Chapter 12

Magnetism and Magnetic Circuits

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The Nature of a Magnetic Field

- Magnetism
  - Force of attraction or repulsion that acts between magnets and other magnetic materials
- Flux lines
  - Show direction and intensity of this field at all points

The Nature of a Magnetic Field

- Field is strongest at poles
  - Direction is from N to S
- Unlike poles attract
  - Like poles repel

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Ferromagnetic Materials

- Attracted by magnets
  - Provide an easy path for magnetic flux
  - Iron, nickel, cobalt, and their alloys
- Nonmagnetic materials such as plastic, wood, and glass
  - Have no effect on the field

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Electromagnetism

- Many applications of magnetism involve magnetic effects due to electric currents
- Direction of magnetic field may be determined by the Right Hand Rule

Electromagnetism

- Place your right hand around conductor with your thumb in the direction of the current
- Your fingers will point in the direction of the magnetic field
  - This will always be perpendicular to the current

Flux and Flux Density

- Flux, Φ
  - Total number of lines
- Flux density, *B*,
  - Number of lines per unit area
  - Divide total flux passing perpendicularly through an area by the area
- $B = \Phi/A$

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Flux and Flux Density

- Units for magnetic flux are webers (Wb)
- Area is measured in square meters
- Units for flux density
  - Wb/m^2 or teslas (T)
  - 1 tesla = 10 000 gauss
- *B* may also be measured in gauss
- We will work only with teslas

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Magnetic Circuits

- Practical applications
  - Use structures to guide and shape magnetic flux
  - Called magnetic circuits
- Magnetic circuit guides flux to an air gap
  - This provides field for the voice coil

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Magnetic Circuits

- Playback heads on tape recorders
  - VCRs and disk drives pick up the varying magnetic field and convert it to voltage

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Air Gaps, Fringing, and Laminated Cores

- Circuits with air gaps may cause fringing
- Correction
  - Increase each cross-sectional dimension of gap by the size of the gap
- Many applications use laminated cores
- Effective area is not as large as actual area

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Series Elements and Parallel Elements

- Magnetic circuits may have sections of different materials
  - Cast iron, sheet steel, and an air gap
- For this circuit, flux is the same in all sections
  - Circuit is a series magnetic circuit

Series Elements and Parallel Elements

- A magnetic circuit may have elements in parallel
  - Sum of fluxes entering a junction is equal to the sum leaving
- Similar to series/parallel electric circuits

Magnetic Circuits with dc Excitation

- Current through a coil creates magnetic flux
- Magnetomotive Force (MMF) $\Im = NI$
- N is the number of turns of the coil
- Opposition of the circuit
  - Reluctance $\Re = \ell/\mu A$

Magnetic Circuits with dc Excitation

- Ohm's Law for magnetic circuits:
  - $\phi = \Im/\Re$
- Useful analogy but not a practical solution method

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Magnetic Field Intensity

- Magnetic field strength
  - H, is the magnetomotive force (mmf) per unit length
- $H = \Im/\ell = NI/\ell$
- Units are Ampere•turns/meter
- $N \bullet I = H \bullet \ell$

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Relationship Between *B* and *H*

- *B* and *H*
  - Related by the equation $B = \mu H$
    - Where μ (Greek letter mu) is the permeability of the core
- Permeability
  - Measure for establishing flux in a material

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Relationship Between *B* and *H*

- The larger the value of μ
  - The larger flux density for a given *H*
- *H* is proportional to *I*
  - The larger the value of μ, the larger the flux density for a given circuit

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Ampere's Circuital Law

- Algebraic sum of mmfs around a closed loop in a magnetic circuit
  - Zero: $\Sigma\Im = 0$
  - Similar to KVL
  - Since $\Im = NI$, $\Sigma NI = \Sigma H\ell$
  - $NI - H_{\text{iron}}\ell_{\text{iron}} - H_{\text{steel}}\ell_{\text{steel}} - H_g\ell_g = 0$

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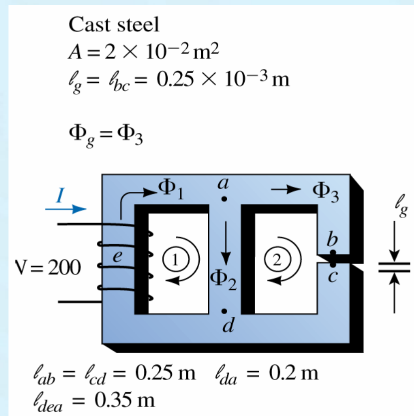
Series Magnetic Circuits

- Solve a circuit where Φ is known
  - First compute B using Φ/A
  - Determine H for each magnetic section from B-H curves
  - Compute NI using Ampere's circuital law
  - Use computed NI to determine coil current or turns as required

Series-Parallel Magnetic Circuits

- Use sum of fluxes principle and Ampere's Law
- Find *B* and *H* for each section
- Then use Ampere's Law



Series Magnetic Circuits

- Solve directly
  - *NI* and required to find Φ, for circuits with one material
  - For two or more substances
    - Cannot calculate either Φ or *H* without knowing the other

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Series Magnetic Circuits

- Trial and error
  - Taking a guess at the flux to compute *NI*
  - Compare this against the given *NI*

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Forces Due to an Electromagnet

- Electromagnets
  - Relays, doorbells, lifting magnets, etc.
- Force computed from flux density, the gap area, and the permeability

$$F = \frac{B_g^2 A_g}{2\mu_0}$$

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Properties of Magnetic Materials

- Atoms produce small, atomic-level magnetic fields
- For nonmagnetic materials, these fields are randomly arranged

Properties of Magnetic Materials

- For ferromagnetic materials
  - Fields do not cancel, but instead form into domains
- If the domains in a material line up, the material is magnetized

Magnetizing a Specimen

- Current passed through it causes domains to line up
- If all fields line up, material is saturated
- If current is turned off, material will retain some residual magnetism

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Magnetizing a Specimen

- Turning off current does not demagnetize the material
  - Some other method must be used
- Effect is called Hysteresis

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Measuring Magnetic Fields

- Hall effect
  - Use when a piece of metal is placed in a magnetic fields
  - Small voltage develops across it
- Fixed current
  - Hall voltage is proportional to the magnetic field strength *B*

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Measuring Magnetic Fields

- Fixed current
  - Hall voltage is proportional to the magnetic field strength *B*.
- Direction of the field may be determined by the right-hand rule

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