

Exam Summer Semester 2024

Student Group

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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.

Tasks

Exercise E1 Electrostatics I

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

Given is the arrangement of the charges as in 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 N on q_0 ?

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

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

Path: $E_4 = 2507 \text{ V/m}$

$$\vec{F}_{01} = \left(\begin{array}{c} +917 \\ \sim \mu \text{N} \end{array} \right) \parallel 0$$

In the beginning the are 5 components, we cannot calculate the resulting magnitude of the force.

$$|\vec{E}_4| = 1.897 \cdot 10^{12} \text{ V/m}$$

$$|\vec{F}_{01}| = \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2}$$

$$|\vec{F}_{01}| = \sqrt{\left(\sum_i q_0 E_{i,x} \right)^2 + \left(\sum_i q_0 E_{i,y} \right)^2}$$

$$|\vec{F}_{01}| = q_0 \sqrt{E_4^2 + E_1^2}$$

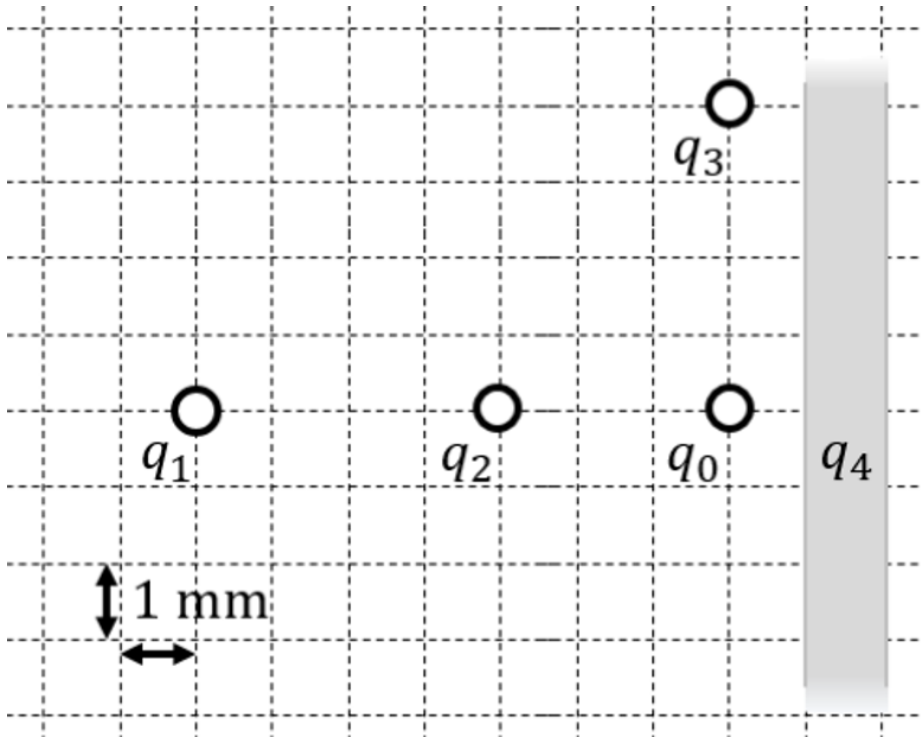
$$|\vec{F}_{01}| = |E_4| \cdot |q_0| \implies E_4 = \frac{|\vec{F}_{01}|}{|q_0|}$$

$$E_4 = \frac{917 \cdot 10^{-6} \text{ N}}{1 \cdot 10^{-9} \text{ C}} = 917 \cdot 10^3 \text{ V/m}$$

$$E_4 = 917 \cdot 10^3 \frac{\text{V}}{\text{m}} = 917 \cdot 10^3 \frac{\text{V}}{\text{m}}$$

$$E_4 = 917 \cdot 10^3 \frac{\text{V}}{\text{m}}$$

$$E_4 = 917 \cdot 10^3 \frac{\text{V}}{\text{m}}$$



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 $F_{01,x}$.

$$\begin{aligned} \vec{F}_{01} &= F_{01,x} \hat{x} = \\ &= \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_0}{r_{01}^2} \hat{x} = \\ &= \frac{1}{4\pi \cdot 8.854 \cdot 10^{-12} \text{ As/Vm}} \cdot \frac{1 \cdot 10^{-9} \text{ C} \cdot 5 \cdot 10^{-9} \text{ C}}{(7 \cdot 10^{-3} \text{ m})^2} \hat{x} = \\ &= 917. \dots \cdot 10^{-6} \frac{\text{As}^2 \cdot \text{Vm}}{\text{As} \cdot \text{m}^2} = \\ &= 917. \dots \cdot 10^{-6} \frac{\text{VA}}{\text{m}} = 917. \dots \cdot 10^{-6} \text{ N} \end{aligned}$$

