

Exam Summer Semester 2024

Student Group

First Name	Surname	Matrikel Nr.

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Exam Summer Semester 2024

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.

Only EEE1-relevant Part

This part is only for about 90 minutes !

Exercise E1 Electrostatics I

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

2. Which net charge must be placed on the ring to get the picture below? The values of the previous results are: E_4 . Which value needs E_4 to have to get a resulting force of $0 \text{ ~}\mu\text{N}$ on q_0 ?

Path: $q_0 = -1 \text{ ~nC}$

- $q_1 = -5 \text{ ~nC}$

Path: $E_4 = 5907 \text{ ~V/m}$

$$\vec{F}_1 = \left(\begin{array}{c} +917 \\ 0 \\ 0 \end{array} \right) \text{ ~}\mu\text{N}$$

In the beginning, the are 5 charges. We can calculate the resulting magnitude of the force with the superposition theorem in a position $\theta = 8.834 \cdot 10^{-12} \text{ ~m}$ as V/m

$$\vec{F}_1 = \left(\begin{array}{c} +917 \\ 0 \\ 0 \end{array} \right) \text{ ~}\mu\text{N}$$

$$|\vec{F}_1| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{917^2 + 0^2} = 917 \text{ ~}\mu\text{N}$$

$$|\vec{F}_2| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 1123^2} = 1123 \text{ ~}\mu\text{N}$$

$$|\vec{F}_3| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{1560^2 + 0^2} = 1560 \text{ ~}\mu\text{N}$$

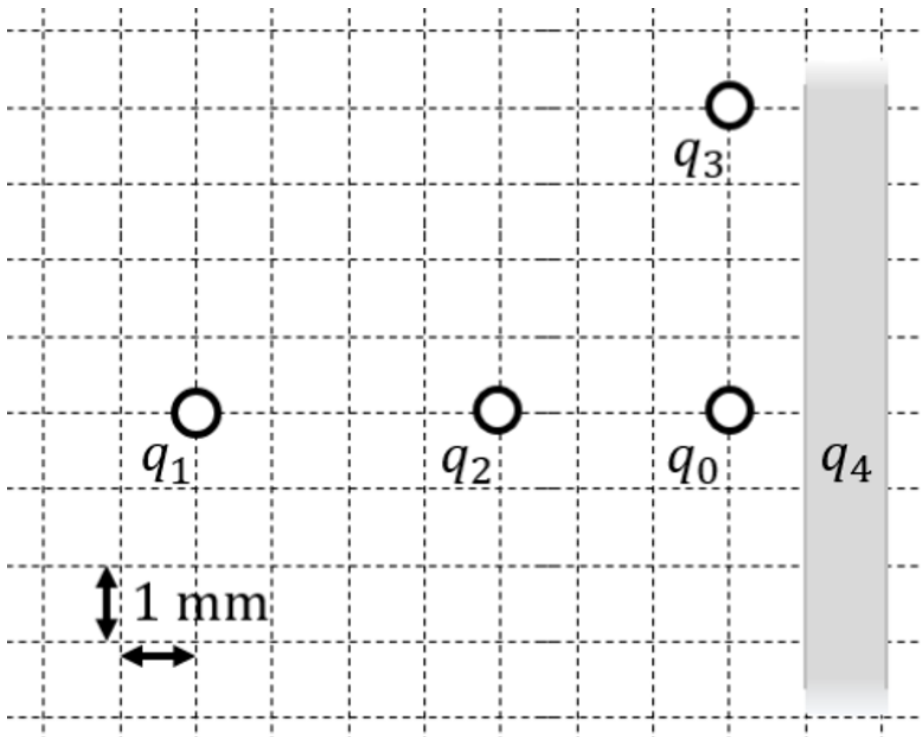
$$|\vec{F}_4| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 0^2} = 0 \text{ ~}\mu\text{N}$$

$$|\vec{F}_5| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 0^2} = 0 \text{ ~}\mu\text{N}$$

$$|\vec{F}_6| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 0^2} = 0 \text{ ~}\mu\text{N}$$

$$|\vec{F}_7| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 0^2} = 0 \text{ ~}\mu\text{N}$$

$$|\vec{F}_8| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} = \sqrt{0^2 + 0^2} = 0 \text{ ~}\mu\text{N}$$



1. Calculate the single forces $\vec{F}_{01}$, $\vec{F}_{02}$, $\vec{F}_{03}$, on the charge q_0 !

Path

First, set up a coordinate system. Here, I choose x pointing to the right (positive values to the right) and y pointing upwards (positive values upwards).

Then, calculate the magnitude of the forces, like $\vec{F}_{01}$ (force on q_0 from q_1).

The force $\vec{F}_{01}$ is purely on the x-axis and therefore equal to $F_{01,x}$.
$$\begin{aligned} \vec{F}_{01} &= F_{01,x} \hat{x} = \\ &= \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_0}{r_{01}^2} \hat{x} = \\ &= \frac{1}{4\pi \cdot 8.854 \cdot 10^{-12} \text{ As/Vm}} \cdot \frac{1 \cdot 10^{-9} \text{ C} \cdot 5 \cdot 10^{-9} \text{ C}}{(7 \cdot 10^{-3} \text{ m})^2} \hat{x} = \\ &= 917. \cdot 10^{-6} \text{ N} \cdot \frac{(As)^2 \cdot Vm}{As \cdot m^2} = 917. \cdot 10^{-6} \text{ N} \cdot \frac{VA}{m} = 917. \cdot 10^{-6} \text{ N} \cdot \frac{Ws}{m} = +917. \cdot 10^{-6} \text{ N} \end{aligned}$$
 Since both q_0 and q_1 have the same sign for their charges, they are repelling each other. Therefore, The force $\vec{F}_{01}$ points to the right (positive value).

Similarly, we get for $\vec{F}_{02}$ and $\vec{F}_{03}$
$$\begin{aligned} \vec{F}_{02} &= F_{02,x} \hat{x} = -197. \cdot 10^{-6} \text{ N} \\ \vec{F}_{03} &= F_{03,y} \hat{y} = -1123. \cdot 10^{-6} \text{ N} \end{aligned}$$
 Since q_0 and q_2 have the different sign for their charges, they are attract each other. Therefore, The force $\vec{F}_{02}$ points to the left (negative value).

Since q_0 and q_3 have the different sign for their charges, they are attract each other. Therefore, The force $\vec{F}_{03}$ points downwards (negative value).

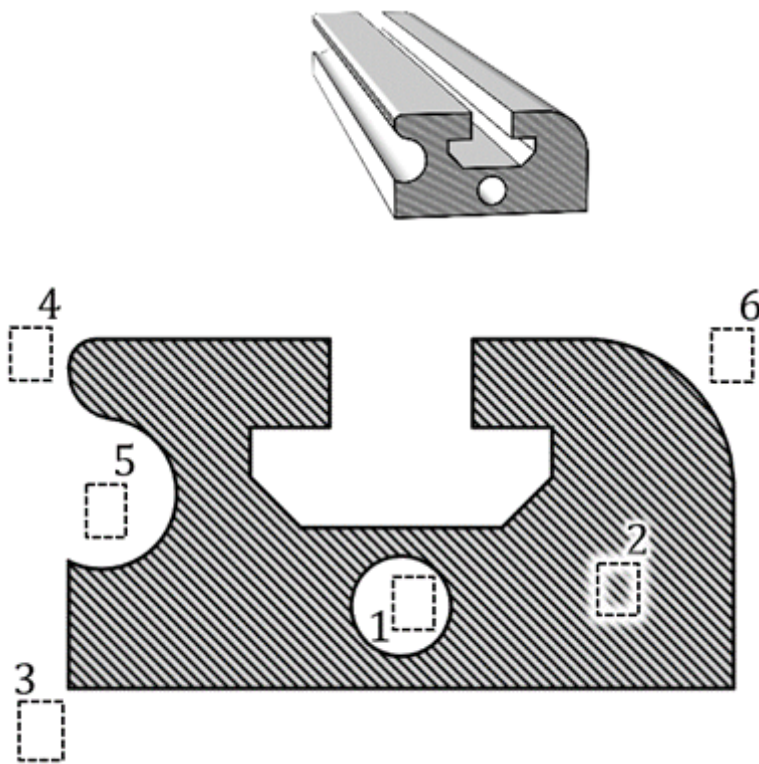
Exercise E1 Electrostatics II

(written test, approx. 10 % of a 120-minute written test, SS2024)

You must analyze an aluminum profile for usage in an environment critical for electrostatic discharge.

The figure on the right shows the cross-section of the aluminum element (hatched). During the application, it might get charged up. All areas in white consist of air (= dielectric).

Six designated areas are shown by dashed frames and numbers n, which are partly inside the object.



Arrange the designated areas clearly according to ascending field strengths $|\vec{E}_n|$ (absolute magnitude)! Indicate also, if designated areas have quantitatively the same field strength.

