ss2021_exam

Student Group

First Name	Surname	Matrikel Nr.

Table of Contents

Exam Summer Semester 2021 3
Additional permitted Aids 3
Hits 3
Tasks 3
Exercise E1 Magnetic Field Lines (written test, approx. 4 % of a 120-minute written test, SS2021) 3
Exercise E2 Magnetic Field Lines (written test, approx. 4 % of a 120-minute written test, SS2021) 4
Exercise E3 Magnetic Flux Density (written test, approx. 6 % of a 120-minute written test, SS2021) 6
Exercise E4 Magnetic Flux Density (written test, approx. 6 % of a 120-minute written test, SS2021) 7
Exercise E5 Toroidal Coil (written test, approx. 5 % of a 120-minute written test, SS2021) 9
Exercise E6 Toroidal Coil (written test, approx. 5 % of a 120-minute written test, SS2021) 10
Exercise E7 Cylindrical Coil (written test, approx. 6 % of a 120-minute written test, SS2021) 12
Exercise E1 Cylindrical Coil (written test, approx. 6 % of a 120-minute written test, SS2021) 12
Exercise E8 effect of induction (written test, approx. 5 % of a 120-minute written test, SS2021) 13
Exercise E9 Coil in a magnetic Field (written test, approx. 4 % of a 120-minute written test, SS2021) 18
Exercise E10 effect of induction (written test, approx. 5 % of a 120-minute written test, SS2021) 19
Exercise E11 Coil in a magnetic Field (written test, approx. 4 % of a 120-minute written test, SS2021) 23
Exercise E12 Magnetic Voltage (written test, approx. 6 % of a 120-minute written test,

SS2021) 24
Exercise E13 Magnetic Voltage (written test, approx. 6 % of a 120-minute written test, SS2021) 25
Exercise E14 Lorentz Force (hard!) (written test, approx. 10 % of a 120-minute written test, SS2021) 26
Exercise E15 Lorentz Force (hard!) (written test, approx. 10 % of a 120-minute written test, SS2021) 31
Exercise E16 Impedance Characteristics (written test, approx. 6 % of a 120-minute written test, SS2021) 35
Exercise E17 Impedance Characteristics (written test, approx. 6 % of a 120-minute written test, SS2021) 35
Exercise E18 Complex series circuit (written test, approx. 8 % of a 120-minute written test, SS2021) 36
Exercise E19 Complex series circuit (written test, approx. 8 % of a 120-minute written test, SS2021) 37
Exercise E20 Component Parameters (written test, approx. 10 % of a 120-minute written test, SS2021) 37
Exercise E1 Component Parameters (written test, approx. 10 % of a 120-minute written test, SS2021) 38
Exercise E21 Signal Analysis (written test, approx. 6 % of a 120-minute written test, SS2021) 39
Exercise E22 Signal Analysis (written test, approx. 6 % of a 120-minute written test, SS2021) 40
Exercise E23 Resonant Circuit (written test, approx. 4 % of a 120-minute written test, SS2021) 40
Exercise E24 Resonant Circuit (written test, approx. 4 % of a 120-minute written test, SS2021) 41
Exercise E25 Multiphase systems (written test, approx. 4 % of a 120-minute written test, SS2021) 42
Exercise E26 Multiphase systems (written test, approx. 4 % of a 120-minute written test, SS2021) 43

Exam Summer Semester 2021

Additional permitted Aids

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

Hits

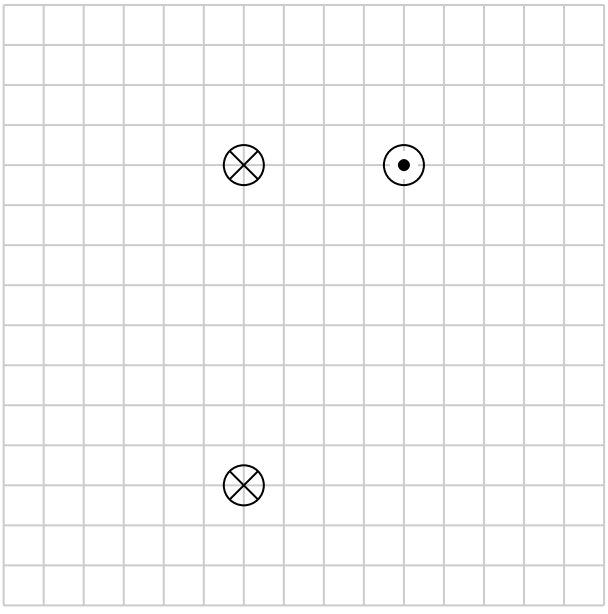
- The duration of the exam is 120 min.
- Attempts to cheat will lead to exclusion and failure of the exam.
- Withdrawal is no longer possible after these exam has been handed out.
- Please write down intermediate calculations and results on the assignment sheet. (when more space is needed also on the 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)

Tasks

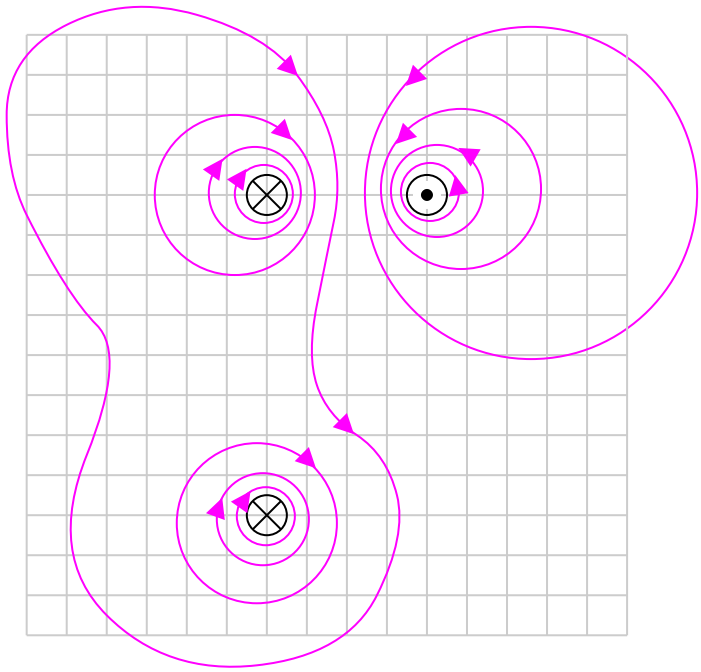
Exercise E1 Magnetic Field Lines
(written test, approx. 4 % of a 120-minute written test, SS2021)

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.



