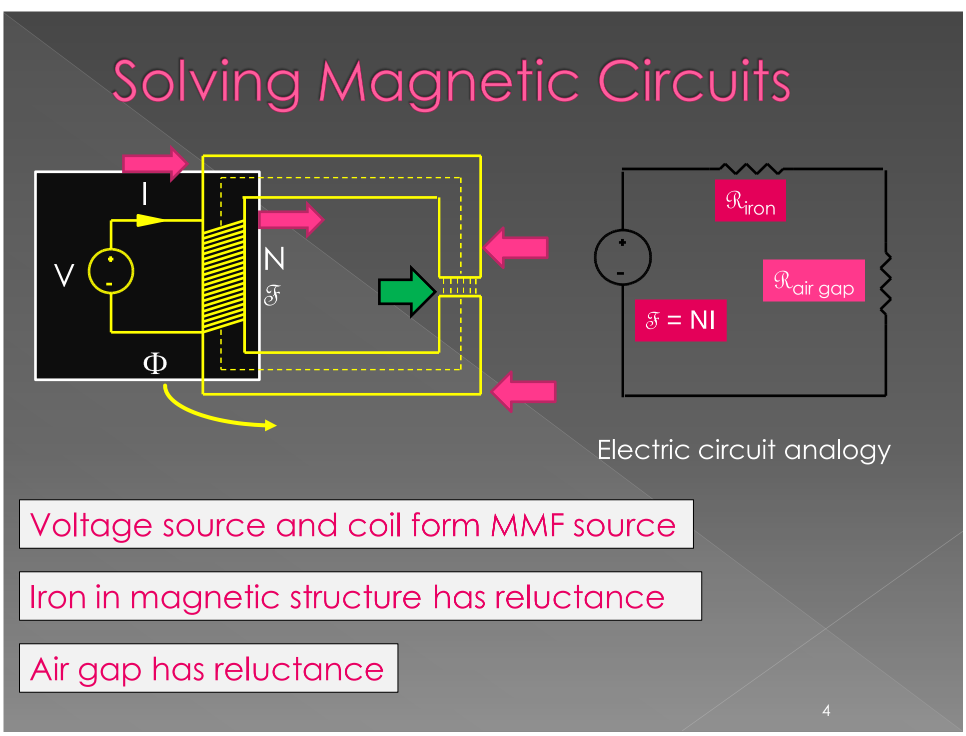
Solving Magnetic Circuits
I
V
N
$\mathcal{F}$
Φ
$\mathcal{R}_{iron}$
$\mathcal{R}_{air\ gap}$
$\mathcal{F}$ = NI
Electric circuit analogy
Voltage source and coil form MMF source
Iron in magnetic structure has reluctance
Air gap has reluctance
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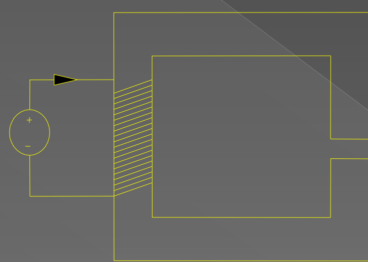
Magnetic Circuit –Example 1

Problem Statement



B in air gap 0.8 T

$N = 200$ turns
Core material:
Silicon Iron (1%)

Core cross-sectional area, $A = 0.1\ m^2$

Total core length
$L = 50$ cm

Air gap length = 0.5 cm

Assume Core $\mathfrak{R}$ negligible: Find H_{air}, Φ, $\mathfrak{R}_{air}$ $\mathfrak{F}_{tot}$

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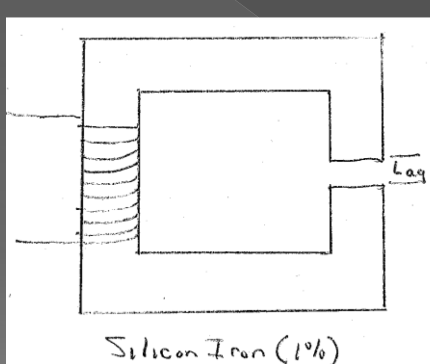
Magnetic Circuit –Example 1