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}

$$\begin{aligned} \vec{F}_{02} &= F_{02,x} \hat{x} = -1123. \dots \text{ N} \\ \vec{F}_{03} &= F_{03,y} \hat{y} = -1123. \dots \text{ N} \end{aligned}$$

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).



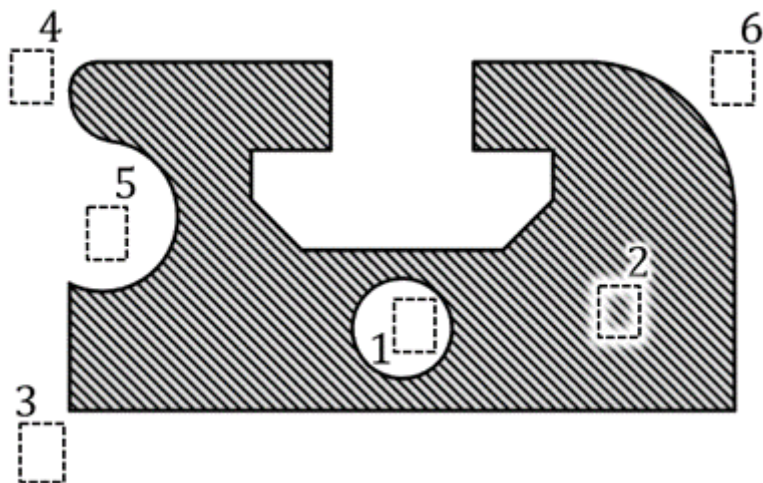
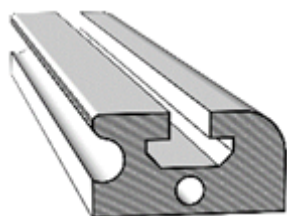
electrical_engineering_and_electronics:task_5u1zbroaz75w39jk_with_calculation
electrostatic, field lines, exam ee2 ss2024

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

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

Exercise E3 Capacitor

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

0. Calculate the capacity of a capacitor, the dielectric is a paper with a relative permittivity $\epsilon_r = 3.3$. The distance between the plates is $d = 200 \mu\text{m}$. The area of the plates is $A = 25 \text{ cm}^2$. The air between the plates has a relative permittivity $\epsilon_r = 1$. The supply voltage is $U = 3.3 \text{ V}$. The result is approx. $C = 146 \text{ pF}$.

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

Path

$$C_2 = f(A, d, x, \epsilon_r, \epsilon_{\text{air}})$$

$$Q = \frac{U \cdot C_2}{d} = \frac{U \cdot \epsilon_0 \cdot A \cdot \left(\frac{\epsilon_r}{d-x} + \frac{\epsilon_{\text{air}}}{x} \right)}{d}$$

There are two ways now. Either: $Q = C \cdot U = 1.1 \text{ nC}$ Or: $Q = D \cdot A = 146 \text{ pC}$

The displacement field is given by: $D = \epsilon_0 \cdot \epsilon_r \cdot E$

The resulting capacity C is now $C = \frac{Q}{U} = \frac{146 \text{ pC}}{3.3 \text{ V}} = 44.2 \text{ pF}$

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

With $C_{\text{air}} = \epsilon_0 \cdot \epsilon_{\text{air}} \cdot \frac{A}{d}$ and $C_{\text{c}} = \epsilon_0 \cdot \epsilon_r \cdot \frac{A}{x}$

$$C_{\text{air}} = \epsilon_0 \cdot \frac{A}{d} = 8.854 \cdot 10^{-12} \cdot \frac{25 \cdot 10^{-6}}{200 \cdot 10^{-6}} = 1.1 \text{ pF}$$

$$C_{\text{c}} = \epsilon_0 \cdot \epsilon_r \cdot \frac{A}{x} = 8.854 \cdot 10^{-12} \cdot 3.3 \cdot \frac{25 \cdot 10^{-6}}{200 \cdot 10^{-6}} = 3.6 \text{ pF}$$