Result

$$|E_1|=|E_2|=0 < |E_5| < |E_6| < |E_4| < |E_3|$$

Exercise E1 Capacitor**(written test, approx. 12 % of a 120-minute written test, SS2024)**

3. Calculate the change of capacitance if the gas is filled between the plates with a contaminant. The distance between the plates remains the same. Give a generalized formula.

The contaminant has $\epsilon_{\text{r,c}} > \epsilon_{\text{r,air}}$, while the distance between the plates remains the same. Give a generalized formula

$C_2 = f(A, d, x, \epsilon_{\text{r,c}}, \epsilon_{\text{r,air}})$.
 $Q = 146 \text{ pC} = 146 \cdot 10^{-12} \text{ C}$
 $Q = C \cdot U = 1.1 \text{ pF} \cdot 3.3 \text{ V} = 3.63 \text{ pC}$
 The displacement field is given by:
 $D = \epsilon_0 \epsilon_{\text{r,air}} E = 8.854 \cdot 10^{-12} \text{ F/m} \cdot 3.3 \text{ V} = 2.92 \cdot 10^{-11} \text{ C/m}^2$
 The resulting capacity C is now a series circuit of C_{air} and C_{c} .
 Therefore:

$$C = \frac{1}{\frac{1}{C_{\text{air}}} + \frac{1}{C_{\text{c}}}}$$

With
 $C_{\text{air}} = \epsilon_0 \epsilon_{\text{r,air}} \frac{A}{d-x}$
 $C_{\text{c}} = \epsilon_0 \epsilon_{\text{r,c}} \frac{A}{x}$

In the following such a sensor is given with:

- This leads to:

$$C = \epsilon_0 A \left(\frac{1}{d-x} + \frac{x}{\epsilon_{\text{r,c}} d} \right)$$
- Plate area: $A = 25 \text{ mm}^2$
- Distance between both plates: $d = 200 \text{ }\mu\text{m}$
- Air between the plates: $\epsilon_{\text{r,air}} = 1$
- Supply voltage: 3.3 V
- Boundary effects on the end of the layers shall be ignored in the following calculations.

$\epsilon_0 = 8.854 \cdot 10^{-12} \text{ F/m}$

1. Calculate the capacity C .

Path

$$C = \epsilon_0 A \left(\frac{1}{d-x} + \frac{x}{\epsilon_{\text{r,c}} d} \right) = 8.854 \cdot 10^{-12} \text{ F/m} \cdot 25 \cdot 10^{-6} \text{ m}^2 \cdot \left(\frac{1}{200 \cdot 10^{-6} \text{ m}} + \frac{x}{\epsilon_{\text{r,c}} \cdot 200 \cdot 10^{-6} \text{ m}} \right)$$

Exercise E1 Magnetic Field Lines

(written test, approx. 6 % of a 120-minute written test, SS2024)

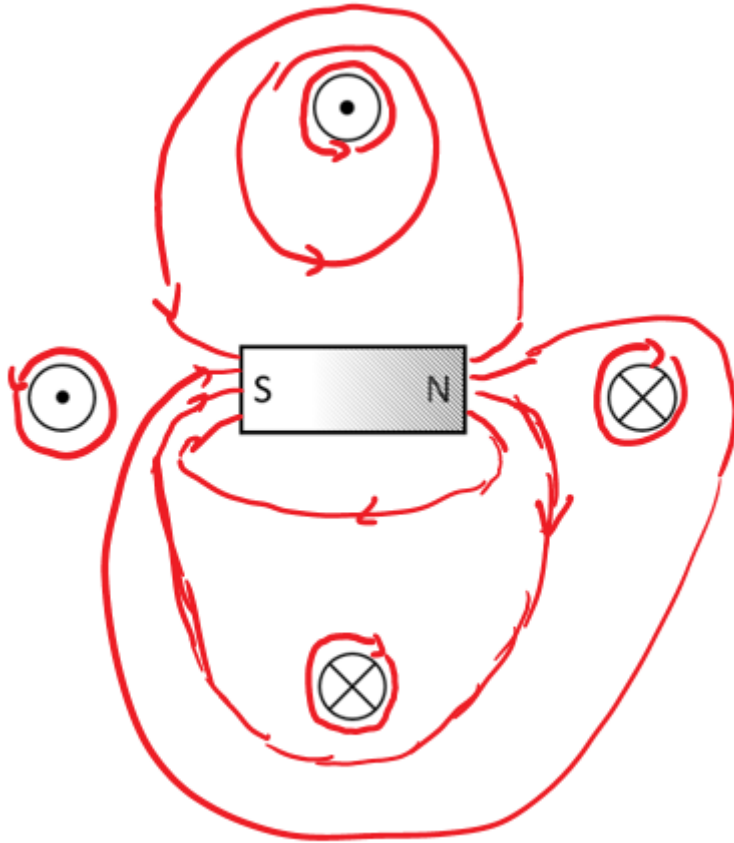
The following setup is given: A permanent magnet affects the H-field, based on the fundamental definition of the H-field.

- Four conductors are located perpendicular to the plane of the diagram

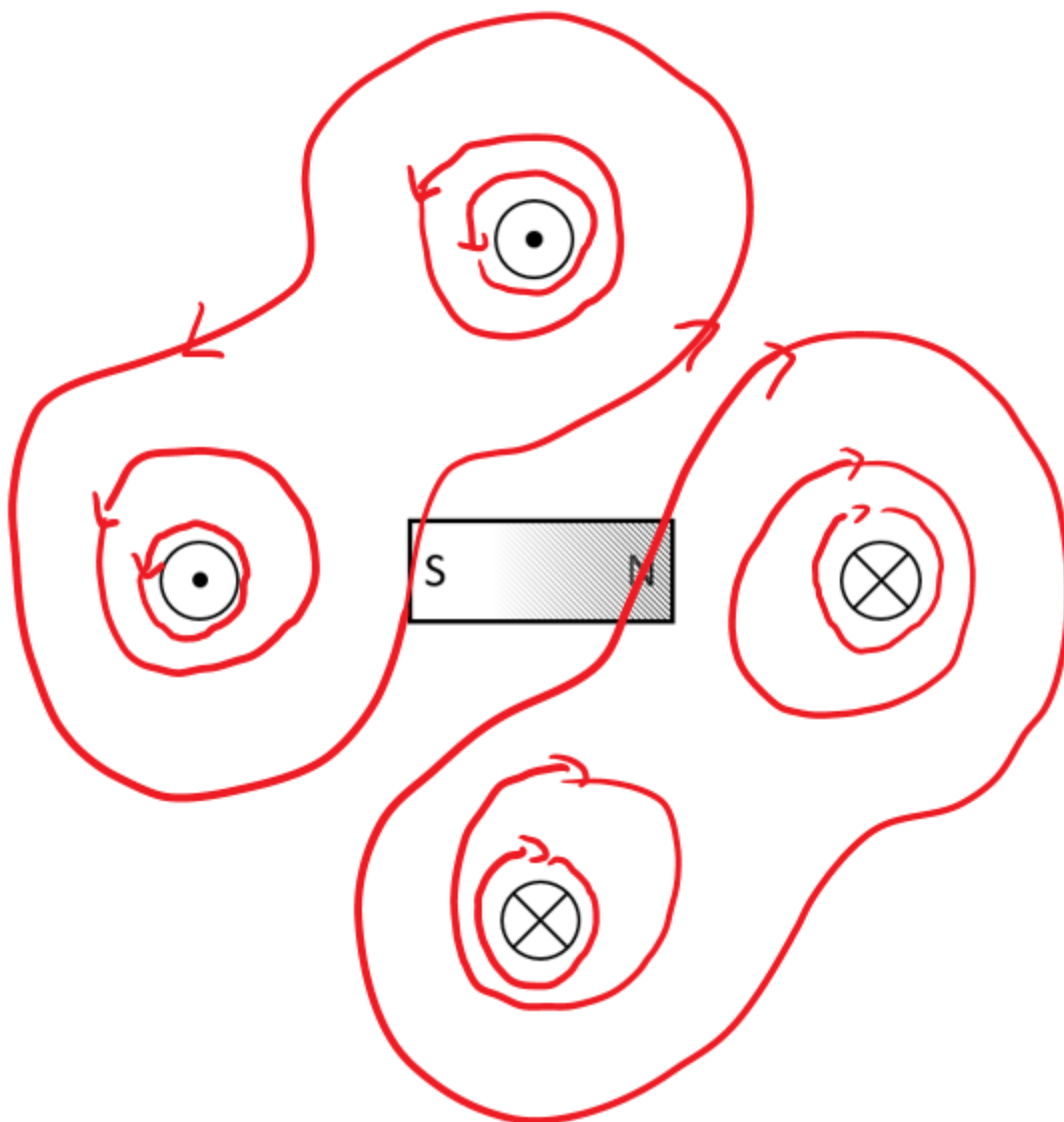
Result: All of them conduct a current with the same magnitude, but not in the same direction.

- A permanent magnet is located in between the conductors.

