Block 18 — Magnetic Flux and Induction

Student Group

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Block 18 — Magnetic Circuits and Inductance

Learning objectives

After this 90-minute block, you can

- …

Preparation at Home

Well, again

- read through the present chapter and write down anything you did not understand.
- Also here, there are some clips for more clarification under 'Embedded resources' (check the text above/below, sometimes only part of the clip is interesting).

For checking your understanding please do the following exercises:

- …

90-minute plan

1. Warm-up (x min):
   1. ….
2. Core concepts & derivations (x min):
   1. …
3. Practice (x min): …
4. Wrap-up (x min): Summary box; common pitfalls checklist.

Conceptual overview

1. …

Core content

…

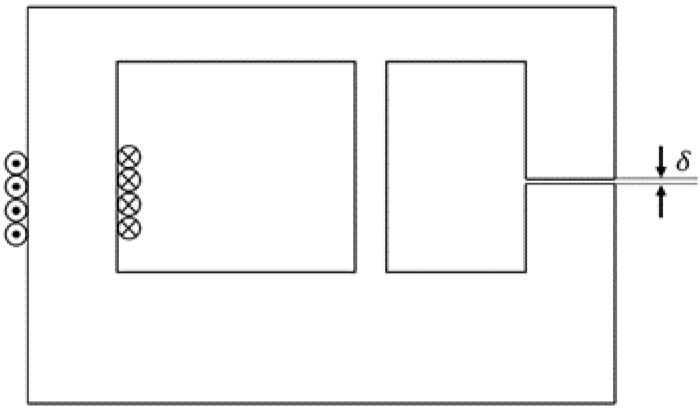
Common pitfalls

- …

Exercises

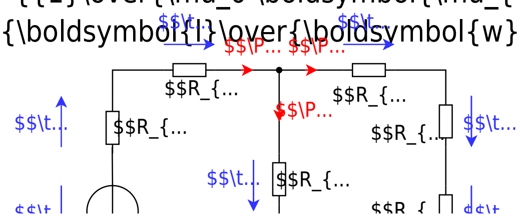
Exercise E10 Magnetic Circuit
(written test, approx. 7 % of a 120-minute written test, SS2022)

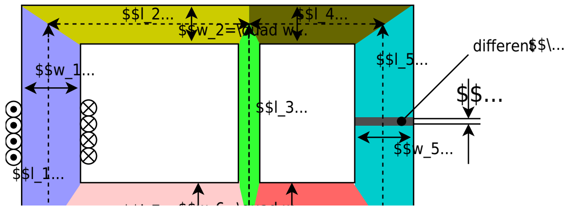
The magnetic setup below shall be given. Draw the equivalent magnetic circuit to represent the setup fully. Name all the necessary magnetic resistances, fluxes, and voltages.
Result
The components shall be designed in such a way, that the magnetic resistance is constant in it.
Formulas are not necessary.



Path

Watch for parts of the magnetic circuit, where the width and material are constant. These parts represent the magnetic resistors which have to be calculated individually. Be aware, that every junction creates a branch with a new resistor, like for an electrical circuit - there must be a node on each “diversion”. \begin{align*} R_{\rm m} = {{1}\over{\mu_0 \boldsymbol{\mu_{\rm r}}} }{\boldsymbol{l}}\over{\boldsymbol{w}\cdot h}} \end{align*}





Exercise E10 Magnetic Circuit
(written test, approx. 9 % of a 120-minute written test, SS2024)

A toroidal core (ferrite, $\mu_{\rm r}=900$) has a cross-sectional area of $A=300 ~\rm mm^2$ and an average circumference of $l=3 ~\rm dm$.

