

Exam Summer Semester 2021

Student Group

First Name	Surname	Matrikel Nr.

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Exam Summer Semester 2021

Additional permitted Aids

- non-programmable calculator,
- formulary (4 one-sided DIN A4 pages)

Hits

- The duration of the exam is 120 min.
- Attempts to cheat will lead to exclusion and failure of the exam.
- Withdrawal is no longer possible after these exam has been handed out.
- Please write down intermediate calculations and results on the assignment sheet. (when more space is needed also on the reverse side. In this case: Mark it clearly).
- Always use units in the calculation.
- Use a document-proof, non-red pen.
- Sub-tasks, which are independently solvable are marked with: (independent)
- Sub-tasks, which are hard are marked with: (hard)

Only EEE1-relevant Part

This part is only for about 65 minutes !

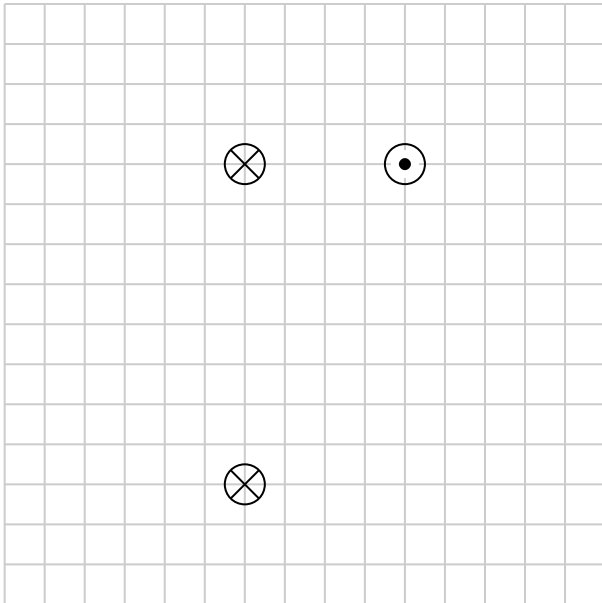
Exercise E2 Magnetic Field Lines

(written test, approx. 4 % of a 120-minute written test, SS2021)

Several parallel conductors are projecting out of the plane.

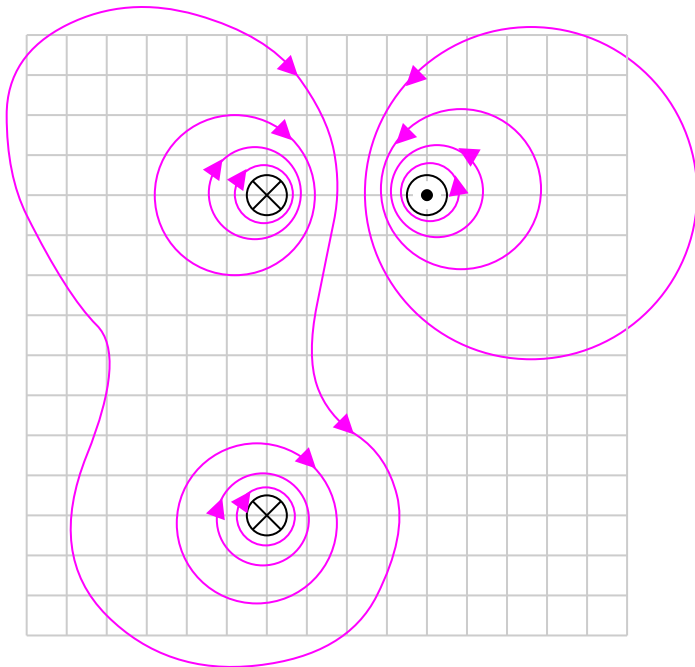
The same current I flows through all the conductors in different directions (see image below).

Sketch at least 10 field lines of the magnetic field strength $\vec{H}$ in such a way that the different properties of the field lines (e.g. direction and density) can be seen.



Result

- high density of field lines near the conductors
- direction of the field lines given by the right-hand rule
- magnetic field has closed field lines
- resulting field given by superposition of field lines



Exercise E3 Magnetic Flux Density**(written test, approx. 6 % of a 120-minute written test, SS2021)**

A) The circuit is operated for a few days in the laboratory. A current of $I = 100 \text{ A}$ with an amplitude of $\hat{I} = 100 \text{ A}$ is operated.

Now stand next to it and think about whether this value is credible? (3 points, independent)

The figure below shows the top view of the laboratory with the supply line between A and B.

Path B = 0.2 m

$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$, $\mu_r = 1$

The formula for the magnetic field strength can be rearranged:
$$H = \frac{I}{2\pi \cdot r} \quad r = \frac{I}{2\pi \cdot H}$$

Again, the magnetic flux density B is given as: $B = \mu_0 \mu_r H$

Therefore:
$$r = \frac{\mu_0 \mu_r I}{2\pi \cdot B} = \frac{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 100 \text{ A}}{2\pi \cdot 100 \cdot 10^{-6} \text{ T}} = 0.2 \text{ m}$$

a) What is the highest magnetic flux density through the line in your body? (3 points)

Path

The magnetic field strength for a conducting wire is given as:

$$\begin{aligned} H &= \frac{I}{2\pi \cdot r} \end{aligned}$$

The magnetic flux density B is given as: $B = \mu_0 \mu_r H$

Here, the maximum current is $\hat{I} = 100 \text{ A}$ and the distance to the cable is $r = \sqrt{(0.1 \text{ m})^2 + (0.4 \text{ m})^2} = 0.412... \text{ m}$.

$$\begin{aligned} B &= 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1 \\ &\cdot \frac{100 \text{ A}}{2\pi \cdot 0.412... \text{ m}} \end{aligned}$$

Exercise E4 Toroidal Coil

(written test, approx. 5 % of a 120-minute written test, SS2021)

A magnetic field with a flux density of at least 50 mT is to be achieved in a ring-shaped coil (toroidal coil).