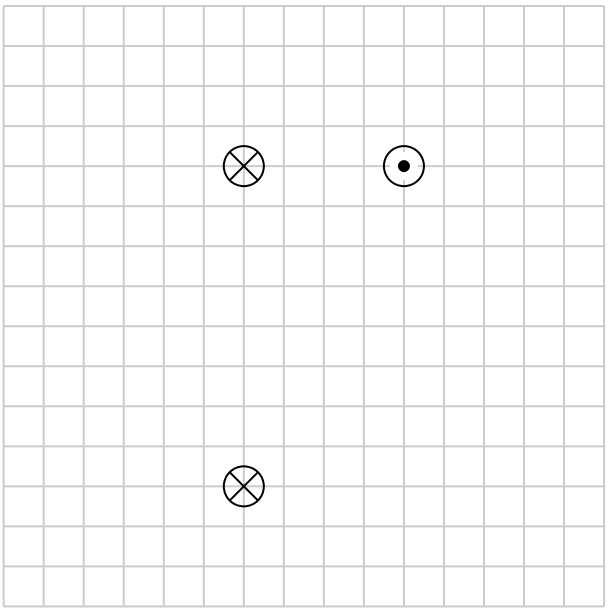
Result

- 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



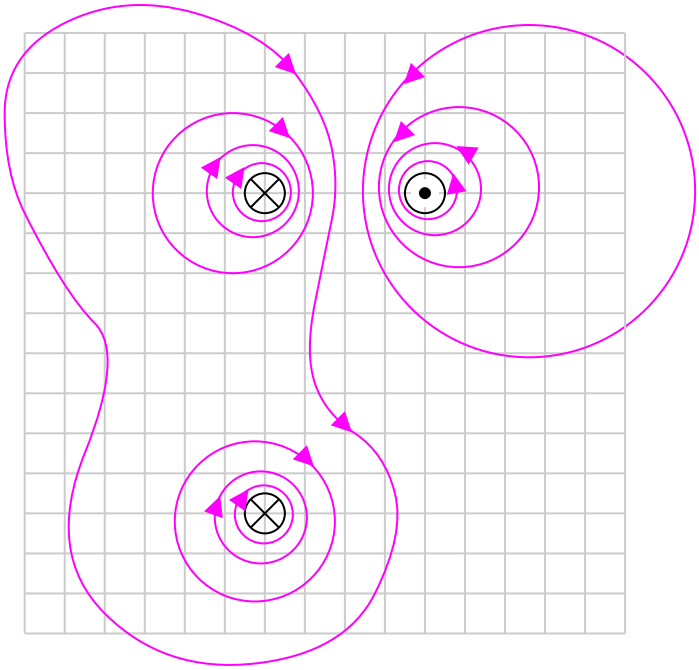
Exercise E2 Magnetic Field Lines
(written test, approx. 4 % of a 120-minute written test, SS2021)

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 instructor is preparing for experiments in the laboratory. A wire with an amplitude of $\hat{I} = 100~\rm A$ is operated.
You stand next to it and think about whether you have exceeded 3 points, independently.
The figure below shows the top view of the laboratory with the supply line between $\rm A$ and $\rm B$.
Path
$B = 42~\mu\rm T$
$\mu_{0} = 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}}$, $\mu_{r}=1$

The formula for the magnetic field strength can be rearranged: \begin{align*} H &= {{I}\over{2\pi \cdot r}} \\ r &= {{I}\over{2\pi \cdot H}} \\ \end{align*}

Again, the magnetic flux density B is given as: $B = \mu_0 \mu_r H$
Therefore: \begin{align*} r &= \mu_0 \mu_r {{ I }\over{2\pi \cdot B}} \\ &= 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}} {{100 ~\rm A}\over{2\pi \cdot 100\cdot 10^{-6} {~\rm T}}} \\ \end{align*}

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:

$$H = \frac{I}{2\pi \cdot r}$$

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

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

Therefore: $$B = 4\pi\cdot 10^{-7} \frac{\rm Vs}{\rm Am} \cdot 1 \cdot \frac{100~\rm A}{2\pi \cdot 0.412\ldots~\rm m}$$

Exercise E4 Magnetic Flux Density
(written test, approx. 6 % of a 120-minute written test, SS2021)

A) The first value to be measured is the magnetic flux density at the laboratory. A cable is $B_0 = 100~\rm mT$ with an amplitude of $\hat{I} = 100~\rm A$ is operated.
At what distance r around the cable would this value be reached? (3 points, independently)

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

Path

$B = 42~\rm mT$

$\mu_{0} = 4\pi\cdot 10^{-7} \frac{\rm Vs}{\rm Am}$, $\mu_{r}=1$

Result

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

Again, the magnetic flux density B is given as: $B = \mu_0 \mu_r H$
Therefore: $$r = \mu_0 \mu_r \frac{ I }{2\pi \cdot B} \\ = 4\pi\cdot 10^{-7} \frac{\rm Vs}{\rm Am} \frac{100~\rm A}{2\pi \cdot 100\cdot 10^{-6} {~\rm T}} \\$$

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:

$$H = \frac{I}{2\pi \cdot r}$$

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

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

Therefore: $$B = 4\pi\cdot 10^{-7} \frac{\rm Vs}{\rm Am} \cdot 1 \cdot \frac{100~\rm A}{2\pi \cdot 0.412...~\rm m}$$

Exercise E5 Toroidal Coil
(written test, approx. 5 % of a 120-minute written test, SS2021)

A magnetic field with a flux density of at least $50 ~\rm mT$ is to be achieved in a ring-shaped coil (toroidal coil).
The coil has 60 turns, wound around soft iron with $\mu_{\rm r} = 1200$.
The average field line length in the coil should be $l = 12 ~\rm cm$.

Result

$\mu_{0} = 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}}$

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

Path

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

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

Based on the flux density the magnetic field strength can be derived by $B = \mu_0 \mu_{\rm r} \cdot H$.
By this, the formula can be rearranged:

$$\begin{align*} H &= {{N \cdot I}\over{l}} \\ {{B}\over{ \mu_0 \mu_{\rm r}}} &= {{N \cdot I}\over{l}} \\ I &= {{B \cdot l}\over{ \mu_0 \mu_{\rm r} \cdot N}} \end{align*}$$

Putting in the numbers: $$\begin{align*} I &= {{ 0.05 {~\rm T} \cdot 0.12{~\rm m} }\over{ 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}} \cdot 1'200 \cdot 60}} \\ &= 0.6631... {{\rm T\cdot m}\over{ {{\rm Vs}\over{\rm Am}} }} &= 0.6631... {{\rm {{\rm Vs}\over{\rm m^2}} \cdot m}\over{ {{\rm Vs}\over{\rm Am}} }} &= 0.6631... ~\rm A \end{align*}$$

Exercise E6 Toroidal Coil
(written test, approx. 5 % of a 120-minute written test, SS2021)

A magnetic field with a flux density of at least $50 ~\rm mT$ is to be achieved in a ring-shaped coil (toroidal coil).
The coil has 60 turns, wound around soft iron with $\mu_{\rm r} = 1200$.
The average field line length in the coil should be $l = 12 ~\rm cm$.

