

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

For this and the following chapter the online Book 'DC Electrical Circuit Analysis - A Practical Approach' is strongly recommended as a reference. In detail this is chapter [10.3 Magnetic Circuits](#)

In the previous chapters, we got accustomed to the magnetic field. During this path, some similarities

from the magnetic field to the electric circuit appeared (see [figure 1](#)).

Fig. 1: Similarities magnetic Circuit vs electric Circuit

In this chapter, we will investigate how far we have come with such an analogy and where it can be practically applied.

Basics for Linear Magnetic Circuits

For the upcoming calculations, the following assumptions are made

1. The relationship between B and H is linear: $B = \mu \cdot H$
This is a good estimation when the magnetic field strength lays well below saturation
2. There is no stray field leaking out of the magnetic field conducting material.

3. The fields inside of airgaps are homogeneous. This is true for small air gaps.

One can calculate a lot of simple magnetic circuits when these assumptions are applied and focusing on the average field line are applied.

Fig. 3: Simplifications and Linearization

over to the airgap must be $\Phi_{\text{airgap}} = \Phi_{\text{core}} = \text{const.}$ This can also be seen in [figure ## \(1\)](#).

A different view of this is the closed surface \vec{A} ([figure ## \(2\)](#)): Based on the examination in [Recap of magnetic Field](#) we know that the flux into the volume must be equal the flux out of the volume, or $\Phi_{\text{m}} = \iint_{\vec{A}} \vec{B} \cdot d\vec{A} = 0$.

The relationship $B = \mu \cdot H$, and $\mu_{\text{core}} \gg \mu_{\text{airgap}}$ lead to the fact that the H -Field must be much stronger within the airgap ([figure ## \(3\)](#)).

Fig. ##: B- and H-field along the ferrite core



Common pitfalls

- ...

Exercises

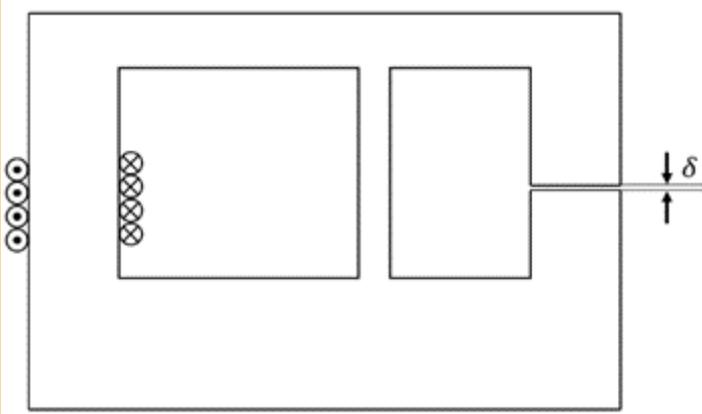
Exercise E7 Magnetic Circuit

(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.

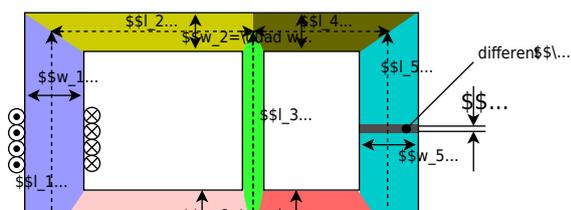
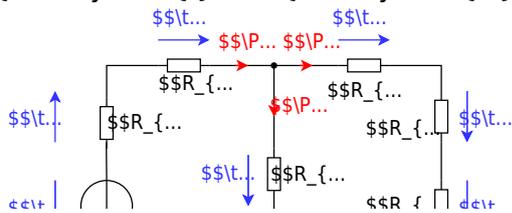
The components shall be designed in such a way, that the magnetic resistance is constant in it.

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".

$$R_{\text{m}} = \frac{l}{\mu_0 \mu_r w h}$$


Exercise E14 Magnetic Circuit
(written test, approx. 9 % of a 120-minute written test, SS2024)

1. Calculate the magnetic resistance R_m for the cross-sectional area of $A=300 \text{ mm}^2$ with an average circumference of $l=3 \text{ dm}$.

Path

l, Φ

$R_m = 0.884 \cdot 10^6 \frac{\text{m}}{\text{Vs}}$

First we have to calculate the magnetic resistance R_m based on the sources:
 $R_m = \frac{l}{\mu \cdot A} = \frac{3 \text{ dm}}{4\pi \cdot 10^{-7} \text{ Vs/A} \cdot 300 \text{ mm}^2} = 0.884 \cdot 10^6 \frac{\text{m}}{\text{Vs}}$

To get the flux Φ , the Hopkinson's Law can be applied - similar to the Ohm's Law:
 $\Phi = \frac{\sum N_i I_i}{R_m} = \frac{1200 \cdot 100 \text{ mA} + 33 \cdot 3 \text{ A} + 270 \cdot 0.3 \text{ A}}{0.884 \cdot 10^6 \frac{\text{m}}{\text{Vs}}} = 67.8 \cdot 10^{-6} \text{ Vs} = 67.8 \cdot 10^{-6} \text{ Vs}$

On the core, there are three coils with:

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

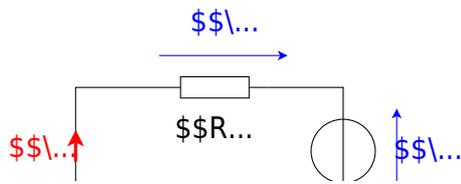
Refer to the drawing for the direction of the windings, current, and flux!

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_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 E4 Cylindrical Coil

(written test, approx. 6 % of a 120-minute written test, SS2021)

A) The magnetic flux (2 points) Information is given:

Result

- Length $l = 30 \text{ cm}$,

Path • Winding diameter $d = 390 \text{ mm}$,

- Number of windings $N = 240$,

• Current through the conductor $I = 500 \text{ mA}$.

- Material inside: Air

• $\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$

The magnetic field strength is $B = \mu_0 \mu_r H$:

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

$$\Phi = B \cdot A \quad \text{and} \quad H = \frac{I \cdot N}{l}$$

- a) Determine the magnetic field strength (2 points)
- $$B = \mu_0 \cdot I \cdot N / l = 4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 500 \cdot 240 / 0.3 \text{ m} = 0.0005026 \text{ Vs/m}^2$$

$$A = \pi r^2 = \pi \left(\frac{d}{2} \right)^2$$

Path

$$\Phi = B \cdot \pi \left(\frac{d}{2} \right)^2$$

`\end{align*}`

Putting in the numbers:
$$\Phi = \frac{0.0005026}{0.00006004...} \cdot \pi \left(\frac{0.39 \text{ m}}{2} \right)^2 \quad \&= 0.00006004... \text{ m}^2$$

Putting in the numbers:
$$H = \frac{240 \cdot 0.5 \text{ A}}{0.3 \text{ m}}$$

Embedded resources

Explanation (video): ...

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