The coil has 60 turns, wound around soft iron with $\mu_r = 1200$.

The average field line length in the coil should be $l = 12 \text{ cm}$.

$$B = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1200 \cdot \frac{60}{12 \cdot 10^{-2} \text{ m}}$$



What is the minimum current that must flow through a single winding?

Path

The magnetic field strength of a toroidal coil is given as:

$$\begin{aligned} H &= \frac{N \cdot I}{l} \end{aligned}$$

Based on the flux density the magnetic field strength can be derived by $B = \mu_0 \mu_{\text{r}} H$.

By this, the formula can be rearranged:

```
\begin{align*} H &= \left\{ \frac{N \cdot I}{l} \right\} \parallel \left\{ \frac{B}{\mu_0 \mu_r} \right\} &= \\ \left\{ \frac{N \cdot I}{l} \right\} \parallel I &= \left\{ \frac{B \cdot l}{\mu_0 \mu_r \cdot N} \right\} \\ \end{align*}
```

Putting in the numbers:
$$I = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \cdot \frac{V_s}{V_m} \cdot \frac{1'200 \cdot 60}} = 0.6631... \frac{\text{T} \cdot \text{m}}{\frac{V_s}{V_m}} = 0.6631... \frac{V_s}{V_m} = 0.6631... \text{ A}$$

Exercise E6 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 $I = 500 \text{ mA}$ in the inductor $I = 500 \text{ mA}$,

- Material inside: Air

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

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

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

$$\Phi = B \cdot A = \mu_0 \mu_r \cdot H \cdot A$$

a) the magnetic field strength (2 points) Putting in the numbers:
$$B = \mu_0 \cdot \frac{N \cdot I}{l} = 4\pi \cdot 10^{-7} \cdot \frac{240 \cdot 0.5}{0.3} = 0.0005026... \frac{\text{Vs}}{\text{m}^2}$$

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

Path

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

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

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

Exercise E8 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) = \dots

\$\$\dots

Path

Based on Faraday's Law of Induction the induced voltage is given by:
$$u_{\text{ind}} = - \frac{d\Phi(t)}{dt} = - \frac{d}{dt} \left(\sum_{n=1}^N \Phi_n(t) \right)$$

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:

$\dots$

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

\$\$\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 Δt :
 - 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: $u_{\text{ind}}(t) = + \frac{1.5 \cdot 10^{-4} \text{ Vs}}{0.2 \text{ s}} = 0.75 \text{ mV}$

\$\$\dots\$

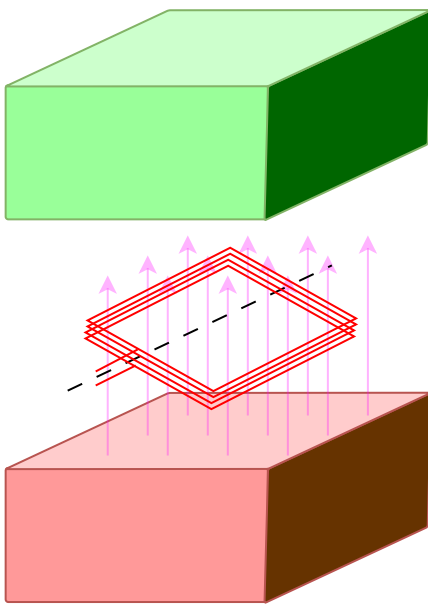
Exercise E9 Coil in a magnetic Field**(written test, approx. 4 % of a 120-minute written test, SS2021)**

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 $\hat{B} = 2 \cdot 10^{-6} \text{ Vs/cm}^2$.

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



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

Path

The induced voltage u_{ind} is given by:

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

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:

$$B(t) = \hat{B} \cdot \sin(\omega t + \varphi) = \hat{B} \cdot \sin(2\pi f t + \varphi)$$

$$u_{\text{ind}} = - n \frac{d}{dt} A \hat{B} \sin(2\pi f t + \varphi) = - n A \hat{B} 2\pi f \cos(2\pi f t + \varphi)$$

The absolute value of the factor in front of the $\cos$ is the maximum induced voltage $\hat{U}_{\text{ind}}$:

$$\hat{U}_{\text{ind}} = n \cdot A \cdot \hat{B} \cdot 2\pi f = 300 \cdot 0.06 \text{ m}^2 \cdot 2 \cdot 10^{-2} \text{ T} \cdot 300 \text{ s}^{-1} = 180.95 \text{ V}$$

$$\frac{U_{\text{eff}}}{U_{\text{eff}}^{\text{max}}} = \frac{1}{\sqrt{2}} \Rightarrow U_{\text{eff}} = \frac{180.95 \text{ V}}{\sqrt{2}} = 127.7 \text{ V}$$

Exercise E1 Magnetic Voltage

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

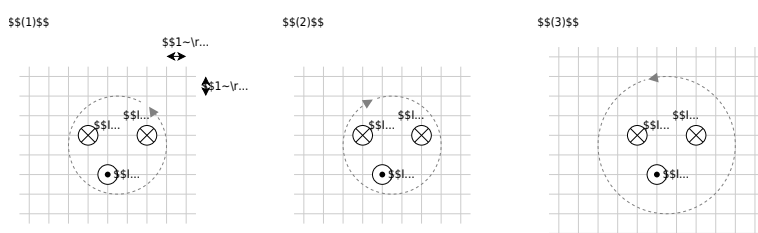
The following images show cross-sections of electrical cables.

Resulted path is shown as a dashed line. The magnetic voltage θ on these paths shall be analyzed.

The following values are given for the currents:

$\theta_1 = -4 \text{ A}$ $\theta_2 = 0 \text{ A}$ $\theta_3 = 1 \text{ A}$ $\theta_4 = 4 \text{ A}$

- $I_3 = 1 \text{ A}$
- $I_4 = 4 \text{ A}$



Specify which magnetic voltages $\theta_{(1)}$, $\theta_{(2)}$, and $\theta_{(3)}$ result.
Note the direction of the path in each case!