- The H-field is defined by currents $\oint \mathbf{H} \cdot d\mathbf{s} = I_{\text{enc}}$.
- In the permanent magnet, there are no free currents.
- The bound currents (of the permanent magnet) create also an H field.
- This exits on the north pole and enters the magnet on the south pole (similar to the B-field)
- $\mathbf{H} = \mathbf{B} / \mu_0$
- The H-field from task 1 gets distracted



st 10 field lines of the H-field
and density for the shown



Exercise E1 Fields of an coax Cable

(written test, approx. 12 % of a 120-minute written test, SS2024)

2. For the graph of the magnitude of $B(r)$ with r in cm (see diagram) the axes are: $B(r)$ in mT and r in cm . The diagram shows the magnitude of the magnetic field $B(r)$ as a function of the radial distance r from the center of the coaxial cable. The field is zero for $r < 0.1 \text{ cm}$ and $r > 0.6 \text{ cm}$. Between $r = 0.1 \text{ cm}$ and $r = 0.55 \text{ cm}$, the field increases linearly from 0 to 3.28 mT . Between $r = 0.55 \text{ cm}$ and $r = 0.6 \text{ cm}$, the field decreases linearly from 3.28 mT to 0. The diagram is labeled with the following values:

- Inner conductor: $+3.3 \text{ mA}$, $+10 \text{ nC}$ (current into the plane of the diagram)
- Outer conductor: -3.3 mA , -10 nC (current out of the plane of diagram)
- for $(0.1 \text{ cm} \leq r < 0.55 \text{ cm})$: $B(r) = 3.28 \cdot \frac{r}{0.1} \text{ mT}$
- for $(0.55 \text{ cm} \leq r < 0.6 \text{ cm})$: $B(r) = 3.28 \cdot \frac{0.6 - r}{0.05} \text{ mT}$

The magnitude of the electric displacement field D can be calculated by: $\oint D \cdot d\mathbf{l} = Q_{\text{enc}}$.

In general, the E -field is proportional to $\frac{1}{r}$ for the situation here, for any position radial to the center, the surrounding area is the surface of a cylindrical shape (here for simplicity without the round endings).

For the charges Q within the surface of the conductor, the electric field E is such that $\oint E \cdot d\mathbf{l} = \frac{Q}{\epsilon_0}$. This leads to: $E(r) = \frac{Q}{2\pi\epsilon_0 r L}$ and $D(r) = \epsilon_0 E(r) = \frac{Q}{2\pi r L}$ within a circle with the radius r .

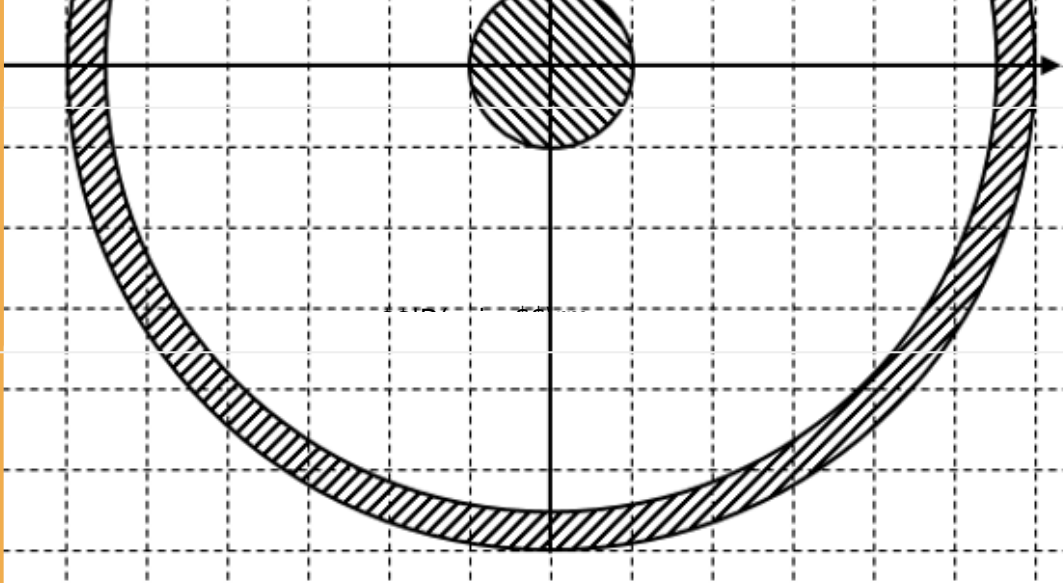
This is proportional to the area within this radius. Therefore, the formula $H = \frac{I}{2 \pi \cdot r}$ gets $H(x) = \frac{I}{2 \pi \cdot x} \cdot \pi$. So we get for $D_{\text{rm i}}$ at $\text{rm } (0.1 \text{ mm} | 0)$ and $D_{\text{rm o}}$ at $\text{rm } (0.55 \text{ mm} | 0)$. For x within the outer conductor one also gets a linear proportionality with a similar approach.

$$D_{\text{rm i}} = \frac{Q}{2 \pi \cdot r_{\text{rm i}} \cdot l} = \frac{10 \cdot 10^{-9} \text{ C}}{2 \pi \cdot \{0.1 \cdot 10^{-3} \text{ m}\} \cdot 0.5 \text{ m}}$$

$$D_{\text{rm o}} = \frac{Q}{2 \pi \cdot r_{\text{rm o}} \cdot l} = \frac{10 \cdot 10^{-9} \text{ C}}{2 \pi \cdot \{0.55 \cdot 10^{-3} \text{ m}\} \cdot 0.5 \text{ m}}$$

Hint: For the direction, one has to consider the sign of the enclosed charge. By this, we see that the D -field is positive.

But here, again only the magnitude was questioned!



.. What is the magnitude of the magnetic field strength H at $\text{rm } (0.1 \text{ mm} | 0)$ and $\text{rm } (0.55 \text{ mm} | 0)$?

Path

The magnitude of the magnetic field strength H can be calculated by: $H = \frac{I}{2 \pi \cdot r}$

So, we get for $H_{\text{rm i}}$ at $\text{rm } (0.1 \text{ mm} | 0)$, and $H_{\text{rm o}}$ at $\text{rm } (0.55 \text{ mm} | 0)$:

$$H_{\text{rm i}} = \frac{I}{2 \pi \cdot r_{\text{rm i}}} = \frac{+3.3 \text{ A}}{2 \pi \cdot \{0.1 \cdot 10^{-3} \text{ m}\}} \quad H_{\text{rm o}} = \frac{I}{2 \pi \cdot r_{\text{rm o}}} = \frac{+3.3 \text{ A}}{2 \pi \cdot \{0.55 \cdot 10^{-3} \text{ m}\}}$$

Hint: For the direction, one has to consider the right-hand rule. By this, we see that the H -field on the right side points downwards.

Therefore, the sign of the H -field is negative.

But here, only the magnitude was questioned!

Exercise E2 Lorentz Force**(written test, approx. 8 % of a 120-minute written test, SS2024)**

2. Describe the lifting system of the lift truck, that is based on the inhomogeneous shorted field of the fixed floor. Explain, how the resulting force can be determined in the image for each of the coils of the shuttle (see image).

Result

Path

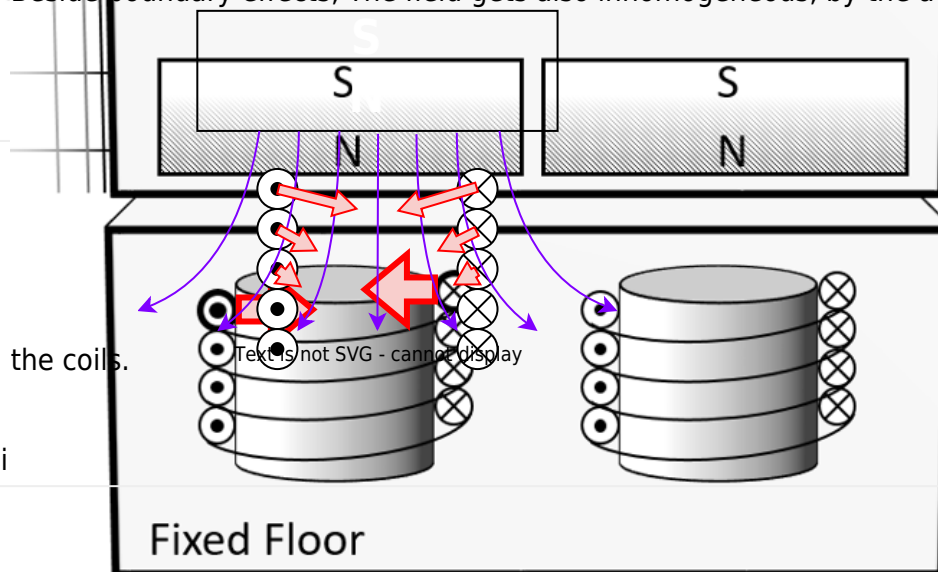
Since the resulting force has to be perpendicular to B -field and conductor, the force has to point to the left or the right.