- in the following such a sensor is given with:
- This leads to: $C = \frac{\epsilon_0 \cdot A}{d} \left(\frac{1}{1} + \frac{x}{\epsilon_r} \right)$
- Plate area: $A = 25 \text{ cm}^2$
 - Distance between both plates: $d = 200 \mu\text{m}$
 - Air between the plates: $\epsilon_r = 1$
 - 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

$$C = \epsilon_0 \cdot \epsilon_r \cdot \frac{A}{d} \left(\frac{1}{1} + \frac{x}{\epsilon_r} \right) = 8.854 \cdot 10^{-12} \cdot 1 \cdot \frac{25 \cdot 10^{-6}}{200 \cdot 10^{-6}} \left(1 + \frac{200 \cdot 10^{-6}}{3.3} \right) = 146 \text{ pF}$$

electrostatic, capacitor, plate capacitor, capacity, exam ee2 ss2024

Exercise E4 Magnetic Field Lines
(written test, approx. 6 % of a 120-minute written test, SS2024)

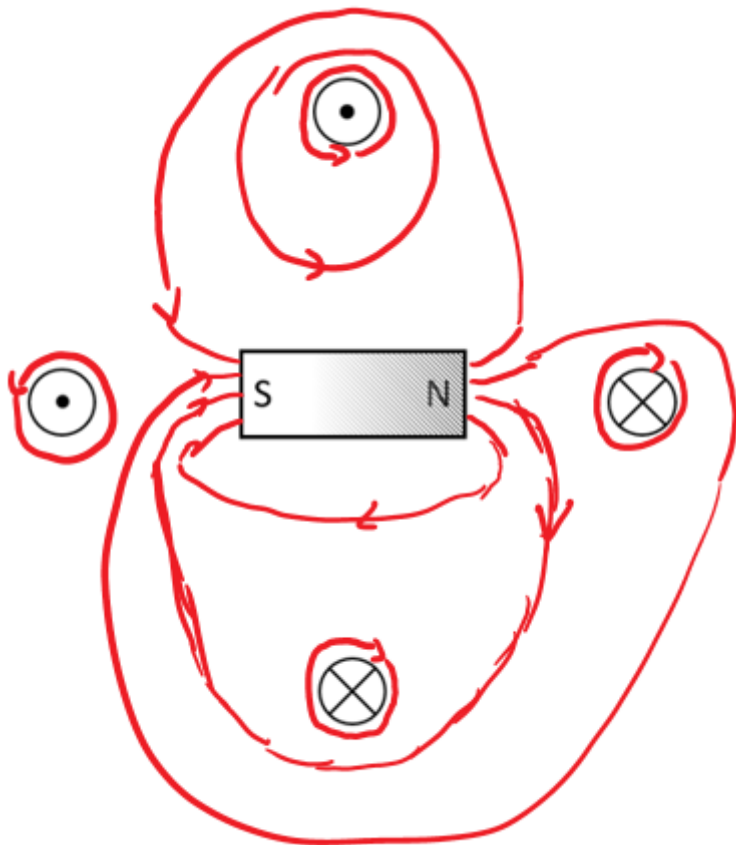
The following setup of a permanent magnet affects the H-field, based on the fundamental definition of the H-field.

- 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 $\sum I = \int H \{ \text{r m d} \} s$.
- 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



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

cylinder shape. We get for a wire with a radius of the conductor r_0 and a length l the enclosed charge $Q_{enc} = \rho \cdot V = \rho \cdot \pi r^2 l$. This leads to the enclosed charge $Q_{enc} = \rho \cdot \pi r^2 l$ with the radius r and the length l . The magnetic field strength H is proportional to the area within this radius. Therefore, the formula $H = \frac{I}{2 \pi r}$ gets $H(r) = \frac{I}{2 \pi r} \cdot \frac{\pi r^2}{\pi r_0^2} = \frac{I r}{2 \pi r_0^2}$. So, we get for $H(r_0)$ at $r = r_0$ the formula $H(r_0) = \frac{I}{2 \pi r_0}$. For $r < r_0$ within the outer conductor one also gets a linear proportionality with a similar approach.

$$H(r_i) = \frac{I}{2 \pi r_i} \cdot \frac{\pi r_i^2}{\pi r_0^2} = \frac{I r_i}{2 \pi r_0^2}$$

$$H(r_o) = \frac{I}{2 \pi r_o} \cdot \frac{\pi r_o^2}{\pi r_0^2} = \frac{I r_o}{2 \pi r_0^2}$$