Result

$\mu_{0} = 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}}$

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

Path

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

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

Based on the flux density the magnetic field strength can be derived by $B = \mu_0 \mu_{\rm r} \cdot H$.
By this, the formula can be rearranged:

\begin{align*} H &= {{N \cdot I}\over{l}} \\ {{B}\over{ \mu_0 \mu_{\rm r}}} &= {{N \cdot I}\over{l}} \\ I &= {{B \cdot l}\over{ \mu_0 \mu_{\rm r} \cdot N}} \end{align*}

Putting in the numbers: \begin{align*} I &= {{ 0.05 {~\rm T} \cdot 0.12{~\rm m} }\over{ 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}} \cdot 1'200 \cdot 60}} \\ &= 0.6631... {{\rm T\cdot m}\over{ {{\rm Vs}\over{\rm Am}} }} &= 0.6631... {{\rm {{\rm Vs}\over{\rm m^2}} \cdot m}\over{ {{\rm Vs}\over{\rm Am}} }} &= 0.6631... ~\rm A \end{align*}

Exercise E7 Cylindrical Coil
(written test, approx. 6 % of a 120-minute written test, SS2021)

A) the magnetic flux (2 points)

Result

Path

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

\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*}

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*}

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

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

A) the magnetic flux (2 points)

Result

- Length $ = 30 {~\rm cm}$,
- Winding diameter $ = 390 {~\rm mm}$,
- Number of windings $ = 240$,
- Current through the conductor $ = 500 {~\rm mA}$,
- $\mu_0 = 4\pi\cdot 10^{-7} {{\rm Vs}\over{\rm Am}}$

The magnetic field strength is $B = \mu_0 \mu_{\rm r} \cdot H$:

\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*}

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

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*}

Putting in the symbols: \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*}

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*}

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 $u_{\rm ind}(t)$ over time and draw it in a separate diagram.

Result

$$u...in$$\...

$$\...in$$\...

Path

Based on Faraday's Law of Induction the induced voltage is given by: \begin{align*} u_{\rm ind} =& - {{ {\rm d} }\over{ {\rm d}t}} \Psi(t) \bigg\rvert_{n=1}\\ =& - {{ {\rm d} }\over{ {\rm d}t}} \Phi(t) \\ \end{align*}

For a linear function, the derivative can be substituted by Deltas ($\rm d \rightarrow \Delta$):
\begin{align*} u_{\rm ind} = - {{ \Delta \Phi(t)}\over{ \Delta t}} = - { { \Phi(t_{\rm n+1}) - \Phi(t_{\rm n}) } \over { t_{\rm n+1} - t_{\rm n} } } \\ \end{align*}

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 $\rm I$ to $\rm V$ from left to right:

$$\...in$$\...

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

$$\..in$$\...

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

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

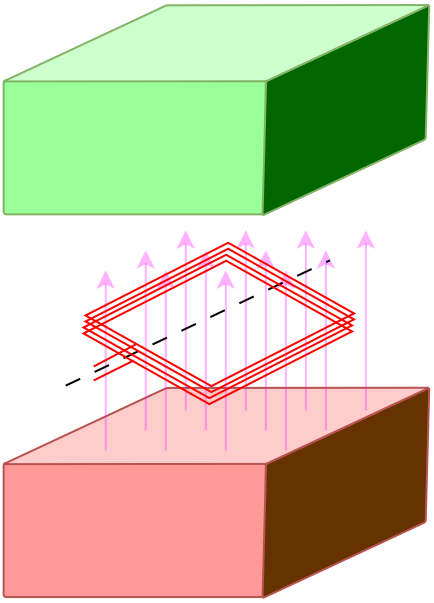
$$\...in$$\...

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 $A = 600 ~\rm cm^2$ 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 $f = 80~\rm Hz$.
The maximum value of the magnetic flux density in the coil is $\hat{B} = 2 \cdot 10^{-6} ~\rm {{Vs}\over{cm^2}}$.

Result

$$\begin{align*} u_{\rm ind} = - 181 {~\rm V} \cdot \cos(503 {{1}\over{\rm s}} \cdot t) \\ \end{align*}$$



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

Path

The induced voltage $u_{\rm ind}$ is given by:

$$\begin{align*} u_{\rm ind} &= - {{{\rm d}\Psi(t)}\over{{\rm d}t}} \\ &= - n{{{\rm d}\Phi(t)}\over{{\rm d}t}} \\ \end{align*}$$

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:

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

This leads to: $$\begin{align*} u_{\rm ind} &= - n{{{\rm d}}\over{{\rm d}t}}A \hat{B} \cdot \sin(2\pi f \cdot t + \varphi) \\ &= - n \cdot A \hat{B} \cdot 2\pi f \cdot \cos(2\pi \cdot f t + \varphi) \\ \end{align*}$$

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

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.

Result

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

$$u...in$$\...

$$\...in$$\...

Path

Based on Faraday's Law of Induction the induced voltage is given by: \begin{align*} u_{\rm ind} =& - {{ {\rm d} }\over{ {\rm d}t}} \Psi(t) \bigg\rvert_{n=1}\\ =& - {{ {\rm d} }\over{ {\rm d}t}} \Phi(t) \\ \end{align*}

For a linear function, the derivative can be substituted by Deltas ($\rm d \rightarrow \Delta$):
\begin{align*} u_{\rm ind} = - {{ \Delta \Phi(t)}\over{ \Delta t}} = - { { \Phi(t_{\rm n+1}) - \Phi(t_{\rm n}) } \over { t_{\rm n+1} - t_{\rm n} } } \\ \end{align*}

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 $\rm I$ to $\rm V$ from left to right:

$$\...in$$\...

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

$$\..in$$\...

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

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

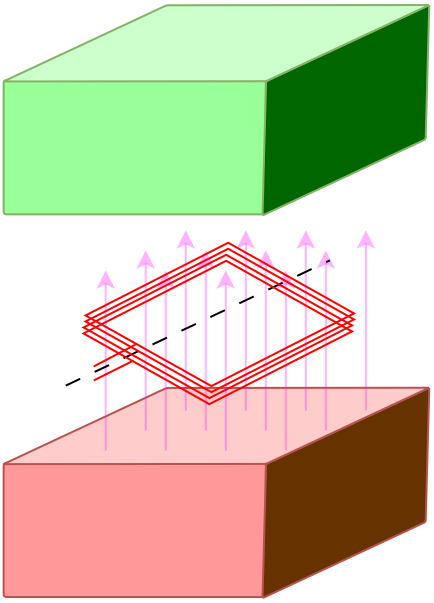
$$\...in$$\...

Exercise E11 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 $A = 600 ~\rm cm^2$ 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 $f = 80~\rm Hz$.
The maximum value of the magnetic flux density in the coil is $\hat{B} = 2 \cdot 10^{-6} ~\rm {{Vs}\over{cm^2}}$.