For a homogeneous B -field ("constant magnetic field of the shuttle"), the Lorentz forces cancel each other out.

The Lorentz force can only have a lifting effect in an inhomogeneous field.

In this case, the sum of the forces results in a repulsing force, see image.

Beside boundary effects, the field gets also inhomogeneous, by the additional field of



- current $I = 1.6 \text{ A}$
- magnetic field of the shuttle is homogeneous with $B = 0.5 \text{ T}$

1. Calculate the magnitude of the resulting force on one coil!

Path

The Lorentz force on a conductor the length l and the current I in a B -field is

$$|\vec{F}_L| = I \cdot l \cdot B \cdot \cos(\angle \vec{B}, \vec{l})$$

$$= I \cdot (N \cdot 2\pi r) \cdot B \cdot \cos(\angle \vec{B}, \vec{l})$$

$$= 1.6 \text{ A} \cdot (500 \cdot 2\pi \cdot 40 \cdot 10^{-3} \text{ m}) \cdot 0.5 \text{ T} \cdot \cos 90^\circ$$

Exercise E2 Magnetic Potential**(written test, approx. 8 % of a 120-minute written test, SS2024)**

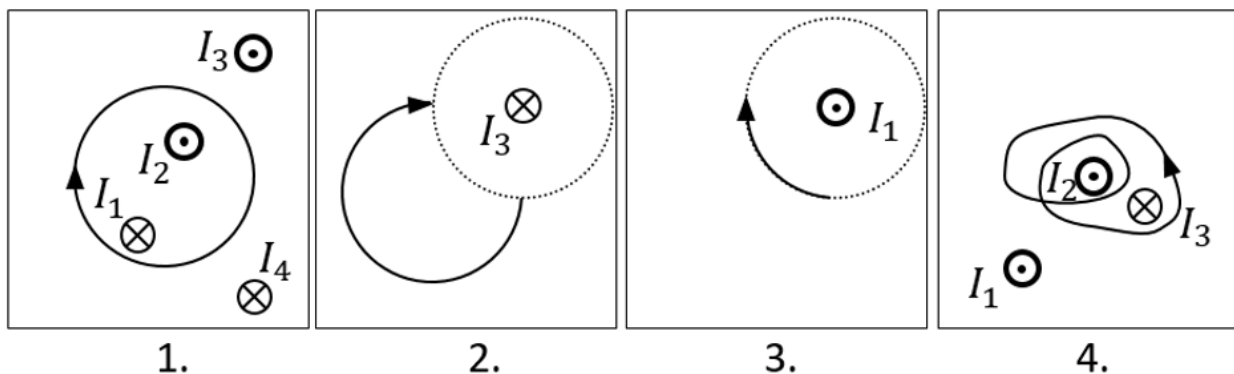
Calculate the magnetic potential difference V_{m} for the following paths as shown by the solid lines.

Dotted lines are only for there for symmetry aspects!

The wires conduct the following currents:

- $|I_1| = 2 \text{ A}$
- $|I_2| = 5 \text{ A}$
- $|I_3| = 11 \text{ A}$
- $|I_4| = 7 \text{ A}$

Pay attention to the signs of the currents (given by the diagrams) and of the results!



Result

Based on the right-hand rule and the part of a full revolution the following results:

1. Task: $+I_1 - I_2 = -3 \text{ A}$
2. Task: $+\frac{1}{4} I_3 = 11/4 \text{ A}$ (it does not matter which way the path goes from the startpoint to the endpoint, as long as it has the same direction and number of revolutions)
3. Task: $-\frac{1}{4} I_1 = -0.5 \text{ A}$
4. Task: $+2 \cdot I_2 - 1 \cdot I_3 = -1 \text{ A}$

Exercise E1 Self-Induction**(written test, approx. 8 % of a 120-minute written test, SS2024)**

2. Determine the length of a 30 V voltage source and the radius of a 2 cm diameter coil with 500 turns.

Result: 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

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

$$U_{\text{ind}} = 1.32 \text{ mV}$$

.. Calculate the (self-)inductance of the coil.

For the linear change of the current the formula of the induced voltage can also be

linearized:
$$u_{\text{ind}} = -L \cdot \frac{di}{dt}$$

$$\rightarrow -L \cdot \frac{\Delta i}{\Delta t} = -1.32 \cdot 10^{-3}$$

$$\cdot \frac{3 \text{ A}}{0.02 \cdot 10^{-3} \text{ s}} \Rightarrow L = 1.98 \text{ mH}$$

The formula for the induction of a long coil is:
$$L = \mu_0 \mu_r \cdot N^2 \cdot \frac{A}{l} = 4\pi \cdot 10^{-7} \cdot (500)^2 \cdot \frac{\pi \cdot (2 \cdot 10^{-2})^2}{2 \cdot 10^{-2}} = 1.98 \text{ mH}$$

Exercise E4 Magnetic Circuit**(written test, approx. 9 % of a 120-minute written test, SS2024)**

1. Calculate the permeability μ_r of the core with cross-sectional area of $A = 300 \text{ mm}^2$

Result: and an average circumference of $l = 3 \text{ dm}$.

Path

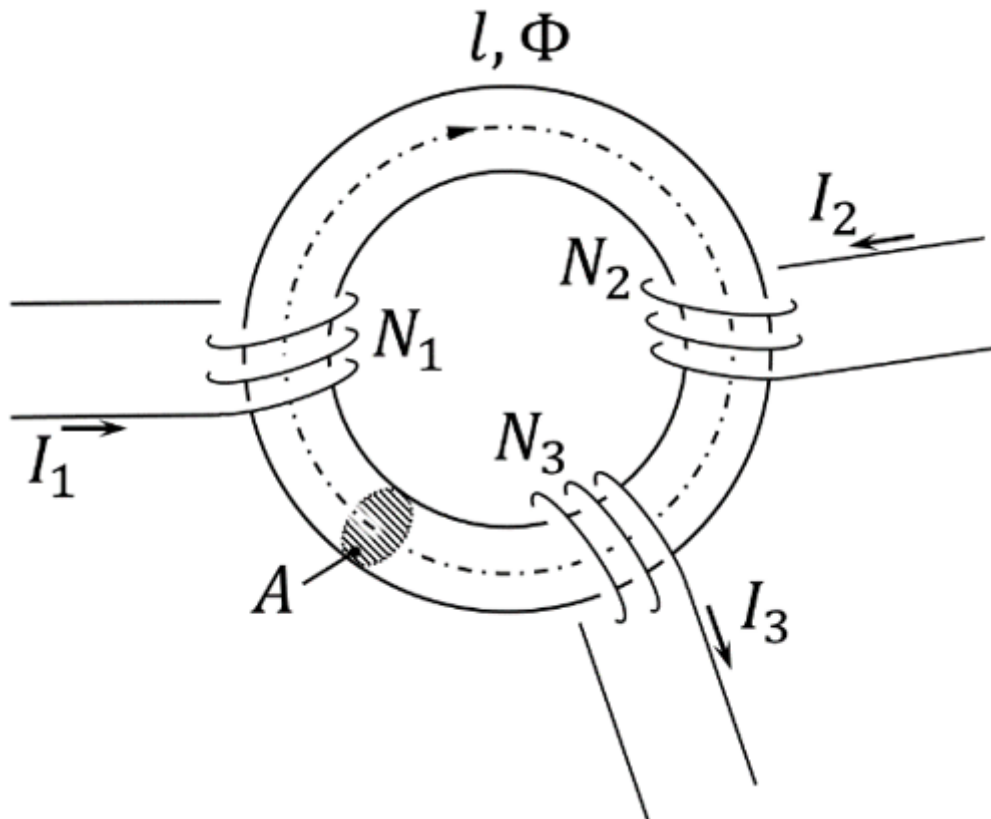
$$\Phi = 67.8 \cdot 10^{-6} \text{ Wb}$$

First we have to calculate the magnetic resistance R_m based on the sources:

$$R_m = \frac{l}{\mu_0 \mu_r A} = \frac{3 \cdot 10^{-1} \text{ m}}{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot \mu_r \cdot 300 \cdot 10^{-6} \text{ m}^2} = \frac{250}{\mu_r} \text{ Vs/Am}$$

To get the flux Φ , the Hopkinson's Law can be applied - similar to the Ohm's Law:

$$\Phi = \frac{I}{R_m} = \frac{60 \text{ A}}{\frac{250}{\mu_r}} = 240 \cdot 10^{-6} \text{ Wb} = 240 \text{ } \mu\text{Wb}$$



On the core, there are three coils with:

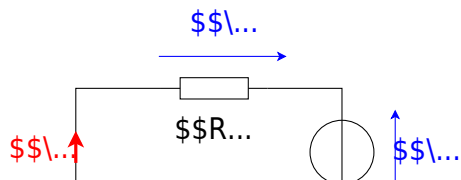
- Coil 1: $N_1 = 1200$, $I_1 = 100 \text{ mA}$
- Coil 2: $N_2 = 33$, $I_2 = 3 \text{ A}$
- Coil 3: $N_3 = 270$, $I_3 = 0.3 \text{ A}$

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

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

Result

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



Full Exam

These is the full exam

Full exam

Exercise E1 Electrostatics I
(written test, approx. 8 % of a 120-minute written test, SS2024)

2. What is the magnitude of the electric field E_4 in the picture below? The value of the permittivity is $\epsilon_0 = 8.854 \cdot 10^{-12} \text{ F/m}$. Which value needs E_4 to have to get a resulting force of $F = 1 \text{ N}$ on q_0 ?

