

Block 19 — Magnetic Circuits and Inductance

Student Group

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Block 19 — Electromagnetic Induction and Energy

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 E14 Self-Induction

(written test, approx. 8 % of a 120-minute written test, SS2024)

2. Determine the time of a 30 V voltage in a coil with a radius of 12 cm and 500 turns. The current through the coil changes linearly from 0 A to 3 A in 0.02 ms. The arrangement is located in air ($\mu_r = 1$).
 Path

$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$ $U_{\text{ind}} = 1.32 \text{ mV}$
<p>.. Calculate the (self-)inductance of the coil. For the linear change of the current the formula of the induced voltage can also be linearized: $u_{\text{ind}} = -L \cdot \frac{di}{dt} \quad \Leftrightarrow \quad L = - \frac{u_{\text{ind}} \cdot dt}{di} = - \frac{1.32 \cdot 10^{-3} \text{ V} \cdot 0.02 \cdot 10^{-3} \text{ s}}{3 \text{ A} - 0 \text{ A}} = 8.8 \cdot 10^{-7} \text{ H}$</p>
<p>The formula for the induction of a long coil is: $L = \mu_0 \cdot \mu_r \cdot N^2 \cdot \frac{A}{l} = 4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot (500)^2 \cdot \frac{\pi \cdot (0.12 \text{ m})^2}{2 \cdot 0.12 \text{ m}} = 1.32 \cdot 10^{-3} \text{ H}$</p>

Exercise E8 Self Induction

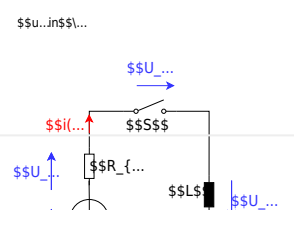
(written test, approx. 8 % of a 120-minute written test, SS2022)

2. What is the maximum magnitude of the voltage U_{ind} which the circuit breaker has to withstand which is fused with a circuit breaker. Sketch the breaker part and its $i(t)$ with a current of 63 A. The induced current is reduced linearly down to 0 A within 1 ms.
 (The inner resistance of the motor shall be neglected.)
 Path

$u_{\text{ind}}(t) = 3150 \text{ V}$
<p>.. Draw the circuit (the circuit breaker can be drawn as a switch), with all voltage and current arrows.</p>
<p>For the maximum voltage on the circuit breaker one has to consider the following:</p>
<p>Result</p> <ul style="list-style-type: none"> external voltage of the voltage source U_{ext} voltage $u_{\text{ind}}(t)$ induced by the change of the current
<p>The first one is not given in the exercise, and therefore not considered here.</p>

The induced voltage can be calculated by linearizing the following:
$$u_{\text{ind}}(t) = -L \frac{di}{dt} \rightarrow u_{\text{ind}}(t) = -L \frac{\Delta i}{\Delta t}$$

With the given details:
$$u_{\text{ind}}(t) = -L \frac{0 - I}{t_1 - t_0} = 50 \cdot 10^{-6} \text{ H} \frac{63 \text{ A}}{1 \cdot 10^{-6} \text{ s}} = 3150 \frac{\text{Vs}}{\text{A}} \cdot \frac{\text{A}}{\text{s}}$$

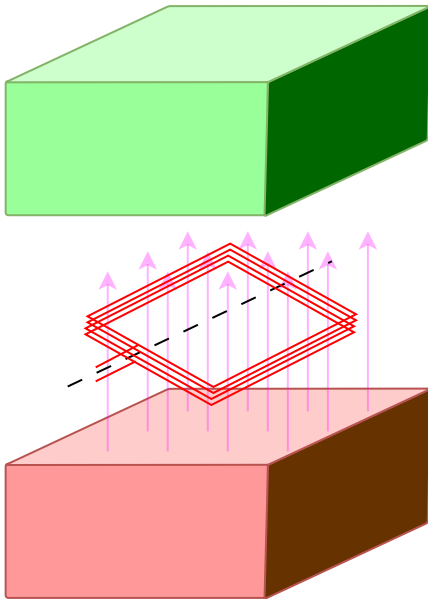


Exercise E1 Coil in a magnetic Field
(written test, approx. 4 % of a 120-minute written test, SS2021)

A coil with $n = 300$ turns and a cross-sectional area $A = 600 \text{ cm}^2$ is located in a homogeneous magnetic field. The rotation of the coil causes a sinusoidal change in the magnetic field in the coil with the frequency $f = 80 \text{ Hz}$.