Path

For the resulting current the direction of the path has to be considered with the right-hand rule:

- $I_{(1)} = +I_2 - I_1 - I_3 \quad \rightarrow \quad \theta_{(1)} = 2 \text{ A} - 5 \text{ A} - 1 \text{ A}$
- $I_{(2)} = +I_3 + I_4 - I_1 \quad \rightarrow \quad \theta_{(2)} = 1 \text{ A} + 4 \text{ A} - 5 \text{ A}$
- $I_{(3)} = +I_3 - I_4 - I_2 \quad \rightarrow \quad \theta_{(3)} = 1 \text{ A} - 4 \text{ A} - 2 \text{ A}$

Exercise E12 Lorentz Force (hard!)

(written test, approx. 10 % of a 120-minute written test, SS2021)

A) The picture below shows a straight high-voltage line where the direction is shown as the Resultant component of $F = (1200 \text{ N})$ on the resulting force is? (Independent)

A homogeneous geomagnetic field is assumed. The magnetic field strength has a vertical component of $B_v = 40 \text{ } \mu\text{T}$ and a horizontal component of $B_h = 20 \text{ } \mu\text{T}$.

Only 10500 A is perpendicular to $\vec{B}_v$ and to $\vec{B}_h$ and points in the right direction by the right-hand rule.

The picture on the right shows the line (black), the field strength components, and the angle in front and top view for illustration purposes.

- a) Calculate the force that results from the current flow on the entire conductor.
First, calculate the vertical and horizontal components and combine them accordingly.

Path
Top View

Path

The force on the transmission line can be calculated via the Lorentz force

$$\vec{F} = I \cdot (\vec{l} \times \vec{B})$$

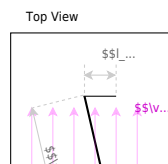
- The horizontal component $\vec{F}_{\text{h}}$ of the force is based on the vertical component $\vec{B}_{\text{v}}$ of the magnetic field.
- The vertical component $\vec{B}_{\text{v}}$ of the magnetic field is not shown in the image but is pointing into the ground.
- Considering the right-hand rule (and the cross product), the vertical field $\vec{B}_{\text{v}}$ has to be perpendicular to $\vec{B}_{\text{h}}$ and to $\vec{l}$. The right-hand rule has to be applied.

The **horizontal component** is given by

$$\begin{aligned} F_{\text{h}} &= l \cdot (l \cdot B_{\text{v}}) \quad \&= 1'200 \text{ A} \cdot 300 \\ &\quad \cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \left\{ \frac{\text{Vs}}{\text{m}^2} \right\} \quad \&= 14'400 \\ &\quad \text{VA} = 14'400 \text{ V} \quad \&= 14'400 \text{ N} \\ \end{aligned}$$

For the **vertical component** the angle α has to be considered.

For the maximum F_{v} the angle α has to be 90° , therefore the $\sin$ has to be used.



$$\begin{aligned} F_{\text{v}} &= l \cdot l \cdot B_{\text{h}} \cdot \sin \alpha \quad \&= 1'200 \\ &\quad \text{A} \cdot 300 \cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \left\{ \frac{\text{Vs}}{\text{m}^2} \right\} \\ &\quad \cdot \sin 20^\circ \quad \&= 2'462.545... \text{ N} \\ \end{aligned}$$

For the **overall force** F the Pythagorean theorem has to be used:

$$\begin{aligned} F &= \sqrt{F_{\text{v}}^2 + F_{\text{h}}^2} \quad \&= \sqrt{(14'400 \text{ N})^2 + (2'462.545... \text{ N})^2} \\ &\quad \&= 14'609.04... \text{ N} \\ \end{aligned}$$

Full Exam

These is the full exam

Full exam

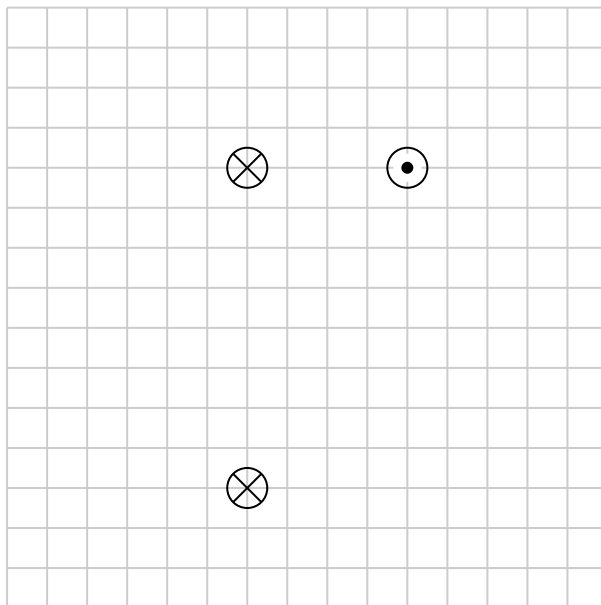
Exercise E2 Magnetic Field Lines

(written test, approx. 4 % of a 120-minute written test, SS2021)

Several parallel conductors are projecting out of the plane.