Path: $q_0 = -1 \text{ nC}$

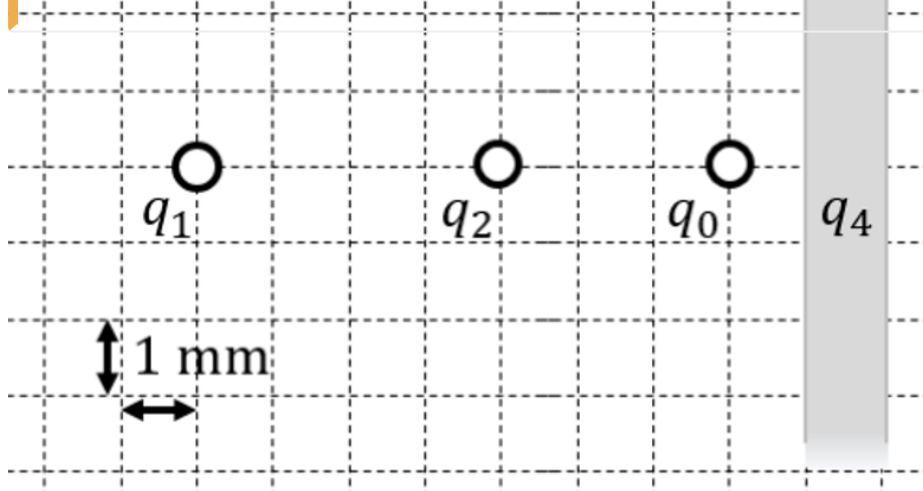
- $q_1 = -5 \text{ nC}$

Path: $E_4 = 1123 \text{ V/m}$

- $\vec{F}_{01} = \left(\begin{array}{c} 0 \\ 0 \\ 0 \end{array} \right) + 917 \cdot 10^{-12} \text{ N}$
- $\vec{F}_{02} = \left(\begin{array}{c} 0 \\ 0 \\ 0 \end{array} \right) + 1987 \cdot 10^{-12} \text{ N}$

With beginning the area of the components we can calculate the resulting magnitude of the electric field E_4 in the picture below. The formula for the electric field is $E = \frac{F}{q}$ and the formula for the force is $F = q \cdot E$. Here $F = 1 \text{ N}$ and $q = -1 \text{ nC}$. So $E = \frac{1 \text{ N}}{-1 \text{ nC}} = -1 \text{ nV/m}$. The magnitude of the electric field is $E = 1 \text{ nV/m}$.

$$\begin{aligned} \vec{F}_{01} &= E_4 \cdot q_0 \rightarrow E_4 = \frac{|\vec{F}_{01}|}{|q_0|} = \frac{917 \cdot 10^{-6} \text{ N}}{1 \cdot 10^{-9} \text{ C}} = 917 \cdot 10^3 \frac{\text{N}}{\text{C}} = 917 \cdot 10^3 \frac{\text{V/m}}{\text{m}} = 917 \cdot 10^3 \frac{\text{V}}{\text{m}} \end{aligned}$$



1. Calculate the single forces $\vec{F}_{01}$, $\vec{F}_{02}$, $\vec{F}_{03}$, on the charge q_0 !

Path

First, set up a coordinate system. Here, I choose x pointing to the right (positive values to the right) and y pointing upwards (positive values upwards).

Then, calculate the magnitude of the forces, like $\vec{F}_{01}$ (force on q_0 from q_1).

The force $\vec{F}_{01}$ is purely on the x-axis and therefore equal to $F_{01,x}$.
$$\vec{F}_{01} = F_{01,x} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 \cdot q_0}{r_{01}^2} = \frac{1}{4\pi \cdot 8.854 \cdot 10^{-12} \text{ As/Vm}} \cdot \frac{1 \cdot 5 \cdot 10^{-9} \text{ C}}{(7 \cdot 10^{-3} \text{ m})^2} = 917 \cdot 10^{-6} \frac{\text{As}^2 \cdot \text{Vm}}{\text{As} \cdot \text{m}^2} = 917 \cdot 10^{-6} \frac{\text{VAs}}{\text{m}} = 917 \cdot 10^{-6} \frac{\text{Ws}}{\text{m}} = +917 \cdot 10^{-6} \text{ N}$$
 Since both q_0 and q_1 have the same sign for their charges, they are repelling each other.

Therefore, The force $\vec{F}_{01}$ points to the right (positive value).

Similarly, we get for $\vec{F}_{02}$ and $\vec{F}_{03}$
$$\vec{F}_{02} = F_{02,x} = -1997 \cdot 10^{-6} \text{ N} \quad \vec{F}_{03} = F_{03,y} = -1123 \cdot 10^{-6} \text{ N}$$
 Since q_0 and q_2 have the different sign for their charges, they are attract each other. Therefore, The force $\vec{F}_{02}$ points to the left (negative value).

Since q_0 and q_3 have the different sign for their charges, they are attract

each other. Therefore, The force $\vec{F}_{03}$ points downwards (negative value).

[electrical_engineering_and_electronics:task_5u1zbroaz75w39jk_with_calculation](#)
electrostatic, field lines, exam ee2 ss2024

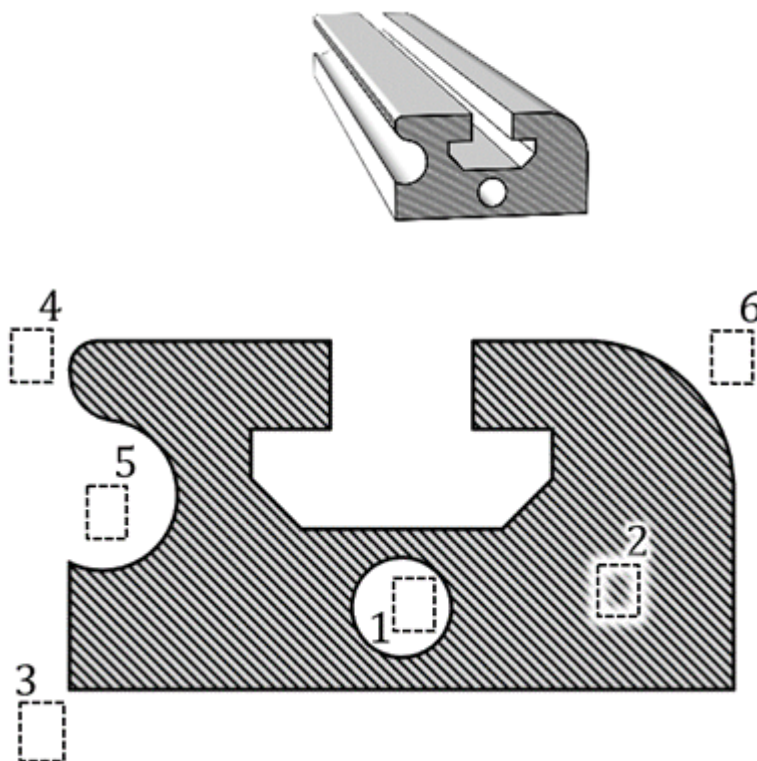
Exercise E1 Electrostatics II

(written test, approx. 10 % of a 120-minute written test, SS2024)

You must analyze an aluminum profile for usage in an environment critical for electrostatic discharge.

The figure on the right shows the cross-section of the aluminum element (hatched). During the application, it might get charged up. All areas in white consist of air (= dielectric).

Six designated areas are shown by dashed frames and numbers n, which are partly inside the object.



Arrange the designated areas clearly according to ascending field strengths $|\vec{E}_n|$ (absolute magnitude)! Indicate also, if designated areas have quantitatively the same field strength.

Result


```
\cdot 10^{-6} \{ \sim \rm m \} \} \} \end{align*}
```

[electrical_engineering_and_electronics:task_k4wrrhf8v46gct49_with_calculation](#)
[electrostatic](#), [capacitor](#), [plate capacitor](#), [capacity](#), [exam ee2 ss2024](#)

Exercise E1 Magnetic Field Lines (written test, approx. 6 % of a 120-minute written test, SS2024)

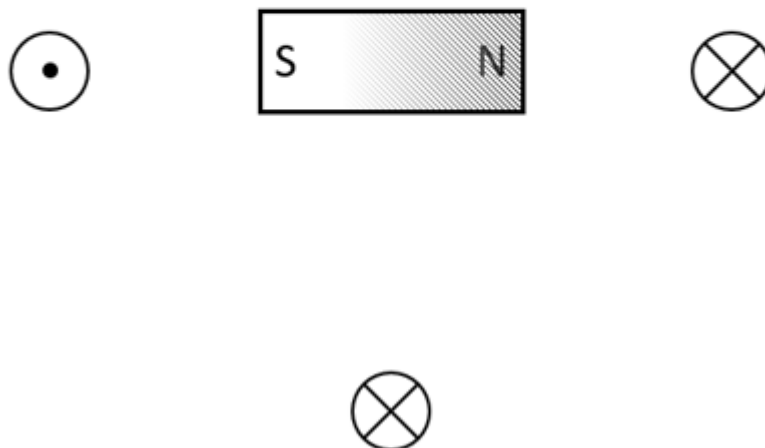
The following setup of a permanent magnet affects the H-field, based on the fundamental definition of the H-field.