2. Calculate the magnetic resistance $R_{\rm m}$ of the core.

Result

Path

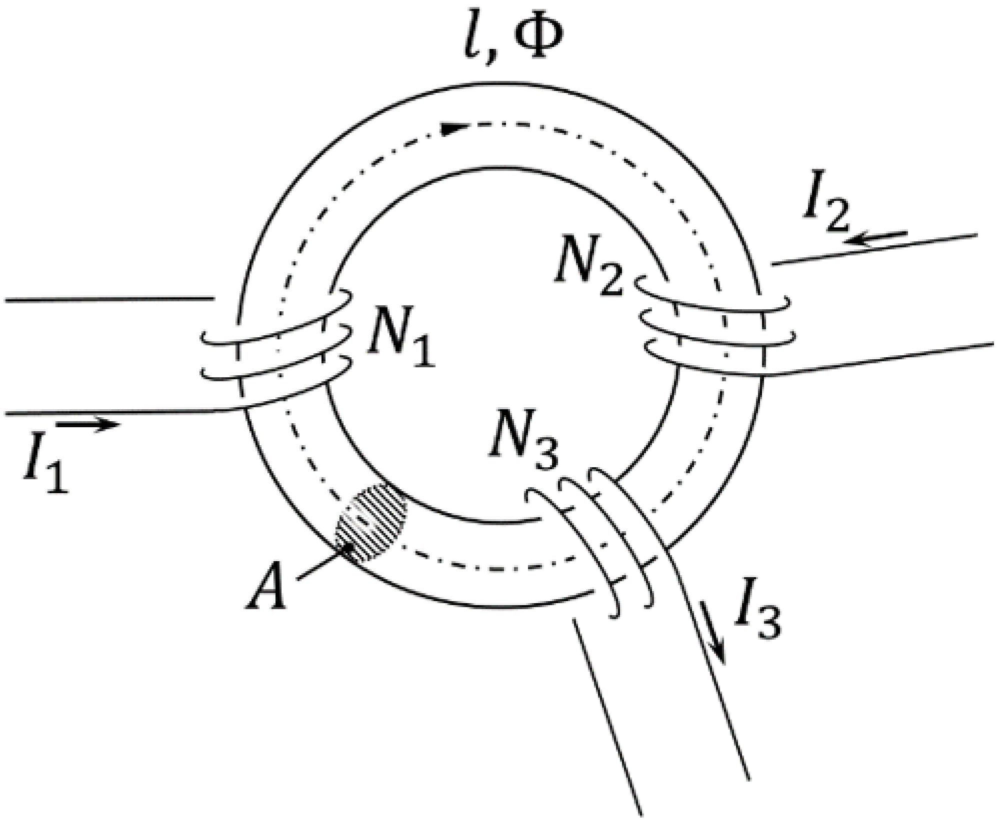
$\Phi = 67.8 ~\rm \mu Vs$

$R_{\rm m} = 0.884 \cdot 10^{6} \rm {{1}\over{H}} $

First we have to calculate the resulting magnetic voltage based on the sources: \begin{align*} \theta_{\rm R} &= \theta_1 + \theta_2 - \theta_3 \\ &= I_1 \cdot N_1 + I_2 \cdot N_2 - I_3 \cdot N_3 \\ &= 3 ~\rm A \cdot 20 ... \\ &= -60~\rm A \\ \end{align*}

The formula of the magnetic resistance is: \begin{align*} R_{\rm m} &= {{1}\over{\mu_0 \mu_{\rm r}}} \cdot {{l}\over{A}} \\ &= {{1}\over{4\pi \cdot 10^{-7} \rm Vs/Am \cdot 900}} \cdot {{3 \cdot 10^{-1} ~\rm m}\over{300 \cdot 10^{-6} ~\rm m^2}} \\ &= 0.884193... \cdot 10^{6} \rm {{1}\over{H}} \end{align*}

To get the flux Φ, the Hopkinson's Law can be applied - similar to the Ohm's Law: \begin{align*} \Phi &= {{\theta_{\rm R} }\over {R_{\rm m}}} \\ &= {{-60~\rm A }\over { 0.884 \cdot 10^{6} \rm {{1}\over{H}} }} \\ &= 67.8 ... \cdot 10^{-6} { \rm A \cdot H} \\ &= 67.8 ... ~\rm \mu Wb \\ &= 67.8 ... ~\rm \mu Vs \\ \end{align*}



On the core, there are three coils with:

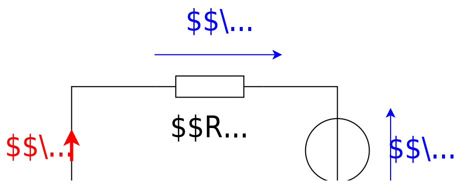
- Coil 1: $N_1 = 1200$, $I_1=100 ~\rm mA$
- Coil 2: $N_2 = 33 $, $I_2= 3 ~\rm A$
- Coil 3: $N_3 = 270 $, $I_3=0.3 ~\rm A$

Refer to the drawing for the direction of the windings, current, and flux!

1. Draw the equivalent magnetic circuit that fully represents the setup.
Name all the necessary magnetic resistances, fluxes, and voltages.

Result

- Since the material, and diameter of the core is constant, one can directly simplify the magnetic resistor into a single $R_\rm m$.
- For the orientation of the magnetic voltages θ_1, θ_2, and θ_3, the orientation of the coils and the direction of the current has to be taken into account by the right-hand rule.
- There is only one flux Φ
- The magnetic voltages are antiparallel to the flux for sources and parallel for the load.



Exercise E1 Cylindrical Coil
(written test, approx. 6 % of a 120-minute written test, SS2021)

A cylindrical coil with the following information is given:

- Length $l = 30 {~\rm cm}$,
- Winding diameter $d = 390 {~\rm mm}$,
- Number of windings $N = 240$,
- Current in the conductor $I = 500 {~\rm mA}$,
- Material inside: Air
- $\mu_0 = 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}}$

The proportion of the magnetic voltage outside the coil can be neglected. Determine the following for the inside of the coil:

a) the magnetic field strength (2 points)

Path

Result

b) the magnetic flux density (2 points)

Path

The magnetic flux density is given as $B = \mu_0 \mu_{\rm r} \cdot H$:

Putting in the numbers: \begin{align*} B &= 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}} \cdot 400 ~\rm {{A}\over{m}} \\ &= 0.0005026... {{\rm Vs}\over{\rm m^2}} \end{align*}

Result

c) the magnetic flux (2 points)

Path

The magnetic flux is given as \begin{align*} \Phi = B \cdot A \end{align*}

Since the coil is cylindrical, the cross-sectional area is given as: \begin{align*} A = \pi r^2 = \pi \left({{d}\over{2}} \right)^2 \end{align*}

Therefore: \begin{align*} \Phi &= B \cdot \pi \left({{d}\over{2}} \right)^2 \end{align*}

Result

Putting in the numbers: \begin{align*} \Phi &= 0.0005026... {{\rm Vs}\over{\rm m^2}} \cdot \pi \left({{0.39{\rm m}}\over{2}} \right)^2 \\ &= 0.00006004... {\rm Vs} \end{align*}

\begin{align*} H &= {{N \cdot I}\over{l}} = {{w \cdot I}\over{l}} \end{align*}

Putting in the numbers: \begin{align*} H &= {{240 \cdot 0.5 {~\rm A}}\over{0.3 {~\rm m}}} \end{align*}

Embedded resources

Explanation (video): …