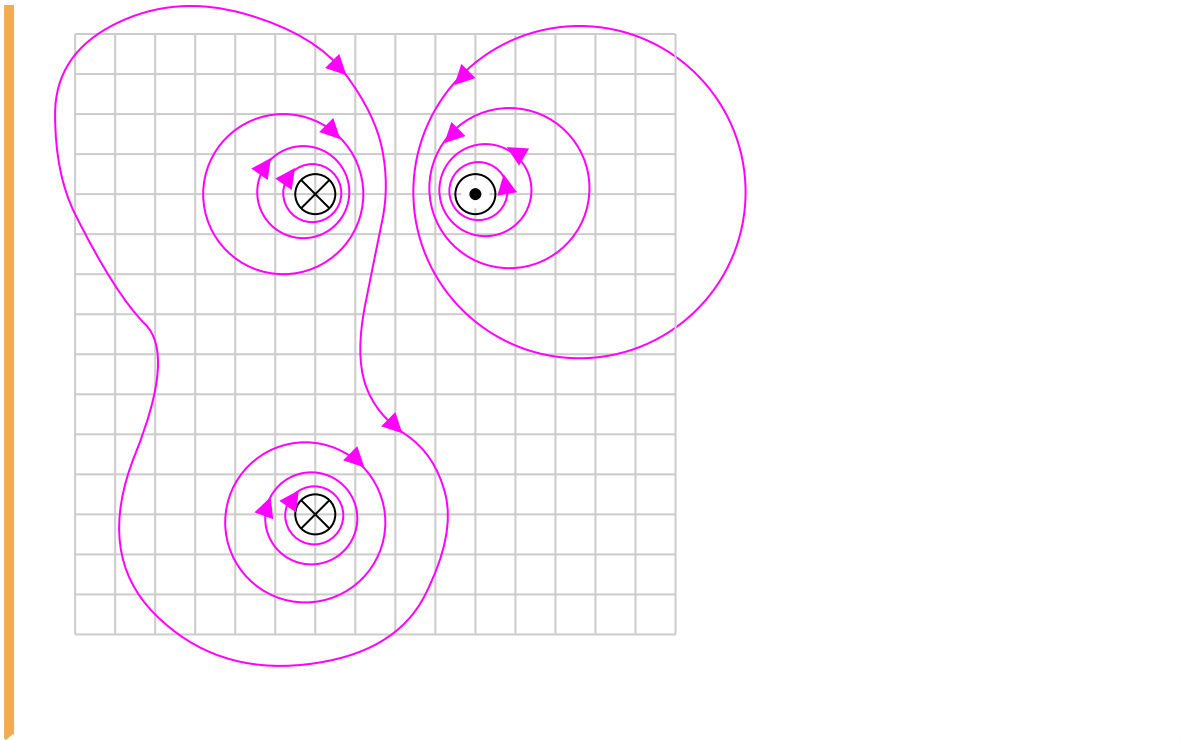
The same current I flows through all the conductors in different directions (see image below).

Sketch at least 10 field lines of the magnetic field strength $\vec{H}$ in such a way that the different properties of the field lines (e.g. direction and density) can be seen.



Result

- high density of field lines near the conductors
- direction of the field lines given by the right-hand rule
- magnetic field has closed field lines
- resulting field given by superposition of field lines



electrical_engineering_and_electronics:task_76ksbc114ylxftfl_with_calculation
magnetostatic, field lines, exam ee2 ss2021

Exercise E3 Magnetic Flux Density

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

A Helmholtz coil is operated for experiments in the laboratory. A series I_0 -current source with an amplitude of $\hat{I} = 100 \text{ A}$ is operated.

Now stand next to it and think about whether its value has exceeded (3 points, independent) about. The figure below shows the top view of the laboratory with the supply line between A and B.

Path $B = 0.2 \text{ m}$

$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$, $\mu_r = 1$

The formula for the magnetic field strength can be rearranged:
$$H = \frac{I}{2\pi \cdot r} \quad \text{or} \quad r = \frac{I}{2\pi \cdot H}$$

Again, the magnetic flux density B is given as: $B = \mu_0 \mu_r H$

Therefore:
$$r = \frac{\mu_0 \mu_r I}{2\pi \cdot B} = \frac{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 100 \text{ A}}{2\pi \cdot 100 \cdot 10^{-6} \text{ T}} = 0.2 \text{ m}$$

a) What is the highest magnetic flux density through the line in your body? (3 points)

Path

The magnetic field strength for a conducting wire is given as:

$$\begin{aligned} H &= \frac{I}{2\pi \cdot r} \end{aligned}$$

The magnetic flux density B is given as: $B = \mu_0 \mu_r H$

Here, the maximum current is $\hat{I} = 100 \text{ A}$ and the distance to the cable is $r = \sqrt{(0.1 \text{ m})^2 + (0.4 \text{ m})^2} = 0.412... \text{ m}$.

$$\begin{aligned} B &= 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1 \cdot \frac{100 \text{ A}}{2\pi \cdot 0.412... \text{ m}} \end{aligned}$$

electrical_engineering_and_electronics:task_ti7loik6aurfewkb_with_calculation
magnetostatic, flux density, exam ee2 ss2021

Exercise E4 Toroidal Coil

(written test, approx. 5 % of a 120-minute written test, SS2021)

A magnetic field with a flux density of at least 50 mT is to be achieved in a ring-shaped coil (toroidal coil).

The coil has 60 turns, wound around soft iron with $\mu_r = 1200$.

The average field line length in the coil should be $l = 12 \text{ cm}$.

Result

$$I = \frac{B \cdot l}{\mu_0 \cdot \mu_r \cdot N} = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 1200 \cdot 60} \approx 1.06 \text{ A}$$

What is the minimum current that must flow through a single winding?

Path

The magnetic field strength of a toroidal coil is given as:

$$H = \frac{N \cdot I}{l}$$

Based on the flux density the magnetic field strength can be derived by $B = \mu_0 \mu_r H$.