Result

\begin{align*} u_{\rm ind} = - 181 {~\rm V} \cdot \cos(503 {{1}\over{\rm s}} \cdot t) \\ \end{align*}



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

Path

The induced voltage $u_{\rm ind}$ is given by:

\begin{align*} u_{\rm ind} &= - {{{\rm d}\Psi(t)}\over{{\rm d}t}} \\ &= - n{{{\rm d}\Phi(t)}\over{{\rm d}t}} \\ \end{align*}

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{align*} B(t) &= \hat{B} \cdot \sin(\omega t + \varphi) \\ &= \hat{B} \cdot \sin(2\pi f \cdot t + \varphi) \\ \end{align*}

This leads to: \begin{align*} u_{\rm ind} &= - n{{{\rm d}}\over{{\rm d}t}}A \hat{B} \cdot \sin(2\pi f \cdot t + \varphi) \\ &= - n \cdot A \hat{B} \cdot 2\pi f \cdot \cos(2\pi \cdot f t + \varphi) \\ \end{align*}

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

Exercise E12 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:

- $I_1 = 5 {~\rm A}$
- $I_2 = -3 {~\rm A}$
- $I_3 = 1 {~\rm A}$
- $I_4 = 4 {~\rm A}$

Result:

\begin{align*} \theta_{(1)} &= -4 {~\rm A} \\ \theta_{(2)} &= 0 {~\rm A} \\ \theta_{(3)} &= 5 {~\rm A} \\ \end{align*}

$$(1)$$ $$(2)$$ $$(3)$$

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

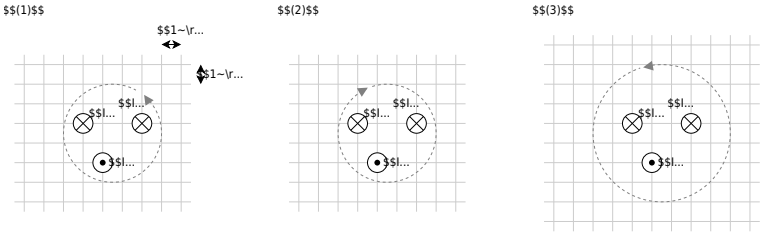
Exercise E13 Magnetic Voltage
(written test, approx. 6 % of a 120-minute written test, SS2021)

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:

- $I_1 = 5 {~\rm A}$
- $I_2 = 2 {~\rm A}$
- $I_3 = 1 {~\rm A}$
- $I_4 = 4 {~\rm A}$

Result

\begin{align*} \theta_{(1)} &= -4 {~\rm A} \\ \theta_{(2)} &= 0 {~\rm A} \\ \theta_{(3)} &= 5 {~\rm A} \\ \end{align*}



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

Exercise E14 Lorentz Force (hard!)

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

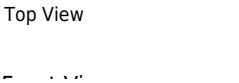
A 300-turn horizontal conductor loop with a diameter of 10 cm is suddenly switched on, so that the high voltage direction of the transmission shown does the analogous. A current of $I = 1 ~\rm A$ flows through it.

Result

A homogeneous geomagnetic field is assumed. The magnetic field strength has a vertical component of $B_{\rm v} = 40 ~\rm \mu T$ and a horizontal component of $B_{\rm h} = 20 ~\rm \mu T$.

The angle between the transmission line and the horizontal component of the field strength is $\alpha = 20 °$.

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



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

The force on the transmission line can be calculated via the Lorentz force $\vec{F}_\rm L$: \begin{align*} \vec{F} = I \cdot (\vec{l} \times \vec{B}) \end{align*}

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

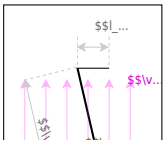
Considering the right-hand rule (and the cross product), the vertical field $B_{\rm v}$ generates a horizontal force $F_{\rm h}$ and vice versa.

The **horizontal component** is given by

$$\begin{align*} F_{\rm h} &= I \cdot (l \cdot B_{\rm v}) \\ &= 1′200 {~\rm A} \cdot 300 \cdot 10^3{~\rm m} \cdot 40 \cdot 10^{-6}{~\rm {{Vs}\over{m²}}} \\ &= 14'400 ~\rm {{VAs}\over{m}} = 14'400 ~\rm {{Ws}\over{m}} = 14'400 ~\rm N \end{align*}$$

For the **vertical component** the angle &\alpha& has to be considered.
For the maximum $F_{\rm v}$ the angle &\alpha& has to be $90°$, therefore the $\sin$ has to be used.

Top View



$$\begin{align*} F_{\rm v} &= I \cdot l \cdot B_{\rm h} \cdot \sin\alpha \\ &= 1′200 {~\rm A} \cdot 300 \cdot 10^3{~\rm m} \cdot 40 \cdot 10^{-6}{~\rm {{Vs}\over{m²}}} \cdot \sin 20° \\ &= 2'462.545... ~\rm N \end{align*}$$

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

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

Exercise E15 Lorentz Force (hard!)
(written test, approx. 10 % of a 120-minute written test, SS2021)

A 300 m long, straight high-voltage direct current transmission line runs in the east-west direction. The current $I = 1200$ A flows through it.
A homogeneous geomagnetic field is assumed. The magnetic field strength has a vertical component of $B_{\rm v} = 40 ~\rm \mu T$ and a horizontal component of $B_{\rm h} = 20 ~\rm \mu T$.
The angle between the transmission line and the horizontal component of the field strength is $\alpha = 20°$.
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 $\vec{F}_{\rm h}$ of the force is based on the vertical component $\vec{B}_{\rm v}$ of the magnetic field.
- The vertical component $\vec{B}_{\rm v}$ of the magnetic field is not shown in the image but is pointing into the ground.
- It has to be perpendicular to $\vec{B}_{\rm v}$ and to $\vec{I}$. The right-

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

$\vec{F}$ and $\vec{B}$ are perpendicular, the right-hand rule has been applied.

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

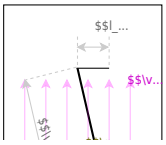
Here, we have two components for the current - and therefore for the force - to evaluate.
Considering the right-hand rule (and the cross product), the vertical field $B_{\rm v}$ generates a horizontal force $F_{\rm h}$ and vice versa.

The **horizontal component** is given by

$$\begin{align*} F_{\rm h} &= I \cdot (l \cdot B_{\rm v}) \\ &= 1′200 {~\rm A} \cdot 300 \cdot 10^3{~\rm m} \cdot 40 \cdot 10^{-6}{~\rm {{Vs}\over{m²}}} \\ &= 14'400 ~\rm {{VAs}\over{m}} = 14'400 ~\rm {{Ws}\over{m}} = 14'400 ~\rm N \end{align*}$$

For the **vertical component** the angle &\alpha& has to be considered.
For the maximum $F_{\rm v}$ the angle &\alpha& has to be $90°$, therefore the $\sin$ has to be used.