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

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

Path

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

So, we get for $H(r_i)$ at $r = 0.1 \text{ mm}$, and $H(r_o)$ at $r = 0.55 \text{ mm}$:

$$H(r_i) = \frac{I}{2 \pi r_i} = \frac{+3.3 \text{ A}}{2 \pi \cdot 0.1 \cdot 10^{-3} \text{ m}}$$

$$H(r_o) = \frac{I}{2 \pi r_o} = \frac{+3.3 \text{ A}}{2 \pi \cdot 0.55 \cdot 10^{-3} \text{ m}}$$

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 E1 Lorentz Force

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

2. Consider a mobile system for the lift of a shuttle consisting of a homogeneous current field in the fixed floor, the resulting force repels the shuttle into the air (see image).

Result

Path

Since the result in \vec{F} has to be perpendicular to \vec{B} -field and conductor, the force has to point to the left or the right.
 For a homogeneous \vec{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.
 Besides boundary effects, The field gets also inhomogeneous, by the additional field of the coils.

- 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 \vec{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 E1 Magnetic Potential

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

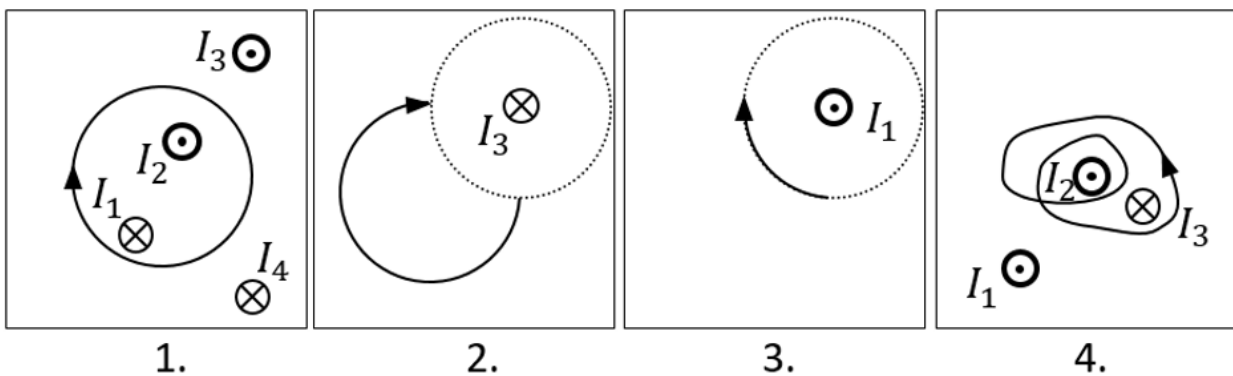
Calculate the magnetic potential difference V_{m} for the following paths as shown by the solid lines.

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: $+\frac{1}{4} I_3 = \frac{11}{4} \text{ A}$ (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 height of a 30 V magnetostatic air core solenoid with 2 turns per cm and 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

$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$
$u_{\text{ind}} = 1.32 \cdot 10^{-3} \text{ V}$
.. Calculate the (self-)inductance of the coil. For the linear change of the current the formula of the induced voltage can also be linearized: $u_{\text{ind}} = -L \cdot \frac{di}{dt} \Rightarrow L = -\frac{u_{\text{ind}} \cdot dt}{di} = -\frac{1.32 \cdot 10^{-3} \text{ V} \cdot 0.02 \cdot 10^{-3} \text{ s}}{3 \text{ A}} = -8.8 \cdot 10^{-7} \text{ H}$
The formula for the induction of a long coil is: $L = \mu_0 \mu_r \cdot N^2 \cdot \frac{A}{l} = 4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot (500)^2 \cdot \frac{\pi \cdot (2 \cdot 10^{-2} \text{ m})^2}{2 \cdot 10^{-2} \text{ m}} = 3.96 \cdot 10^{-3} \text{ H}$

electrical_engineering_and_electronics:task_ljxf80q7vxywehqf_with_calculation
induction, exam ee2 ss2024