By this, the formula can be rearranged:

$$H = \frac{N \cdot I}{l} \quad \parallel \quad B = \mu_0 \mu_r H$$

$$\Rightarrow \frac{N \cdot I}{l} = \frac{B}{\mu_0 \mu_r} \quad \parallel \quad I = \frac{B \cdot l}{\mu_0 \mu_r \cdot N}$$

Putting in the numbers:

$$I = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1200 \cdot 60}$$

$$\Rightarrow I = 0.6631... \frac{\text{T} \cdot \text{m}}{\frac{\text{Vs}}{\text{m}^2} \cdot \text{m}} = 0.6631... \text{ A}$$

[electrical_engineering_and_electronics:task_w3m7fo4hjzhkogw_with_calculation_magnetostatic, flux density, coil, toroid, exam ee2 ss2021](#)

Exercise E6 Cylindrical Coil

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

A) The magnetic flux density B is given:

Result

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

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

- Number of windings $N = 240$,
- Current through the inductor $I = 500 \text{ mA}$,
- Material inside: Air

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

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

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

$$B = \mu_0 \mu_r H$$

Putting in the numbers:

$$B = \mu_0 \mu_r \frac{N \cdot I}{l} = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot \frac{240 \cdot 0.5 \text{ A}}{0.3 \text{ m}} = 0.0005026... \frac{\text{Vs}}{\text{m}^2}$$

Path

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

\end{align*}

Putting in the numbers: \begin{align*} \Phi &= 0.0005026 \over{\rm V} \over{\rm m} \over{\rm m^2}} \cdot \pi \left(\frac{0.39 \rm m}{2} \right)^2 \quad \&= 0.00006004... \\ \text{Putting in the numbers: } H &= \frac{240 \cdot 0.5 \rm A}{0.3 \rm m} \end{align*}

electrical_engineering_and_electronics:task_0j7accfimmemytq9_with_calculation
magnetostatic, flux density, magnetic field strength, coil, flux, exam ee2 ss2021

Exercise E8 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) = \dots

\$\$\dots

Path

Based on Faraday's Law of Induction the induced voltage is given by:

$$u_{\text{ind}} = - \frac{d}{dt} \Psi(t) \\ \bigg|_{n=1} = - \frac{d}{dt} \Phi(t)$$

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

$$\begin{aligned} u_{\mathrm{ind}} &= - \left\{ \frac{\Delta \Phi(t)}{\Delta t} \right\} = - \left\{ \frac{\Phi(t_{\mathrm{n}+1}) - \Phi(t_{\mathrm{n}})}{t_{\mathrm{n}+1} - t_{\mathrm{n}}} \right\} \end{aligned}$$

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:

$\dots$

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

\$\$\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: $u_{\text{ind}}(t) = + \frac{1.5 \cdot 10^{-4} \text{ Vs}}{0.2 \text{ s}} = 0.75 \text{ mV}$

\$\$\dots in \$\$\dots

electrical_engineering_and_electronics:task_ludzwiuhjxitz85b_with_calculation
induction, flux, induced voltage, exam ee2 ss2021

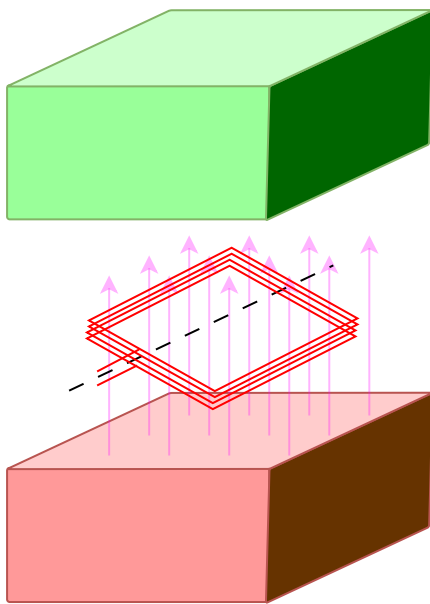
Exercise E9 Coil in a magnetic Field**(written test, approx. 4 % of a 120-minute written test, SS2021)**

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 $\hat{B} = 2 \text{ V} \cdot \text{s} / \text{cm}^2$.

$$u_{\text{ind}}(t) = 181 \text{ V} \cdot \cos(503 t)$$



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

Path

The induced voltage u_{ind} is given by:

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

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:

$$B(t) = \hat{B} \cdot \sin(\omega t + \varphi) = \hat{B} \cdot \sin(2\pi f \cdot t + \varphi)$$

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

$$\cos(2\pi \cdot f \cdot t + \varphi) \quad \text{\textbackslash\end{align*}}$$

The absolute value of the factor in front of the $\cos$ is the maximum induced voltage $\hat{U}_{\text{ind}}$:

$$\hat{U}_{\text{ind}} = n \cdot A \cdot \hat{B} \cdot 2\pi f = 300 \cdot 0.06 \text{ m}^2 \cdot 2 \cdot 10^{-2} \text{ T} \cdot \frac{\text{Vs}}{\text{m}^2 \cdot \text{s}} = 180.95... \text{ V}$$

$$\hat{U}_{\text{ind}} = 180.95... \text{ V}$$

[electrical_engineering_and_electronics:task_rdz03rspbwusy7wk_with_calculation](#)
[induction, coil, induced voltage, exam ee2 ss2021](#)

Exercise E1 Magnetic Voltage

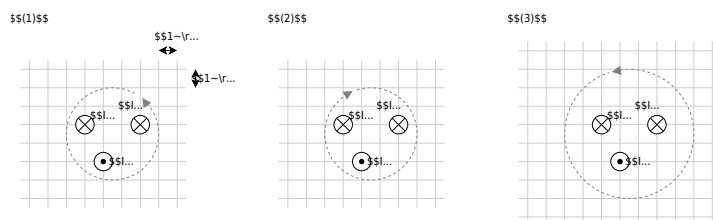
(written test, approx. 6 % of a 120-minute written test, SS2021)

The following images show cross-sections of electrical cables.

A closed path is shown as a dashed line. The magnetic voltage θ on these paths shall be analyzed.