The maximum value of the magnetic flux density in the coil is $\hat{B} = 2 \cdot 10^{-6} \text{ Vs/cm}^2$.

$$u_{\text{ind}} = -181 \frac{\text{V}}{\text{s}} \cdot \cos\left(503 \frac{1}{\text{s}} \cdot t\right)$$



Derive the formula for the voltage induced in the coil and calculate the voltage amplitude.

Path

The induced voltage u_{ind} is given by:

$$\begin{aligned} u_{\text{ind}} &= - \frac{d\Phi(t)}{dt} \quad \&= - n \frac{d\Phi(t)}{dt} \end{aligned}$$

With $\Phi(t) = B(t) \cdot A$, where A is the constant area of a single winding and $B(t)$ is the changing field through this winding.

Due to the rotation, the field changes as:

$$\begin{aligned} B(t) &= \hat{B} \cdot \sin(\omega t + \varphi) \quad \&= \hat{B} \cdot \sin(2\pi f \cdot t + \varphi) \end{aligned}$$

$$\begin{aligned} \text{This leads to: } u_{\text{ind}} &= - n \frac{d}{dt} A \hat{B} \cdot \sin(2\pi f \cdot t + \varphi) \quad \&= - n \cdot A \hat{B} \cdot 2\pi f \cdot \cos(2\pi f \cdot t + \varphi) \end{aligned}$$

$$\begin{aligned} \text{The absolute value of the factor in front of the } \cos & \text{ is the maximum induced voltage } \hat{U}_{\text{ind}}: \\ \hat{U}_{\text{ind}} &= n \cdot A \hat{B} \cdot 2\pi f \quad \&= 300 \cdot 0.06 \text{ m}^2 \cdot 2 \cdot 10^{-2} \text{ s}^{-1} \cdot \frac{\text{Vs}}{\text{m}^2} \cdot 2\pi \cdot 80 \text{ s}^{-1} \quad \&= 180.95... \text{ V} \\ & \quad \&= 180.95... \text{ V} \end{aligned}$$

Exercise E10 effect of induction
(written test, approx. 5 % of a 120-minute written test, SS2021)

A single conductor loop is penetrated by a changing magnetic flux.

The following figure shows the variation of the flux $\Phi(t)$ over time.

Calculate the variation of the induced voltage $u_{\text{ind}}(t)$ over time and draw it in a separate diagram.

\$\$u_{\text{ind}}(t) = - \frac{d\Phi(t)}{dt}\$\$

\$\$u_{\text{ind}}(t) = - \frac{d\Phi(t)}{dt}\$\$

Path

Based on Faraday's Law of Induction the induced voltage is given by:
$$u_{\text{ind}} = - \frac{d\Phi(t)}{dt} = - \frac{d}{dt} \int_{n=1}^n \mathbf{B} \cdot d\mathbf{s}$$

For a linear function, the derivative can be substituted by Deltas ($\frac{d}{dt} \rightarrow \frac{\Delta}{\Delta t}$):

$$u_{\text{ind}} = - \frac{\Delta \Phi(t)}{\Delta t} = - \frac{\Phi(t_{n+1}) - \Phi(t_n)}{t_{n+1} - t_n}$$

For a piece-wise linear function, the induced voltage can be calculated for each interval.

Here, there are 5 different intervals - in the following called I to V from left to right:

...

- For the intervals I , III , and V , the flux $\Phi(t)$ is constant. Therefore, $\Delta \Phi(t) = 0$ and $u_{\text{ind}}(t) = 0$.

\$\$\dots\$\$

- For the interval Δt :
 - The change in the flux is: $\Delta \Phi(t) = 1.5 \cdot 10^{-4} \text{ Vs} - 4.5 \cdot 10^{-4} \text{ Vs} = -3.0 \cdot 10^{-4} \text{ Vs}$
 - The time span is: 0.2 s
 - Conclusively, the induced voltage is: $u_{\text{ind}}(t) = + \frac{3.0 \cdot 10^{-4} \text{ Vs}}{0.2 \text{ s}} = 1.5 \text{ mV}$

- For the interval IV :
 - The change in the flux is: $\Delta \Phi(t) = 0 \cdot 10^{-4} \text{ Vs} - 1.5 \cdot 10^{-4} \text{ Vs} = -1.5 \cdot 10^{-4} \text{ Vs}$
 - The time span is: 0.2 s
 - Conclusively, the induced voltage is: $u_{\text{ind}}(t) = + \frac{1.5 \cdot 10^{-4} \text{ Vs}}{0.2 \text{ s}} = 0.75 \text{ mV}$

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Embedded resources

Explanation (video): ...

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