Top View



$$\begin{align*} F_{\rm v} &= I \cdot l \cdot B_{\rm h} \cdot \sin\alpha \\ &= 1′200 {~\rm A} \cdot 300 \cdot 10^3{~\rm m} \cdot 40 \cdot 10^{-6}{~\rm {{Vs}\over{m²}}} \cdot \sin 20° \\ &= 2'462.545... ~\rm N \end{align*}$$

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

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

Exercise E16 Impedance Characteristics
(written test, approx. 6 % of a 120-minute written test, SS2021)

A coil has an inductive reactance of $X_0 = X(f_0) = 80~\rm \Omega$ at a frequency $f_0 = 60~\rm kHz$.
Calculate the frequencies f_1, f_2, f_3 at which the following reactances are measured:

- $X_1 = 50 ~\rm \Omega$
- $X_2 = 121 ~\rm \Omega$
- $X_3 = 147 ~\rm \Omega$

Result

- $f_1 = 37.5~\rm kHz$
- $f_2 = 90.75~\rm kHz$
- $f_3 = 110.25~\rm kHz$

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: \begin{align*} {{X_n}\over{X_0}} &= {{f_n}\over{f_0}} \\ f_n &= {{X_n}\over{X_0}}\cdot f_0 = {{f_0}\over{X_0}}\cdot X_n \\ \end{align*}

Putting in the numbers: \begin{align*} f_n &= {{60 ~\rm kHz}\over{80~\rm \Omega}}\cdot X_n \\ &= 0.75 {{\rm \Omega}\over{\rm kHz}}\cdot X_n \\ \end{align*}

Exercise E17 Impedance Characteristics
(written test, approx. 6 % of a 120-minute written test, SS2021)

A coil has an inductive reactance of $X_0 = X(f_0) = 80~\rm \Omega$ at a frequency $f_0 = 60~\rm kHz$.
Calculate the frequencies f_1, f_2, f_3 at which the following reactances are measured:

- $X_1 = 50 ~\rm \Omega$
- $X_2 = 121 ~\rm \Omega$
- $X_3 = 147 ~\rm \Omega$
  - $f_1 = 37.5~\rm kHz$
  - $f_2 = 90.75~\rm kHz$
  - $f_3 = 110.25~\rm kHz$

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: \begin{align*} {{X_n}\over{X_0}} &= {{f_n}\over{f_0}} \\ f_n &= {{X_n}\over{X_0}}\cdot f_0 = {{f_0}\over{X_0}}\cdot X_n \\ \end{align*}

Putting in the numbers: \begin{align*} f_n &= {{60 ~\rm kHz}\over{80~\rm \Omega}}\cdot X_n \\ &= 0.75 {{\rm \Omega}\over{\rm kHz}}\cdot X_n \\ \end{align*}

Exercise E18 Complex series circuit
(written test, approx. 8 % of a 120-minute written test, SS2021)

A series circuit of $C = 4.95 ~\rm nF$, $R = 200 ~\rm \Omega$ and $f = 40 ~\rm kHz$ shall be investigated.

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

Result

$\underline{Z}_C = -{\rm j} \cdot 804 ~\rm \Omega $

Path

The complex impedance $\underline{Z}_C$ is given as \begin{align*} \underline{Z}_C &= {{1}\over{{\rm j} \cdot 2\pi \cdot f \cdot C }} \\ &= {{-{\rm j}}\over{2\pi \cdot 40 \cdot 10^3 ~\rm Hz \cdot 4.95 \cdot 10^{-9} ~\rm F }} \\ &= -{\rm j} \cdot 803.81... ~\rm \Omega \\ \end{align*}

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

Exercise E19 Complex series circuit
(written test, approx. 8 % of a 120-minute written test, SS2021)

A series circuit of $R = 200 ~\Omega$ and $C = 4.95 ~\rm nF$ is connected to a sinusoidal voltage source with a frequency of $f = 40 ~\rm kHz$.

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

Result

$\underline{Z}_C = -{\rm j} \cdot 804 ~\rm \Omega $

Path

The complex impedance $\underline{Z}_C$ is given as \begin{align*} \underline{Z}_C &= {{1}\over{{\rm j} \cdot 2\pi \cdot f \cdot C }} \\ &= {{-{\rm j}}\over{2\pi \cdot 40 \cdot 10^3 ~\rm Hz \cdot 4.95 \cdot 10^{-9} ~\rm F }} \\ &= -{\rm j} \cdot 803.81... ~\rm \Omega \\ \end{align*}

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

Exercise E20 Component Parameters
(written test, approx. 10 % of a 120-minute written test, SS2021)

The determination of the parameters $R_{\rm M}$ and $L_{\rm M}$ from measurements is to be carried out!

For the next exercises consider the following:

If two measurements, an AC voltage with a constant RMS value of $U = U_1 = U_2 = 50 ~\rm V$ but two different frequencies, f_1 and f_2 was applied.

This resulted in the recorded current of

- for $f_1 = 50 ~\rm Hz$: $I_1 = 8 ~\rm A$
- for $f_2 = 100 ~\rm Hz$: $I_2 = 5 ~\rm A$

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

\begin{align*} Z &= \sqrt{ (2\pi \cdot f \cdot L_{\rm M})^2 + R_{\rm M}^2 } \end{align*}

b) Determine the absolute values of the impedances from the specified RMS values at f_1 and f_2 (independent).

Since we have Z_1 and Z_2 from b) we can subtract two of the formulas from a). This has the advantage that $R_{\rm M}$ will cancel out: \begin{align*} Z_2^2 - Z_1^2 &= (2\pi \cdot f_2 \cdot L_{\rm M})^2 + R_{\rm M}^2 - \left((2\pi \cdot f_1 \cdot L_{\rm M})^2 + R_{\rm M}^2 \right) \\ &= (2\pi \cdot f_2)^2 \cdot L_{\rm M}^2 - (2\pi \cdot f_1)^2 \cdot L_{\rm M}^2 \end{align*}

The complex impedance $\underline{Z}$ for a resistive-inductive load ($=R$-L series circuit) is given as \begin{align*} \underline{Z} &= {\rm j} \cdot X_L + R_{\rm M} \\ &= {\rm j} \cdot 2\pi \cdot f \cdot L_{\rm M} + R_{\rm M} \\ \end{align*}

Now we can rearrange to $L_{\rm M}^2$:

The Pythagorean theorem can derive the absolute value: \begin{align*} \underline{Z}| = \sqrt{ (2\pi \cdot f \cdot L_{\rm M})^2 + R_{\rm M}^2 }\\ \end{align*}

The absolute value of the impedance is given as $Z = {U \over I}$.