- Four conductors are located perpendicular to the plane of the diagram

Result All of them conduct a current with the same magnitude, but not in the same direction.

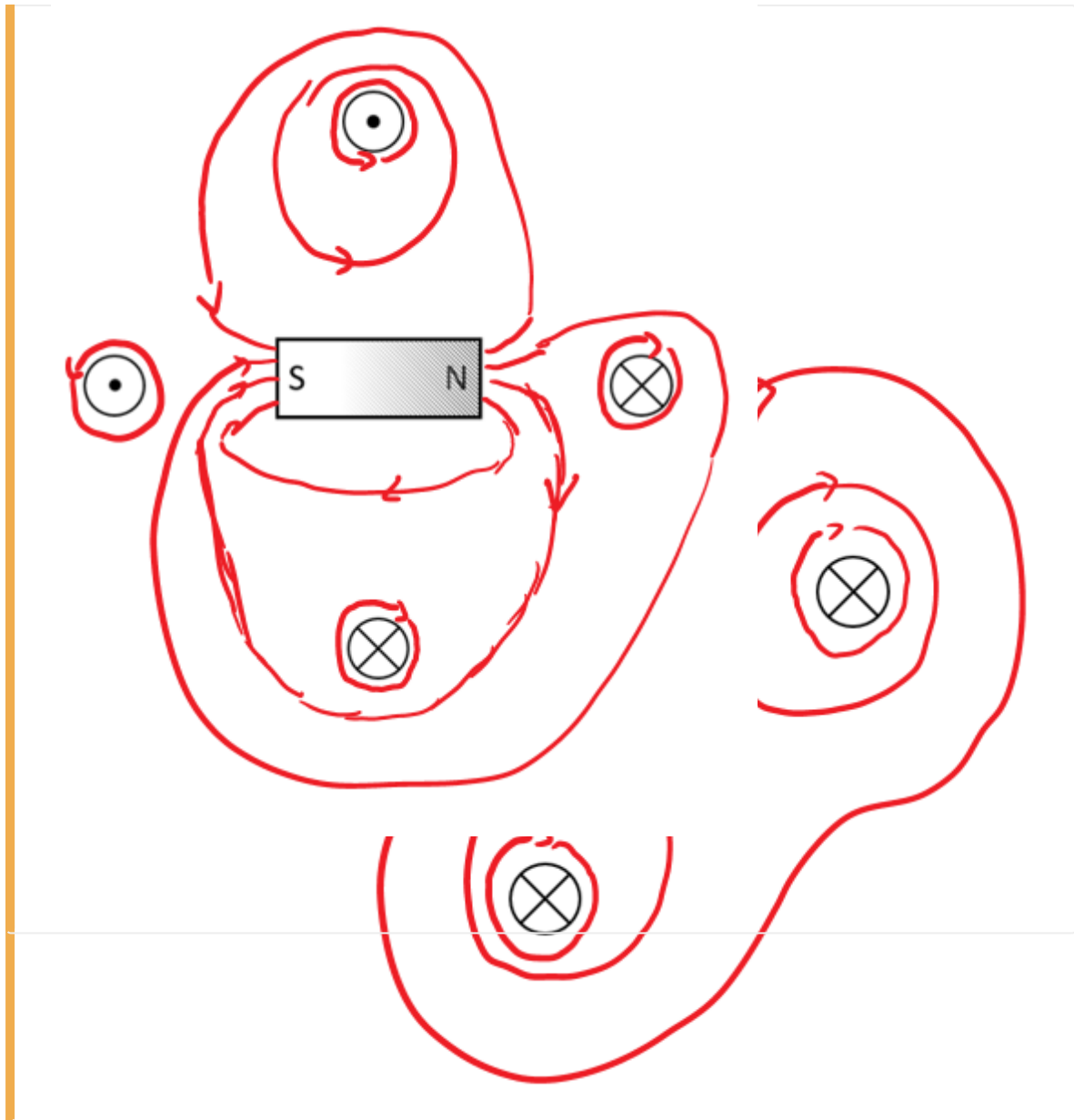
- A permanent magnet is located in between the conductors.

- The H-field is defined by currents $\sum I = \int H \{ \rm d \} s$.
- In the permanent magnet, there are no free currents.
- The bound currents (of the permanent magnet) create also an H field.
- This exits on the north pole and enters the magnet on the south pole (similar to the B-field)
- $H = B/\mu$
- The H-field from task 1 gets distracted



... Do not consider the permanent magnet at first. Draw at least 10 field lines of the H-field qualitatively. Give a correct representation of their direction, and density for the shown area.

Result



electrical_engineering_and_electronics:task_8a117vmnbbsbfz3_with_calculation
magnetostatic, magnetic field lines, exam ee2 ss2024

Exercise E1 Fields of an coax Cable

(written test, approx. 12 % of a 120-minute written test, SS2024)

2. With the graph of the magnitude of $B(r)$ with r in cm and B in mT at $r = 0.6$ shows the result $B(0.6) = 0.5 \text{ mT}$. To $r = 0$ with the origin $(0,0)$ in the diagram use proper dimensions and labels for the diagram appears:

- Inner conductor: $+3.3 \text{ mA}$, $+10 \text{ nC}$ (current into the plane of the diagram)
- for $(0.1 \text{ mm} | 0)$: $B_{(r=i)} = 328 \dots \text{ A/cm}^2$
- Outer conductor: -3.3 mA , 0 nC (current out of the plane of the diagram)
- for $(0.55 \text{ mm} | 0)$: $B_{(r=o)} = 0.985 \dots \text{ A/m}^2$

The magnitude of the electric displacement field D can be calculated by: $\int D \cdot dA = Q$.

- In general, the B -field is proportional to $\frac{1}{r}$ for the

Here, situation between two parallel conductors, the surrounding area is the surface of a cylinder. Since the charges are uniformly distributed on the conductors, the electric field is radial. This leads to the proportionality of the field with the radius r . Therefore, the formula $H = \frac{I}{2\pi \cdot r}$ is proportional to the area within this radius. So, we get for $H_{\text{rm i}}$ at $r_{\text{rm i}} = 0.1 \text{ mm}$, and $H_{\text{rm o}}$ at $r_{\text{rm o}} = 0.55 \text{ mm}$.

• For r within the outer conductor one also gets a linear proportionality. With a similar approach:

$$D_{\text{rm i}} = \frac{Q}{2\pi \cdot r_{\text{rm i}} \cdot l} \quad \text{and} \quad D_{\text{rm o}} = \frac{Q}{2\pi \cdot r_{\text{rm o}} \cdot l}$$

Hint: For the direction, one has to consider the sign of the enclosed charge. By this, we see that the D -field is positive. But here, again only the magnitude was questioned!

.. What is the magnitude of the magnetic field strength H at $r_{\text{rm i}} = 0.1 \text{ mm}$ and $r_{\text{rm o}} = 0.55 \text{ mm}$?

Path

The magnitude of the magnetic field strength H can be calculated by: $H = \frac{I}{2\pi \cdot r}$
 So, we get for $H_{\text{rm i}}$ at $r_{\text{rm i}} = 0.1 \text{ mm}$, and $H_{\text{rm o}}$ at $r_{\text{rm o}} = 0.55 \text{ mm}$:

$$H_{\text{rm i}} = \frac{I}{2\pi \cdot r_{\text{rm i}}} \quad \text{and} \quad H_{\text{rm o}} = \frac{I}{2\pi \cdot r_{\text{rm o}}}$$

Hint: For the direction, one has to consider the right-hand rule. By this, we see that the H -field on the right side points downwards. Therefore, the sign of the H -field is negative. But here, only the magnitude was questioned!

electrical_engineering_and_electronics:task_ddjurcpk494go2q1_with_calculation
electric field, magnetic field, exam ee2 ss2024

Exercise E2 Lorentz Force

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

2. Design a lifting system for a mobile shuttle with two coils in a homogeneous magnetic field of the shuttle. To do this, the resulting force exerted by the permanent magnets of the shuttle must be repulsive (see image).