Example Solution



$L = 50$ cm N = 200 turns
$A = 0.1\ m^2$
Air gap length 0.5 cm = L_{ag}
$B_{AG} = 0.8\ T = 0.8\ wb/m^2$

$\Phi = B_{AG} A = 0.8\ wb/m^2\ (0.1\ m^2)$

$\Phi = 0.08$ Wb Answ

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Magnetic Circuit –Example 1

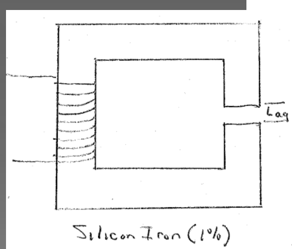
Example Solution (continued)

For Air Gap, $\mu = \mu_0 = 4\pi \times 10^{-7}\ wb/A\text{-}t\text{-}m$

$$\mu_0 = \frac{B}{H_{air}} \quad \text{so} \quad H_{air} = \frac{B}{\mu_0}$$

$$H_{air} = \frac{0.8\ wb/m^2}{4\pi \times 10^{-7}\ wb/A\text{-}t\text{-}m}$$

$$H_{air} = 636,620\ A\text{-}t/m \quad \text{Answ}$$



Permeability is constant in the air gap

Magnetic Circuit –Example 1

Example Solution (continued)
Computing reluctance in air gap

$$R_{air} = \frac{L_{ag}}{\mu_0 A} = \quad L = 0.5cm = 0.5cm\left(\frac{1m}{100cm}\right) = 0.005\ m$$

$$A = 0.1\ m^2$$

$$R_{air} = \frac{0.005\ m}{(4\pi \times 10^{-7}\ wb/A\text{-}t\text{-}m)(0.1\ m^2)}$$

$$R_{air} = 39,789\ \frac{A\text{-}t}{wb}$$

Magnetic Circuit –Example 1

Example Solution (continued)
Computing total MMF

$\mathcal{F}_{tot}$ is only the MMF required to drive Φ through air gap since iron $\mathcal{R}$ is neglected.

$\mathcal{F}_{tot} = H_{air} L_{ag} \Rightarrow \mathcal{F}_{tot} = 636{,}620$ At/m (0.005m)

$L_{ag} = 0.005$ m

$\mathcal{F}_{tot} = 3183$ A-t ANSW

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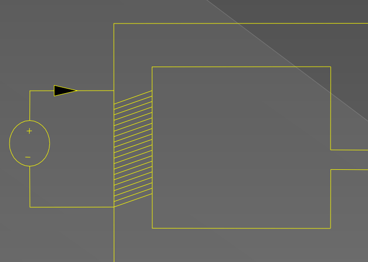
Magnetic Circuit –Example 2

Problem Statement



B in air gap 0.8 T

N = 200 turns
Core material:
Silicon Iron (1%)

Core cross-sectional
area, A = 0.1 m^2

Total core length
L = 50 cm

Air gap length = 0.5 cm

Include the effects of the iron core: Find I, H_{air}, H_{iron}, Φ, $\mathcal{R}_{air}$, $\mathcal{R}_{iron}$, $\mathcal{F}_{tot}$

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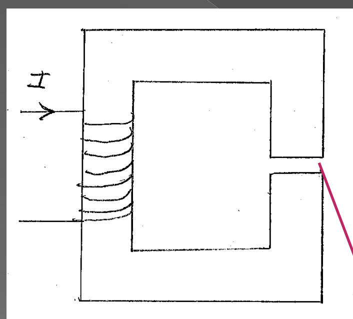
Magnetic Circuit –Example 2

Example Solution



$N = 200 \quad L = 50\ cm \quad A = 0.1\ m^2$

CORE MATERIAL: Silicon Iron (1%)