This leads to:

\begin{align*} Z_2^2 - Z_1^2 &= L_{\rm M}^2 \cdot \left((2\pi \cdot f_2)^2 - (2\pi \cdot f_1)^2 \right) \\ L_{\rm M}^2 &= {{Z_2^2 - Z_1^2} \over { (2\pi \cdot f_2)^2 - (2\pi \cdot f_1)^2 }} \\ L_{\rm M}^2 &= {{Z_2^2 - Z_1^2} \over { (2\pi)^2 \cdot (f_2^2 - f_1^2)}}\\ \end{align*}

- $Z_1 = {U_1 \over I_1} = {{50 ~\rm V}\over{8~\rm A}}$
- $Z_2 = {U_2 \over I_2} = {{50 ~\rm V}\over{5~\rm A}}$

And then to $L_{\rm M}$:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{Z_2^2 - Z_1^2} \over { f_2^2 - f_1^2 }} }\\ \end{align*}

With the values:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{(10~\Omega)^2 - (6.25~\Omega)^2} \over { (100 {{1}\over{s}})^2 - (50 {{1}\over{s}})^2 }} }\\ &=14.346... ~\rm mH\\ \end{align*}

The resistance value $R_{\rm M}$ can be derived from \begin{align*} Z_2^2 &= (2\pi \cdot f_2 \cdot L_{\rm M})^2 + R_{\rm M}^2 \\ R_{\rm M}^2 &= Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2 \\ R_{\rm M} &=\sqrt{ Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2}\\ \end{align*}

The values have to be inserted also for $R_{\rm M}$: \begin{align*} R_{\rm M} &=\sqrt{ (10~\rm \Omega)^2 - (2\pi \cdot 100 {{1}\over{s}} \cdot 0.014346... ~\rm H)^2}\\ &= 4.3301...~\Omega \end{align*}

Exercise E1 Component Parameters
(written test, approx. 10 % of a 120-minute written test, SS2021)

For the next exercises consider the following:

Determine the circuit diagram of a motor ($R_{\rm M}$ and $L_{\rm M}$ in series) from two measurements, an AC voltage with a constant RMS value of $U = U_1 = U_2 = 50 ~\rm V$ but two different frequencies, f_1 and f_2 was applied.

This resulted in the recorded current of

- for $f_1 = 50~\rm Hz$: $I_1 = 8~\rm A$
- for $f_2 = 100~\rm Hz$: $I_2 = 5~\rm A$

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

b) Determine the absolute values of the impedances from the specified RMS values at f_1 and f_2 (independent).

The complex impedance $\underline{Z}$ for a resistive-inductive load (=R-L series circuit) is given as \begin{align*} \underline{Z} &= {\rm j} \cdot X_L + R_{\rm M} \\ &= {\rm j} \cdot 2\pi \cdot f \cdot L_{\rm M} + R_{\rm M} \\ \end{align*}

Now we can rearrange to $L_{\rm M}^2$:

The Pythagorean theorem can derive the absolute value: \begin{align*} \underline{Z}| = \sqrt{ (2\pi \cdot f \cdot L_{\rm M})^2 + R_{\rm M}^2 }\\ \end{align*}

The absolute value of the impedance is given as $Z = {U \over I}$.

This leads to:

\begin{align*} Z_2^2 - Z_1^2 &= L_{\rm M}^2 \cdot \left((2\pi \cdot f_2)^2 - (2\pi \cdot f_1)^2 \right) \\ L_{\rm M}^2 &= {{Z_2^2 - Z_1^2} \over { (2\pi \cdot f_2)^2 - (2\pi \cdot f_1)^2 }} \\ L_{\rm M}^2 &= {{Z_2^2 - Z_1^2} \over { (2\pi)^2 \cdot (f_2^2 - f_1^2)}}\\ \end{align*}

- $Z_1 = {U_1 \over I_1} = {{50 ~\rm V}\over{8~\rm A}}$
- $Z_2 = {U_2 \over I_2} = {{50 ~\rm V}\over{5~\rm A}}$

And then to $L_{\rm M}$:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{Z_2^2 - Z_1^2} \over { f_2^2 - f_1^2 }} }\\ \end{align*}

With the values:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{(10~\Omega)^2 - (6.25~\Omega)^2} \over { (100 {{1}\over{s}})^2 - (50 {{1}\over{s}})^2 }} }\\ &=14.346... ~\rm mH\\ \end{align*}

The resistance value $R_{\rm M}$ can be derived from \begin{align*} Z_2^2 &= (2\pi \cdot f_2 \cdot L_{\rm M})^2 + R_{\rm M}^2 \\ R_{\rm M}^2 &= Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2 \\ R_{\rm M} &=\sqrt{ Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2}\\ \end{align*}

The values have to be inserted also for $R_{\rm M}$: \begin{align*} R_{\rm M} &=\sqrt{ (10~\rm \Omega)^2 - (2\pi \cdot 100 {{1}\over{s}} \cdot 0.014346... ~\rm H)^2}\\ &= 4.3301...~\Omega \end{align*}

(2\pi \cdot f_1)^2 }} \\ L_{\rm M}^2 &= {{Z_2^2 - Z_1^2} \over { (2\pi)^2 \cdot (f_2^2 - f_1^2) }} \\ \end{align*}

And then to $L_{\rm M}$:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{Z_2^2 - Z_1^2} \over { f_2^2 - f_1^2 }} }\\ \end{align*}

With the values:

\begin{align*} L_{\rm M} &={{1}\over{2\pi}} \sqrt{{{(10~\Omega)^2 - (6.25~\Omega)^2} \over { (100 {{1}\over{s}})^2 - (50 {{1}\over{s}})^2 }} }\\ &=14.346... ~\rm mH\\ \end{align*}

The resistance value $R_{\rm M}$ can be derived from \begin{align*} Z_2^2 &= (2\pi \cdot f_2 \cdot L_{\rm M})^2 + R_{\rm M}^2 \\ R_{\rm M}^2 &= Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2 \\ R_{\rm M} &=\sqrt{ Z_2^2 - (2\pi \cdot f_2 \cdot L_{\rm M})^2}\\ \end{align*}

The values have to be inserted also for $R_{\rm M}$: \begin{align*} R_{\rm M} &=\sqrt{ (10~\rm \Omega)^2 - (2\pi \cdot 100 {{1}\over{s}} \cdot 0.014346... ~\rm H)^2}\\ &= 4.3301...~\Omega \end{align*}

Exercise E21 Signal Analysis
(written test, approx. 6 % of a 120-minute written test, SS2021)

A) Determine the following quantities from the given time function (assumed)
The quantities are available in the consumer arrow system. (hard)

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

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

The frequency can be derived by the term in the sine function: \begin{align*} \omega &= 2\pi f \\ f &= {{\omega}\over{2\pi}} {{1}\over{\rm s}} \\ f &= 954.93... ~\rm Hz \\ \end{align*}