Result

Mobile Shuttle

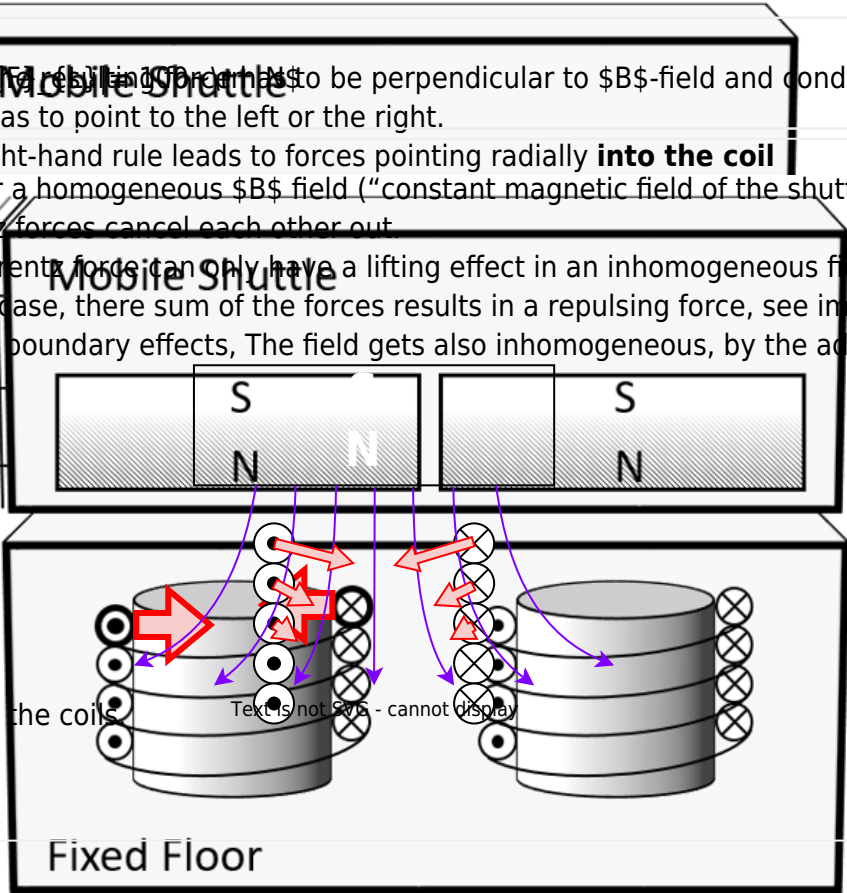
Since the resulting force has to be perpendicular to B -field and conductor, the force has to point to the left or the right.

The right-hand rule leads to forces pointing radially **into the coil**.

No. For a homogeneous B -field ("constant magnetic field of the shuttle"), the Lorentz forces cancel each other out.

The Lorentz force can only have a lifting effect in an inhomogeneous field. In this case, the sum of the forces results in a repulsive force, see image.

Beside boundary effects, the field gets also inhomogeneous, by the additional



field of the coils

Text is not seen - cannot display

Fixed Floor

- current $I = 1.6 \text{ A}$
- magnetic field of the shuttle is homogeneous with $B = 0.5 \text{ T}$

1. Calculate the magnitude of the resulting force on one coil!

Path

The Lorentz force on a conductor the length l and the current I in a B -field is

$$|\vec{F}_L| = I \cdot l \cdot B \cdot \cos(\angle \vec{B}, \vec{l})$$

$$= I \cdot (N \cdot 2\pi r) \cdot B \cdot \cos(\angle \vec{B}, \vec{l})$$

$$= 1.6 \text{ A} \cdot (500 \cdot 2\pi \cdot 40 \cdot 10^{-3} \text{ m}) \cdot 0.5 \text{ T} \cdot \cos 90^\circ$$

electrical_engineering_and_electronics:task_5efsj705cf97jxga_with_calculation
 lorentz force, magnetic field, exam ee2 ss2024

Exercise E2 Magnetic Potential

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

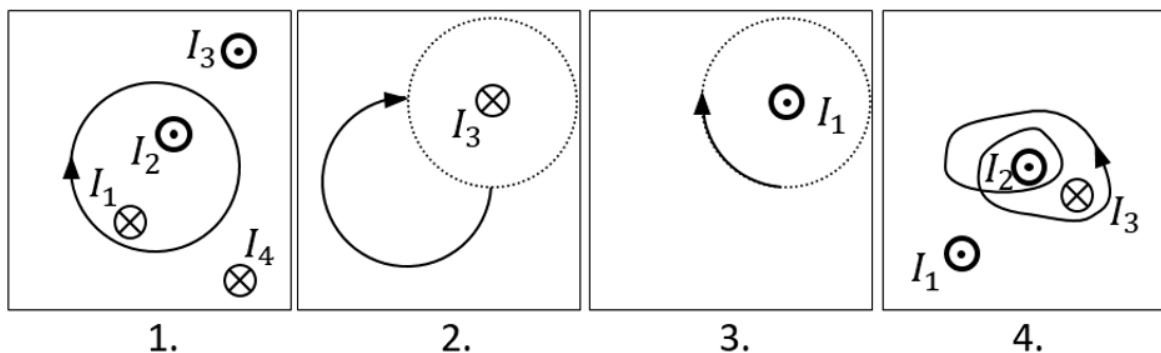
Calculate the magnetic potential difference V_{m} for the following paths as shown by the solid lines.

Dotted lines are only for there for symmetry aspects!

The wires conduct the following currents:

- $|I_1| = 2 \text{ A}$
- $|I_2| = 5 \text{ A}$
- $|I_3| = 11 \text{ A}$
- $|I_4| = 7 \text{ A}$

Pay attention to the signs of the currents (given by the diagrams) and of the results!



Result

Based on the right-hand rule and the part of a full revolution the following results:

1. Task: $+I_1 - I_2 = -3 \text{ A}$
2. Task: $+\frac{1}{4} I_3 = 11/4 \text{ A}$ (it does not matter which way the path goes from the startpoint to the endpoint, as long as it has the same direction and number of revolutions)
3. Task: $-\frac{1}{4} I_1 = -0.5 \text{ A}$
4. Task: $+2 \cdot I_2 - 1 \cdot I_3 = -1 \text{ A}$

electrical_engineering_and_electronics:task_kmp8r8y6lvwjnoc3_with_calculation
magnetic potential, exam ee2 ss2024

Exercise E1 Self-Induction

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

2. Determine the length of a solenoid with a diameter of 2 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 ($\mu_r = 1$).

$$L = 1.32 \cdot 10^{-3} \text{ Vs/Am}$$

For the linear change of the current the formula of the induced voltage can also be linearized:
$$u_{\text{ind}} = -L \cdot \frac{di}{dt} \Rightarrow -L \cdot \frac{\Delta i}{\Delta t} = -1.32 \cdot 10^{-3} \cdot \frac{3 \text{ A}}{0.02 \cdot 10^{-3} \text{ s}}$$

The formula for the induction of a long coil is:
$$L = \mu_0 \mu_r N^2 A \Rightarrow 4\pi \cdot 10^{-7} \cdot (500)^2 \cdot \frac{\pi (2 \cdot 10^{-2} \text{ m})^2}{2 \cdot 10^{-2} \text{ m}} = 1.32 \cdot 10^{-3} \text{ Vs/Am}$$

electrical_engineering_and_electronics:task_ljxf80q7vxywehqf_with_calculation
induction, exam ee2 ss2024

Exercise E4 Magnetic Circuit

(written test, approx. 9 % of a 120-minute written test, SS2024)

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

Path

$$R_{\text{m}} = \frac{l}{\mu_0 \mu_r A} = 0.84 \cdot 10^6 \frac{1}{\text{Vs/Am}}$$

First we have to calculate the magnetic resistance is a magnetic circuit. Based on the sources:
$$R_{\text{m}} = \frac{l}{\mu_0 \mu_r A} = \frac{3 \text{ dm}}{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 1 \cdot 300 \cdot 10^{-6} \text{ m}^2} = 0.84 \cdot 10^6 \frac{1}{\text{Vs/Am}}$$

$$\Phi = \frac{N \cdot I}{R_m}$$

$$\Phi = \frac{N_1 I_1 + N_2 I_2 + N_3 I_3}{R_m}$$

$$\Phi = \frac{1200 \cdot 0.1 + 33 \cdot 3 + 270 \cdot 0.3}{0.884 \cdot 10^{-6} \cdot \frac{1}{H}}$$

$$\Phi = 67.8 \cdot 10^{-6} \cdot H$$

$$\Phi = 67.8 \cdot 10^{-6} \cdot H$$

$$\Phi = 67.8 \cdot 10^{-6} \cdot H$$

On the core, there are three coils with:

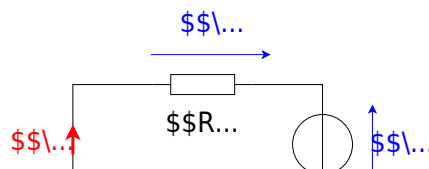
- Coil 1: $N_1 = 1200$, $I_1 = 100 \text{ mA}$
- Coil 2: $N_2 = 33$, $I_2 = 3 \text{ A}$
- Coil 3: $N_3 = 270$, $I_3 = 0.3 \text{ A}$

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

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

Result

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



electrical_engineering_and_electronics:task_n1kwu944m7jac3tf_with_calculation
magnetic circuit, exam ee2 ss2024

Exercise E5 Magnetic Circuit

(written test, approx. 10 % of a 120-minute written test, SS2024)

2. **Resultant** $\$10$ in voltage on the inductor and $\$6$ in the $\$4$ shown circuit?