$L_{ag} = 0.5\ cm = 0.5\ cm\left(\frac{1\ m}{100\ cm}\right) = 0.005\ m$

$B_{air} = 0.8\ T = 0.8\ Wb/m^2$

$\Phi = B_{air} A = 0.8\ Wb/m^2\ (0.1\ m^2) = 0.08\ Wb$

L_{ag}

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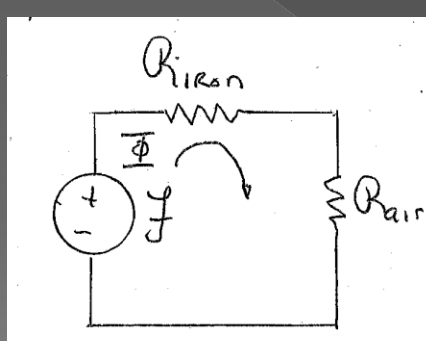
Magnetic Circuit –Example 2

Example Solution (continued)
Include effects of iron core



Find H for air gap

$\mu_0 = \frac{B_{Air}}{H_{air}} \rightarrow H_{air} = \frac{B_{air}}{\mu_0}$

$H_{air} = \frac{0.8\ Wb/m^2}{4\pi \times 10^{-7}\ Wb/A\text{-}t\text{-}m}$

$H_{air} = 636{,}619\ A\text{-}t/m$ Answ

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Magnetic Circuit –Example 2

Example Solution (continued)
Include effects of iron core

USE B-H curves to find H_{iron} and μ_{iron} $\quad B_{air} = B_{iron}$ $\quad$ X-section A same, Fringing neglected

$B_{iron} = 0.8\text{ T}$ $\quad H_{iron} = 250\text{ A-t/m}$ ANSW

$$\mu_{iron} = \frac{B_{iron}}{H_{iron}} = \frac{0.8\text{ wb/m}^2}{250\text{ At/m}}$$

$\mu_{iron} = 0.0032\text{ wb/A-t-m}$

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Magnetic Circuit –Example 2

Example Solution (continued)
Include effects of iron core

$$\mathcal{R}_{air} = \frac{L_{ag}}{\mu_0 A}$$

$$\mathcal{R}_{air} = \frac{0.005\text{ m}}{4\pi \times 10^{-7}\text{ wb/A-t-m}(0.1\text{ m}^2)}$$

$\mathcal{R}_{air} = 39789\text{ A-t/wb}$ ANSW

$$\mathcal{R}_{iron} = \frac{L_{iron}}{\mu_{iron} A} = \frac{0.5\text{ m}}{(0.0032\text{ wb/A-t-m})(0.1\text{ m}^2)} = 1563\text{ A-t/wb}$$ Answ

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Magnetic Circuit –Example 2

Example Solution (continued)
Include effects of iron core

$$\Phi = \frac{\mathfrak{F}_{tot}}{\mathfrak{R}_{air} + \mathfrak{R}_{IRON}} \Rightarrow \Phi(\mathfrak{R}_{air} + \mathfrak{R}_{IRON}) = \mathfrak{F}_{tot}$$

$$\mathfrak{F}_{tot} = (0.08\ wb)(39789\ A\text{-}t/wb + 1563\ A\text{-}t/wb) = 3308\ A\text{-}t$$ ANSW

$$\mathfrak{F}_{tot} = NI \text{ so } \frac{\mathfrak{F}_{tot}}{N} = I \qquad \frac{3308}{200} = 16.5\ A$$ ANSW.

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Magnetic/Electric Circuit Analogy

Φ corresponds to I
$\mathfrak{F}$ corresponds to E
$\mathfrak{R}$ corresponds to R

So this gives an "Ohms Law" for magnetic circuits

$$\Phi = \frac{\mathfrak{F}}{\mathfrak{R}}$$

All laws and principles from dc circuits are analogous to magnetic circuits

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Magnetic/Electric Circuit Analogy

Combining Reluctances in series and parallel

$$\mathcal{R}_{series} = \mathcal{R}_1 + \mathcal{R}_2 + \mathcal{R}_3 \ldots + \mathcal{R}_n$$

$$\mathcal{R}_{parallel} = \frac{1}{\left(\frac{1}{\mathcal{R}_1} + \frac{1}{\mathcal{R}_2} + \frac{1}{\mathcal{R}_3} \ldots + \frac{1}{\mathcal{R}_n}\right)}$$

Other rules: Sum of MMFs around loop must be zero (KVL)
Sum of fluxes entering node must equal zero (KCL)

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End Lesson 3: Solving Magnetic Circuits

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