The following values are given for the currents:

$$\begin{aligned} I_1 &= -4 \text{ A} \\ I_2 &= 0 \text{ A} \\ I_3 &= 1 \text{ A} \\ I_4 &= 4 \text{ A} \end{aligned}$$



Specify which magnetic voltages $\theta_{(1)}$, $\theta_{(2)}$, and $\theta_{(3)}$ result.

Note the direction of the path in each case!

Path

For the resulting current the direction of the path has to be considered with the right-hand rule:

- $I_{\{1\}} = +I_2 - I_1 - I_3 \quad \rightarrow \quad \theta_{\{1\}} = 2 \{ \sim \text{rm A} \} - 5 \{ \sim \text{rm A} \} - 1 \{ \sim \text{rm A} \}$
- $I_{\{2\}} = +I_3 + I_4 - I_1 \quad \rightarrow \quad \theta_{\{2\}} = 1 \{ \sim \text{rm A} \} + 4 \{ \sim \text{rm A} \} - 5 \{ \sim \text{rm A} \}$
- $I_{\{3\}} = +I_3 - I_4 - I_2 \quad \rightarrow \quad \theta_{\{3\}} = 1 \{ \sim \text{rm A} \} - 4 \{ \sim \text{rm A} \} - 2 \{ \sim \text{rm A} \}$

electrical_engineering_and_electronics:task_jfzImsucghsqvop5_with_calculation
magnetic voltage, exam ee2 ss2021

Exercise E12 Lorentz Force (hard!)**(written test, approx. 10 % of a 120-minute written test, SS2021)**

A) The picture below shows a straight high-voltage direct current transmission line with a current of $I = 1500 \text{ A}$. The line is oriented horizontally. A homogeneous geomagnetic field is assumed. The magnetic field strength has a vertical component of $B_{\text{v}} = 40 \text{ } \mu\text{T}$ and a horizontal component of $B_{\text{h}} = 20 \text{ } \mu\text{T}$. The angle between the transmission line and the horizontal component of the field strength is $\alpha = 20^\circ$.

Result: A) $F_{\text{h}} = 1.15 \text{ MN}$, $F_{\text{v}} = 0.7 \text{ MN}$. The resulting force acts perpendicular to the transmission line and to the magnetic field components.

Only 1.15 MN is perpendicular to $\vec{B}_{\text{v}}$ and to $\vec{I}$ and points in the right direction by the right-hand rule.

The picture on the right shows the line (black), the field strength components, and the angle in front and top view for illustration purposes.

Top View

Path

a) Calculate the force that results from the current flow on the entire conductor. First, calculate the vertical and horizontal components and combine them accordingly.

Path

- The horizontal component $\vec{F}_{\text{h}}$ of the force is based on the vertical component $\vec{B}_{\text{v}}$ of the magnetic field.
- The vertical component $\vec{B}_{\text{v}}$ of the magnetic field is not shown in the image but is pointing into the ground.
- It has to be perpendicular to $\vec{B}_{\text{v}}$ and to $\vec{I}$. The force on the transmission line can be calculated via the Lorentz force $\vec{F}_{\text{L}}$:
$$\vec{F} = I \cdot (\vec{I} \times \vec{B})$$

Here, we have two components for the current - and therefore for the force - to evaluate.

Considering the right-hand rule (and the cross product), the vertical field B_{v}

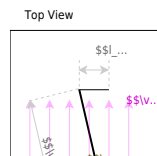
v generates a horizontal force F_{h} and vice versa.

The **horizontal component** is given by

$$\begin{aligned} F_{\text{h}} &= l \cdot (l \cdot B_{\text{v}}) = 1'200 \text{ A} \\ &\cdot 300 \cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \frac{\text{Vs}}{\text{m}^2} \\ &= 14'400 \text{ VAs} = 14'400 \text{ Ws} = 14'400 \text{ N} \end{aligned}$$

For the **vertical component** the angle α has to be considered.

For the maximum F_{v} the angle α has to be 90° , therefore the $\sin$ has to be used.



$$\begin{aligned} F_{\text{v}} &= l \cdot l \cdot B_{\text{h}} \cdot \sin \alpha = 1'200 \text{ A} \\ &\cdot 300 \cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \frac{\text{Vs}}{\text{m}^2} \cdot \sin 20^\circ \\ &= 2'462.545... \text{ N} \end{aligned}$$

For the **overall force** F the Pythagorean theorem has to be used:

$$\begin{aligned} F &= \sqrt{F_{\text{v}}^2 + F_{\text{h}}^2} = \sqrt{(14'400 \text{ N})^2 + (2'462.545... \text{ N})^2} \\ &= 14'609.04... \text{ N} \end{aligned}$$

[electrical_engineering_and_electronics:task_elndbo3xwi2klxuu_with_calculation](#)
[lorentz force, exam ee2 ss2021](#)

Exercise E14 Impedance Characteristics (written test, approx. 6 % of a 120-minute written test, SS2021)

A coil has an inductive reactance of $X_0 = X(f_0) = 80 \, \Omega$ at a frequency $f_0 = 60 \, \text{kHz}$.

Calculate the frequencies f_1 , f_2 , f_3 at which the following reactances are measured:

- $X_1 = 50 \, \Omega$
- $f_1 = 37.5 \, \text{kHz}$
- $X_2 = 121 \, \Omega$
- $f_2 = 90.75 \, \text{kHz}$
- $X_3 = 147 \, \Omega$
- $f_3 = 110.25 \, \text{kHz}$

Path

There are multiple ways to solve this question.

One way would be, to calculate the inductance L first by rearranging $X(f) = 2\pi \cdot f \cdot L$.

Another way uses ratios (or “rule of three”), since $X(f) = f \cdot k$ with a constant k .

Therefore one can set up two formulas $X_n = f_n \cdot k$, $X_0 = f_0 \cdot k$, and divide the formulae by each other.