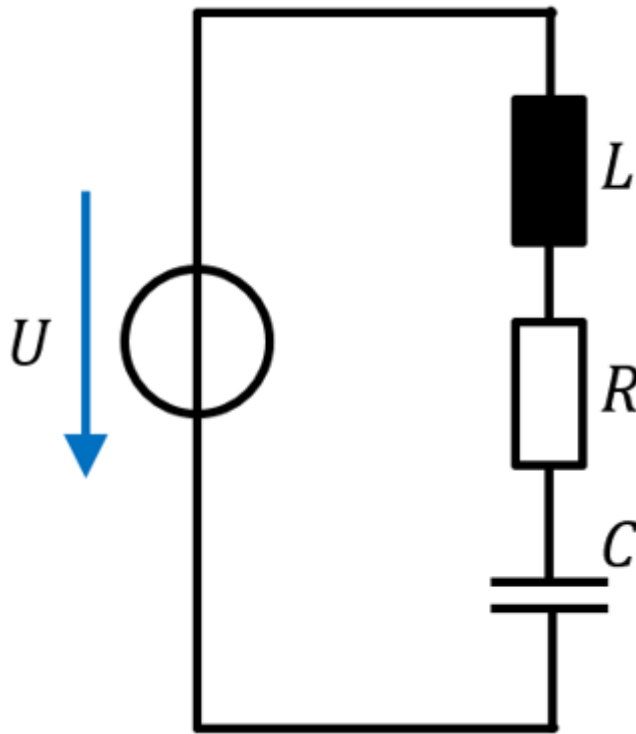
Path

$U_C = 100 \text{ ~V}$

- $f_{\text{under}} \{Z\} \text{ MLE} = 83.0 \sim \text{m} \Omega$

- $\underline{Z_0} = 20.0 \, \Omega$

The formula for the resonance frequency f_r is:
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$
 The voltage on the ideal capacitor is the input voltage by the Q -factor $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ increased.
$$U_C = U \cdot Q = U \cdot \frac{1}{R}\sqrt{\frac{L}{C}}$$
 The impedance at resonance is purely the resistance $Z = R$ and
$$I = \frac{U}{Z} = \frac{U}{R}$$



A given capacitor shall have the following values:

- $C = 10 \text{ nF}$
- $R = 20 \text{ m}\Omega$
- $L = 1.6 \text{ nH}$

1. What is the impedance Z_{RLC} of this real capacitor for $f_0 = 44 \text{ MHz}$? (Phase and magnitude)

Path

The impedance is based on the resistance R and the reactance $X_{\text{LC}} = \text{Im}(Z_{\text{RLC}})$:
$$\underline{Z}_{\text{RLC}} = R + j(X_L - X_C) = R + j(\omega L - \frac{1}{\omega C}) = R + j(2\pi f \cdot L - \frac{1}{2\pi f \cdot C})$$

The reactive part is
$$X_{\text{LC}} = 2\pi f \cdot L - \frac{1}{2\pi f \cdot C} = 2\pi \cdot 44 \cdot 10^6 \text{ MHz} \cdot 1.6 \cdot 10^{-9} \text{ nH} - \frac{1}{2\pi \cdot 10^6 \text{ MHz} \cdot 10 \cdot 10^{-9} \text{ nF}} = +0.08062 \dots \Omega$$

To get the magnitude of the impedance $|\underline{Z}_{\text{RLC}}|$ one can use the Pythagorean Theorem:
$$|\underline{Z}_{\text{RLC}}| = \sqrt{R^2 + X_{\text{LC}}^2} = \sqrt{(0.020 \text{ m}\Omega)^2 + (0.08062 \dots \Omega)^2} = 0.0830 \dots \Omega$$

For the phase φ the $\arctan$ can be applied:
$$\varphi = \arctan\left(\frac{X_{\text{LC}}}{R}\right) = \arctan\left(\frac{0.08062 \dots}{0.020}\right)$$

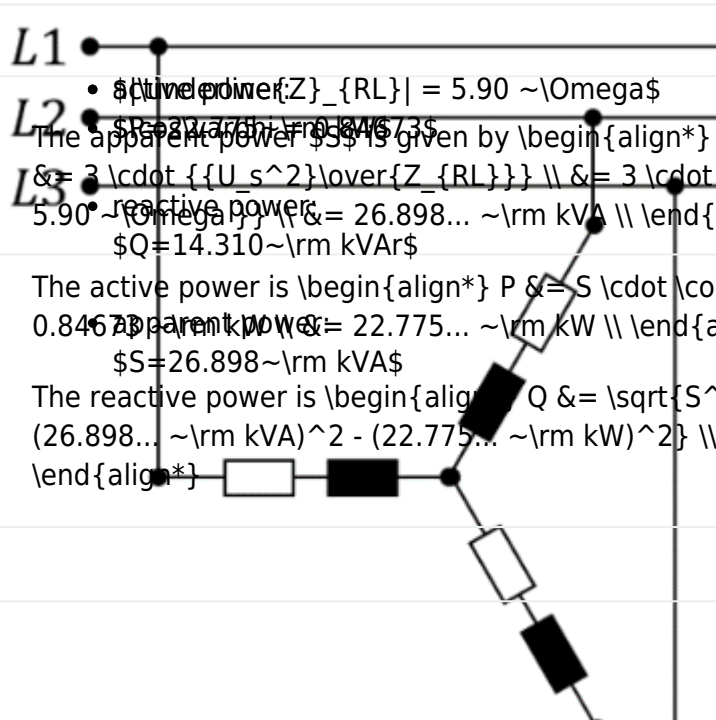
$$\sim \Omega \over{0.020 \sim \Omega} \right) \parallel \hat{=} 1.3276 \dots \hat{=} +76^\circ \parallel$$

electrical_engineering_and_electronics:task_yh4srwxu1bo1r4dy4_with_calculation
resonance, impedance, resonant circuit, exam ee2 ss2024

Exercise E6 Magnetic Circuit

(written test, approx. 10 % of a 120-minute written test, SS2024)

2. Calculate and draw the apparent power, and the active and reactive power of the 400 V, 50 Hz three-phase power net. Each single string has a resistor $R=5 \sim \Omega$ and an inductance of $L=10 \sim \text{mH}$.
Path



$|Z_{RL}| = 5.90 \sim \Omega$
 $S = 26.898 \sim \text{kVA}$
 $P = 22.775 \sim \text{kW}$
 $Q = 14.310 \sim \text{kVAr}$

The apparent power S is given by
$$S = 3 \cdot U_s \cdot I_s \parallel \hat{=} 3 \cdot \frac{U_s^2}{|Z_{RL}|} \parallel \hat{=} 3 \cdot \frac{(230 \sim \text{V})^2}{5.90 \sim \Omega} \parallel \hat{=} 26.898 \dots \sim \text{kVA}$$

The active power is
$$P = S \cdot \cos \varphi \parallel \hat{=} 26.898 \dots \cdot 0.8467 \parallel \hat{=} 22.775 \dots \sim \text{kW}$$

The reactive power is
$$Q = \sqrt{S^2 - P^2} \parallel \hat{=} \sqrt{(26.898 \dots \sim \text{kVA})^2 - (22.775 \dots \sim \text{kW})^2} \parallel \hat{=} 14.310 \dots \sim \text{kVAr}$$

1. Calculate the $\cos \varphi$, and the magnitude of the impedance $|Z|$ for a single string.

Path

$$\varphi = \arctan \left(\frac{X_L}{R} \right) \parallel \hat{=} \arctan \left(\frac{2\pi \cdot f \cdot L}{R} \right) \parallel \hat{=} \arctan \left(\frac{2\pi \cdot 50 \sim \text{Hz} \cdot 10 \cdot 10^{-3} \sim \text{H}}{5 \sim \Omega} \right) \parallel \hat{=} 0.5609 \dots \hat{=} +32^\circ$$

With this, the $\cos \varphi$ becomes $\begin{align*} \cos \varphi &= \cos(0.5609 \dots) \\ &= 0.84673 \dots \end{align*}$

The impedance is given by: $\begin{align*} |\underline{Z}_{RL}| &= \sqrt{X_L^2 + R^2} \\ &= \sqrt{(2\pi \cdot f \cdot L)^2 + R^2} \\ &= \sqrt{(2\pi \cdot 50 \text{ Hz} \cdot 10 \cdot 10^{-3} \text{ H})^2 + (5 \Omega)^2} \\ &= 5.905 \dots \Omega \end{align*}$

electrical_engineering_and_electronics:task_d9io924n0e3du21g_with_calculation
resonance, impedance, resonant circuit, exam ee2 ss2024

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