For the phase φ, we have to subtract $\varphi_i $ from φ_u.
But to get these values, both the $u(t)$ and $i(t)$ need to have the same sinusoidal function! Therefore:

- For the RMS values of sinusoidal functions the amplitudes have to be multiplied with ${{1}\over{2}}\sqrt{2}$

By this we get for φ \begin{align*} \varphi &= \varphi_u - \varphi_i \\ &= 4 + {{\pi}\over{2}} - 5 \\ &= 2.14159... \\ \end{align*}

Converted in degree: \begin{align*} \varphi &= 2.14159... \cdot {{360°}\over{2\pi}}

\\ &= 32.7042...° \\ \end{align*}

Exercise E22 Signal Analysis
(written test, approx. 6 % of a 120-minute written test, SS2021)

A) Determine the following quantities for the given sinusoidal voltage and current (independent)
The quantities are available in the consumer arrow system. (hard)

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

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

The frequency can be derived by the term in the sine function: \begin{align*} \omega &= 6000 {{1}\over{\rm s}} \\ f &= {{6000}\over{2\pi}} {{1}\over{\rm s}} \\ f &= 954.93... ~\rm Hz \\ \end{align*}

RMS values:

- $U = 35.4{~\rm V}$
- $I = 21.2{~\rm A}$

b) Determine the phase angle φ between the two elements.

For the phase φ, we have to subtract $\varphi_i $ from φ_u.
But to get these values, both the $u(t)$ and $i(t)$ need to have the same sinusoidal function! Therefore:

- The amplitude values $\hat{U}$, $\hat{I}$ are given directly by the coefficient of the cosine and sine functions
- For the RMS values of sinusoidal functions the amplitudes have to be multiplied with ${{1}\over{2}}\sqrt{2}$
- $\varphi_i = 5$
- $\varphi_u = 4 + {{\pi}\over{2}}$

By this we get for φ \begin{align*} \varphi &= \varphi_u - \varphi_i \\ &= 4 + {{\pi}\over{2}} - 5 \\ &= 2.14159... \\ \end{align*}

Converted in degree: \begin{align*} \varphi &= 2.14159... \cdot {{360°}\over{2\pi}} \\ &= 32.7042...° \\ \end{align*}

Exercise E23 Resonant Circuit
(written test, approx. 4 % of a 120-minute written test, SS2021)

A) How large must R be, so that the resonance voltage across the capacitor is $U_C = 4 \cdot U_{\rm s}$?
The voltage $U_{\rm s}$ and the capacitance C are fixed. The resistance R can be varied.

- $u_{\rm s} = 12{~\rm V} \cdot \sin (2 \pi \cdot f_0 \cdot t) $
- $R_i = 200~\rm m\Omega$
- $f_0 = 6.365~\rm kHz$
- $C = 30~\rm \mu F$

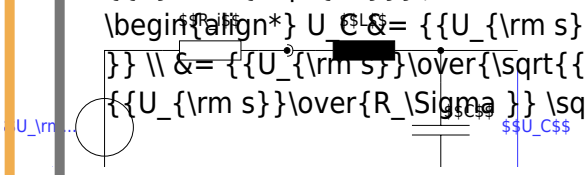
For the following calculation, the internal resistance R_i and the resistance R have to be combined: \begin{align*} R_\Sigma = R_i + R \\ \end{align*}

Here, either one knows that the gain factor Q stands for $Q={{U_C}\over{U_{\rm s}}}$ and therefore can directly use the following formula: \begin{align*} Q = {{U_C}\over{U_{\rm s}}} &= {{1}\over{R_\Sigma}} \sqrt{ {{L}\over{C}} } \\ R_\Sigma &= {{U_{\rm s}}\over{U_C}} \sqrt{ {{L}\over{C}} } \\ \end{align*}

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_Σ and the source voltage $U_{\rm s}$: \begin{align*} I = {{U_{\rm s}}\over{R_\Sigma}} \end{align*}

This current flow also through the impedance of the capacitor \begin{align*} U_C &= Z_C \cdot I \\ &= {{1}\over{\omega C}} \cdot I \\ &= {{U_{\rm s}}\over{\omega C R_\Sigma }} \\ \end{align*}

At resonance, the angular frequency ω is given by $\omega= {{1}\over{\sqrt{LC}}}$.
\begin{align*} U_C &= {{U_{\rm s}}\over{{{1}\over{\sqrt{LC}}} C R_\Sigma }} \\ &= {{U_{\rm s}}\over{\sqrt{{{C}\over{L}}} R_\Sigma }} \\ &= {{U_{\rm s}}\over{R_\Sigma }} \sqrt{{{L}\over{C}}} \\ \end{align*}



a) What is the resonance frequency f_0?
In both cases, we end up with the same formula, where we have to insert the physical values: \begin{align*} R_\Sigma &= {{U_{\rm s}}\over{U_C}} \sqrt{ {{L}\over{C}} } \\ &= {{1}\over{4}} \sqrt{ {{20\cdot 10^{-3} ~\rm H}\over{30\cdot 10^{-6} ~\rm C}} } \\ &= 6.4549...~\Omega \\ \end{align*}

And so, the resistance R is: \begin{align*} R &= R_\Sigma - R_i \\ &= 6.4549...~\Omega - 0.2~\Omega \\ &= 6.2549...~\Omega \end{align*}

The resonant frequency f_0 is given as \begin{align*} f_0 = {{1}\over{ 2\pi \sqrt{LC} }} \end{align*}

With the values: \begin{align*} f_0 &= {{1}\over{ 2\pi \sqrt{20 \cdot 10^{-3} ~\rm H \cdot 30 \cdot 10^{-6} ~\rm F} }} \\ &= 205.4681... \rm Hz \end{align*}

Exercise E24 Resonant Circuit
(written test, approx. 4 % of a 120-minute written test, SS2021)

b) How large must R be, so that the resonance voltage across the capacitor is $U_C = 4 \cdot U_{\rm s}$?

Given are the source voltage $U_{\rm s}$, the inductance L and the capacitance C are fixed. The resistance R can be varied.