This leads to:
$$\frac{X_n}{X_0} = \frac{f_n}{f_0} \quad \parallel f_n = \frac{X_n}{X_0} \cdot f_0$$

Putting in the numbers:
$$f_n = \frac{60 \, \text{kHz}}{80 \, \Omega} \cdot X_n = 0.75 \frac{\Omega}{\text{kHz}} \cdot X_n$$

[electrical_engineering_and_electronics:task_okznhljyycuqkbsh_with_calculation](#)
[impedance, inductor, exam ee2 ss2021](#)

Exercise E15 Complex series circuit (written test, approx. 8 % of a 120-minute written test, SS2021)

Result: Determine the absolute value of the resulting impedance of the series circuit using an impedance vector diagram. Pay attention to the correct dimensioning.

a) Determine the complex impedance $\underline{Z}_C$.

Result: $\underline{Z}_C = -j \cdot 804 \, \Omega$

Path:

The complex impedance $\underline{Z}_C$ is given as

$$\underline{Z}_C = \frac{1}{j \cdot 2\pi \cdot f \cdot C} = \frac{-j}{2\pi \cdot 40 \cdot 10^3 \cdot 4.95 \cdot 10^{-9}} = -j \cdot 803.81 \dots \, \Omega$$

Based on the diagram: $|\underline{Z}| = 828 \, \Omega$

electrical_engineering_and_electronics:task_9xy69axg3gi3nr26_with_calculation
complex voltage divider, exam ee2 ss2021

Exercise E16 Component Parameters

(written test, approx. 10 % of a 120-minute written test, SS2021)

The diagram shows the connection of a motor. The motor presents a resistive inductive load! Result: From the measurements, an AC voltage with a constant value of $U = 100 \, \text{V}$ and two different frequencies, $f_1 = 50 \, \text{Hz}$ and $f_2 = 100 \, \text{Hz}$, were applied.

This resulted in the recorded current of

a) Derive in general the equation for the absolute value of the impedance of the motor.

$$|\underline{Z}| = \sqrt{R^2 + (2\pi f L)^2}$$

$$R = 10 \, \Omega, L = 10 \, \text{mH}$$

Path: $|\underline{Z}| = \sqrt{R^2 + (2\pi f L)^2}$

b) Since we have Z_1 and Z_2 from b) we can subtract two of the formulas from a) (independent).

This has the advantage that R will cancel out:

$$Z_2^2 - Z_1^2 = (2\pi f_2 L)^2 - (2\pi f_1 L)^2$$

The complex impedance $\underline{Z}$ for a resistive inductive load (not a series circuit) is given as

$$\underline{Z} = R + j2\pi f L$$

Now we can rearrange to L :

The absolute value of the impedance is given as

$$|\underline{Z}| = \sqrt{R^2 + (2\pi f L)^2}$$

$$Z_2^2 - Z_1^2 = (2\pi f_2 L)^2 - (2\pi f_1 L)^2$$

$$Z_2^2 - Z_1^2 = (2\pi L)^2 (f_2^2 - f_1^2)$$

$$L = \frac{\sqrt{Z_2^2 - Z_1^2}}{2\pi \sqrt{f_2^2 - f_1^2}}$$

And then to L :

$$\begin{aligned} L_{\text{M}} &= \frac{1}{2\pi} \sqrt{\frac{Z_2^2 - Z_1^2}{f_2^2 - f_1^2}} \end{aligned}$$

With the values:

$$\begin{aligned} L_{\text{M}} &= \frac{1}{2\pi} \sqrt{\frac{(10 \sim \Omega)^2 - (6.25 \sim \Omega)^2}{(100 \frac{1}{s})^2 - (50 \frac{1}{s})^2}} \\ &= 14.346 \dots \sim \text{mH} \end{aligned}$$

The resistance value R_{M} can be derived from
$$Z_2^2 = (2\pi \cdot f_2 \cdot L_{\text{M}})^2 + R_{\text{M}}^2 \quad R_{\text{M}}^2 = Z_2^2 - (2\pi \cdot f_2 \cdot L_{\text{M}})^2 \quad R_{\text{M}} = \sqrt{Z_2^2 - (2\pi \cdot f_2 \cdot L_{\text{M}})^2}$$

The values have to be inserted also for R_{M} :
$$R_{\text{M}} = \sqrt{(10 \sim \Omega)^2 - (2\pi \cdot 100 \frac{1}{s} \cdot 0.014346 \dots \sim \text{H})^2} = 4.3301 \dots \sim \Omega$$

electrical_engineering_and_electronics:task_wjttvmydrskzhcim_with_calculation
complex voltage divider, rms, inductor, exam ee2 ss2021

Exercise E18 Signal Analysis

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

A) Determine the following signal parameters for voltage $u(t)$ and current $i(t)$ (measured in the consumer arrow system). (hard)

- $u(t) = 50 \sim \text{V} \cdot \cos(6000 \frac{1}{s} \cdot t + 4)$
- $i(t) = 30 \sim \text{A} \cdot \sin(6000 \frac{1}{s} \cdot t + 5)$

Result

a) Determine the amplitude values $\hat{U}$, $\hat{I}$ and the RMS values U , I

- $f = 955 \sim \text{Hz}$
- $\hat{U} = 50 \sim \text{V}$
- $\hat{I} = 30 \sim \text{A}$

Path: The phase shift can be determined by the time difference in degree:
$$\omega = 6000 \frac{1}{s} \quad 2\pi \cdot f = 6000 \frac{1}{s} \quad f = 954.93 \dots \sim \text{Hz}$$

- $U = 35.4 \sim \text{V}$
- The amplitude values $\hat{U}$, $\hat{I}$ are given directly by the coefficient of the cosine and sine functions. But to get these values, both the $u(t)$ and $i(t)$ need to have the same sinusoidal function! Therefore:

- $\varphi_i = 5$
- $\varphi_u = 4 + \frac{\pi}{2}$

By this we get for φ
$$\varphi = \varphi_u - \varphi_i = 4 + \frac{\pi}{2} - 5 = 2.14159 \dots$$

Converted in degree:
$$\varphi = 2.14159 \dots \cdot$$

$$\{ \{ 360^\circ \} \over {2 \pi} \} \} \ \&= \ 32.7042...^\circ \ \&\end{align*}$$

electrical_engineering_and_electronics:task_abh4vhlgczdmbni37_with_calculation
signal analysis, rms, exam ee2 ss2021

Exercise E20 Resonant Circuit

(written test, approx. 4 % of a 120-minute written test, SS2021)

Given a resonant RLC circuit that has to be designed (circuit diagram on the U_C

Result: U_{rms} ? (independent)

The inductance L and capacitance C are fixed. The resistance R can be varied.

Path: $u_{\text{rms}} = 12 \sqrt{2} \text{ V} \cdot \sin(2 \pi \cdot f_0 \cdot t)$

$$R = 6.25 \Omega$$

$$L = 20 \text{ mH}$$

$$C = 30 \mu\text{F}$$

For the following calculation, the internal resistance R_i and the resistance R have to be combined: $R_{\Sigma} = R_i + R$

Here, either one knows that the gain factor Q stands for

$Q = \frac{U_C}{U_{\text{rms}}}$ and therefore can directly use the following

formula: $Q = \frac{U_C}{U_{\text{rms}}} = \frac{1}{R_{\Sigma}} \sqrt{\frac{L}{C}}$

$$Q = \frac{U_C}{U_{\text{rms}}} = \frac{1}{R_{\Sigma}} \sqrt{\frac{L}{C}} \Rightarrow R_{\Sigma} = \frac{1}{Q} \sqrt{\frac{L}{C}}$$

When the gain factor is not known, one has to derive it:

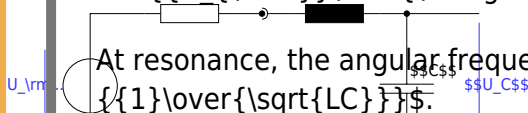
The voltage I at resonance is only given by the total ohmic resistance

$$R_{\Sigma} \text{ and the source voltage } U_{\text{rms}}: I = \frac{U_{\text{rms}}}{R_{\Sigma}}$$

This current flow also through the impedance of the capacitor

$$U_C = Z_C \cdot I = \frac{1}{\omega C} \cdot I$$

$$U_C = \frac{U_{\text{rms}}}{\omega C R_{\Sigma}}$$



At resonance, the angular frequency ω is given by $\omega = \frac{1}{\sqrt{LC}}$

$$U_C = \frac{U_{\text{rms}}}{\frac{1}{\sqrt{LC}} R_{\Sigma}} = \frac{U_{\text{rms}} \sqrt{LC}}{R_{\Sigma}}$$

a) What is the resonance frequency f_0 ? $f_0 = \frac{1}{2\pi \sqrt{LC}}$

$$U_C = \frac{U_{\text{rms}} \sqrt{LC}}{R_{\Sigma}} = \frac{U_{\text{rms}}}{R_{\Sigma}} \sqrt{\frac{L}{C}}$$

Path:

In both cases, we end up with the same formula, where we have to insert the physical values: $R_{\Sigma} = \frac{U_{\text{rms}}}{U_C} \sqrt{\frac{L}{C}}$

$$R_{\Sigma} = \frac{12 \sqrt{2} \text{ V}}{6.25 \text{ V}} \sqrt{\frac{20 \cdot 10^{-3} \text{ H}}{30 \cdot 10^{-6} \text{ F}}} = 6.4549... \Omega$$

$$\text{With the helices being } \left(R_0^{\pm} s_{\pm}^{\pm} \right) \begin{matrix} \text{begin}{align*} \\ \overline{R}_0 = 2 \sqrt{s_0} \sin \alpha - 20 \end{matrix} \quad \text{ddot=} 10^{-3}$$

electrical_engineering_and_electronics:task_nyniewamxfshpuwt_with_calculation
resonance, resonant circuit, rms, exam ee2 ss2021

Exercise E22 Multiphase systems

(written test, approx. 4 % of a 120-minute written test, SS2021)

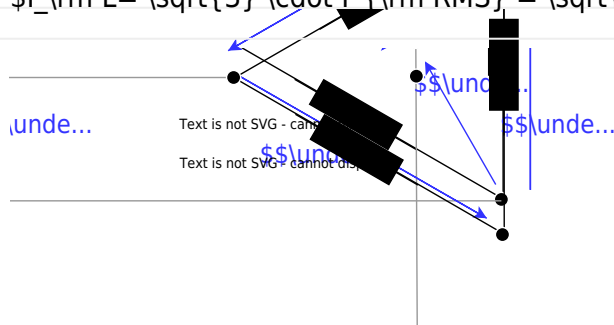
A) Specify the RMS value of the phase current i_{ϕ} and the line current i_L in the following.

A voltage with the RMS value $U_{\text{RMS}} = 110 \sim \text{V}$ is applied between the terminals of each winding.

Through each of the windings, there is a current with an RMS value $I_{\text{RMS}} = 5$ A. The RMS value of the induced voltage $\varphi = +25^\circ$ compared to the voltage.

a) Draw the equivalent diagram of the AC RMS = 5 A is running through each branch, a power of 10 W is being given by RMS = 5 A, 10 V is applied across the remaining branch and 10 W is being given by RMS = 5 A, 10 V is applied across the remaining branch and 10 W is being given by RMS = 5 A, 10 V is applied across the remaining branch.

Under the notation $\sqrt{3} \cdot I_{\text{RMS}}$ (where I_{RMS} is equal to the string `I_RMS` in the example in the image below), One can see, that



one single phase as an example



electrical_engineering_and_electronics:task_ezrkjzifcegttcpc_with_calculation
multiphase systems, rms, power, exam ee2 ss2021

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