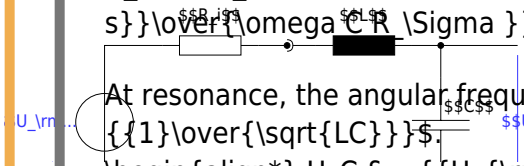
- $u_{\rm s} = 12{~\rm V} \cdot \sin (2 \pi \cdot f_0 \cdot t) $
- $R_i = 200~\rm m\Omega$
- $L = 20~\rm mH$
- $C = 30~\rm \mu F$

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

Here, either one knows that the gain factor Q stands for $Q={{U_C}\over{U_{\rm s}}}$ and therefore can directly use the following formula: \begin{align*} Q = {{U_C}\over{U_{\rm s}}} &= {{1}\over{R_\Sigma}} \sqrt{ {{L}\over{C}} } \\ R_\Sigma &= {{U_{\rm s}}\over{U_C}} \sqrt{ {{L}\over{C}} } \\ \end{align*}

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_Σ and the source voltage $U_{\rm s}$: \begin{align*} I = {{U_{\rm s}}\over{R_\Sigma}} \end{align*}

This current flow also through the impedance of the capacitor \begin{align*} U_C &= Z_C \cdot I \\ &= {{1}\over{\omega C}} \cdot I \\ &= {{U_{\rm s}}\over{\omega C R_\Sigma }} \\ \end{align*}



At resonance, the angular frequency ω is given by $\omega= {{1}\over{\sqrt{LC}}}$.
\begin{align*} U_C &= {{U_{\rm s}}\over{{{1}\over{\sqrt{LC}}} C R_\Sigma }} \\ &= {{U_{\rm s}}\over{\sqrt{{{C}\over{L}}} R_\Sigma }} \\ &= {{U_{\rm s}}\over{R_\Sigma }} \sqrt{{{L}\over{C}}} \\ \end{align*}

a) What is the resonance frequency f_0?

Path

In both cases, we end up with the same formula, where we have to insert the physical values: \begin{align*} R_\Sigma &= {{U_{\rm s}}\over{U_C}} \sqrt{ {{L}\over{C}} } \\ &= {{1}\over{4}} \sqrt{ {{20\cdot 10^{-3} ~\rm H}\over{30\cdot 10^{-6} ~\rm F}} } \\ &= 6.4549...~\Omega \\ \end{align*}

The resonant frequency f_0 is given as \begin{align*} f_0 = {{1}\over{ 2\pi \sqrt{LC} }} \end{align*}

With the values: \begin{align*} f_0 &= {{1}\over{ 2\pi \sqrt{20 \cdot 10^{-3} ~\rm H \cdot 30 \cdot 10^{-6} ~\rm F} }} \\ &= 205.4681...~\rm Hz \end{align*}

And so, the resistance R_i is: \begin{align*} R &= R_\Sigma - R_i \\ &= 6.4549...~\Omega - 0.2~\Omega \\ &= 6.2549...~\Omega \end{align*}

Exercise E25 Multiphase systems
(written test, approx. 4 % of a 120-minute written test, SS2021)

a) Specify the RMS value of the phase voltage $U_{\rm RMS}$ and the line voltage $U_{\rm LL}$.
Result
A voltage with the RMS value $U_{\rm RMS} = 110~\rm V$ is applied between the terminals of each winding.

Through each of the windings, there is a current with an RMS value $I_{\rm RMS} = 5 ~\rm A$ and a phase shift of $\varphi = +25°$ compared to the voltage.

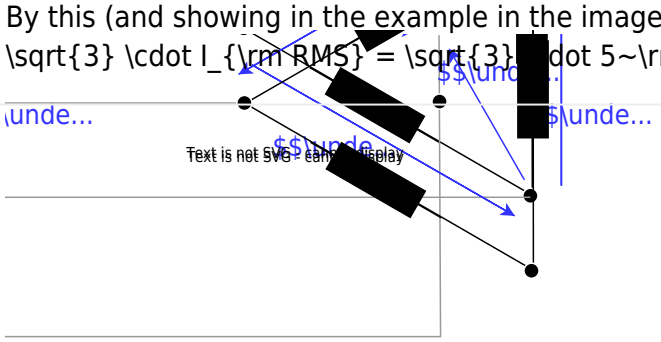
- $W = 1.61~\rm kW$
- $U_{\rm RMS} = 110~\rm V$

Since the voltage of $U_{\rm RMS} = 110~\rm V$ is applied between each winding,

a) Draw the circuit diagram.

Path

Resistance is also given by $R = \frac{U_{\rm RMS}}{I_{\rm RMS}}$. The current $I_{\rm RMS}$ is the same in all three windings.
For the phase angle between voltage and current φ we have $\varphi = 0$.
By this (and showing in the example in the image below), One can see, that $I_\rm L= \sqrt{3} \cdot I_{\rm RMS} = \sqrt{3} \cdot 5~\rm A$



Exercise E26 Multiphase systems
(written test, approx. 4 % of a 120-minute written test, SS2021)

A) Specify the RMS value of the phase current $I_{\rm RMS}$ and the line current $I_{\rm L}$.
Result:
B) Specify the RMS value of the phase voltage $U_{\rm RMS}$ and the line voltage $U_{\rm L}$.
Result:
C) Specify the active power P of the three-phase system.
Result:

A voltage with the RMS value $U_{\rm RMS} = 110~\rm V$ is applied between the terminals of each winding.
Through each of the windings, there is a current with an RMS value $I_{\rm RMS} = 5 ~\rm A$ and a phase shift of $\varphi = +25°$ compared to the voltage.

- $U_{\rm RMS} = 110~\rm V$
- $I_{\rm RMS} = 5~\rm A$
- $W = 1.61~\rm kW$

a) Draw the [illegible] and [illegible] $\rm A$

Since the given voltage of $U_{\rm RMS}=5110~\rm V$ is applied between the terminals of each winding, this is also the string voltage $U_{\rm S}$.

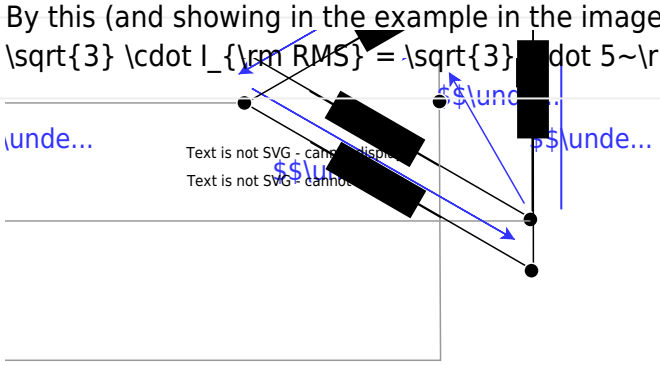
The active power P is given by: $P=3 \cdot U \cdot I \cdot \sin(\varphi)$

Result

$$\begin{aligned} P &= 3 \cdot 110~\rm V \cdot 5~\rm A \cdot \sin(25°) \\ &= 1610.888...~\rm W \end{aligned}$$

For [illegible] one phase voltage U_S is applied between the voltage and the [illegible]. [illegible] must be zero: $\sum I_i =0$.

By this (and showing in the example in the image below), One can see, that $I_\rm L= \sqrt{3} \cdot I_{\rm RMS} = \sqrt{3} \cdot 5~\rm A$



From:
https://wiki.mexle.org/ - **MEXLE Wiki**

Permanent link:
https://wiki.mexle.org/electrical_engineering_1/ss2021_exam?rev=1720125625

Last update: **2024/07/04 22:40**