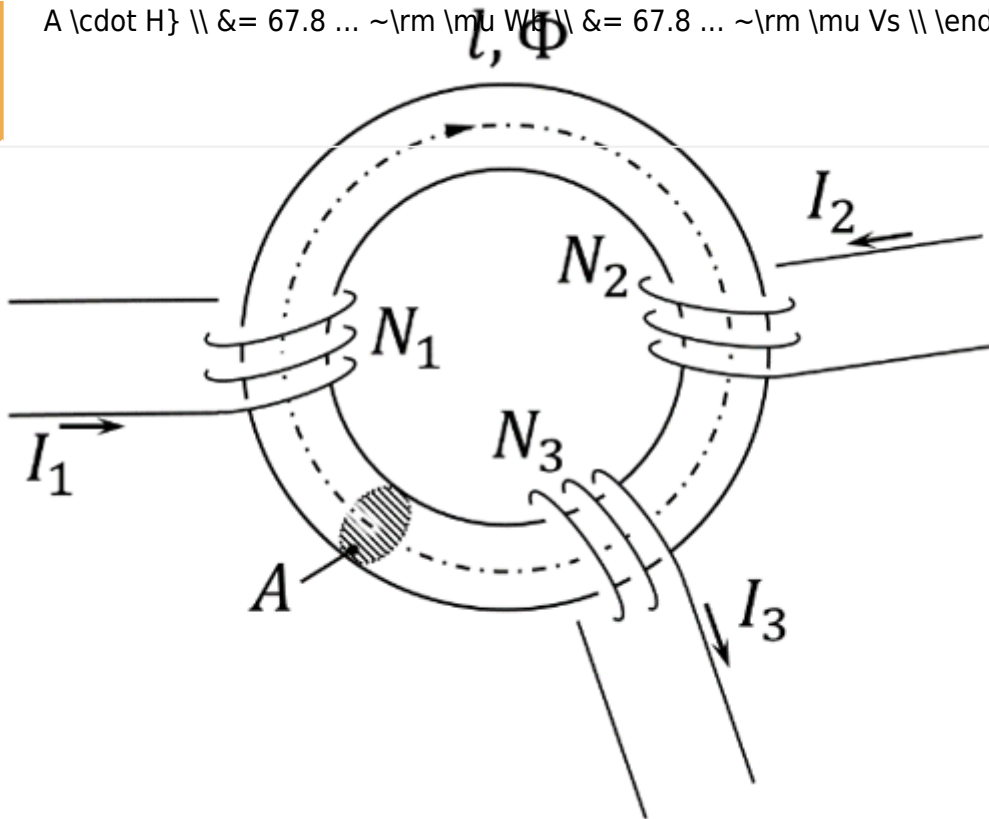
Exercise E10 Magnetic Circuit

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

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

$R_{\text{m}} = 0.884 \cdot 10^6 \text{ 1/H}$
First we have to calculate the magnetic resistance R_m based on the sources: $R_m = \frac{l}{\mu_0 \mu_r A} = \frac{3 \text{ m}}{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 300 \cdot 10^{-6} \text{ m}^2} = 7.96 \cdot 10^6 \text{ 1/H}$ $R_m = 7.96 \cdot 10^6 \text{ 1/H} \cdot 0.11 = 8.84 \cdot 10^5 \text{ 1/H}$
To get the flux Φ , the Hopkinson's Law can be applied - similar to the Ohm's Law: $\Phi = \frac{I}{R_m} = \frac{60 \text{ A}}{8.84 \cdot 10^5 \text{ 1/H}} = 6.78 \cdot 10^{-5} \text{ Wb}$

$$A \cdot H = 67.8 \dots \text{ (m Wb)} = 67.8 \dots \text{ (}\mu\text{Vs)}$$



On the core, there are three coils with:

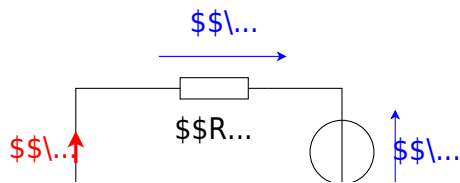
- Coil 1: $N_1 = 1200$, $I_1 = 100 \text{ mA}$
- Coil 2: $N_2 = 33$, $I_2 = 3 \text{ A}$
- Coil 3: $N_3 = 270$, $I_3 = 0.3 \text{ A}$

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

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

Result

- Since the material, and diameter of the core is constant, one can directly simplify the magnetic resistor into a single $R \text{ m}$.
- 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 E12 Magnetic Circuit
(written test, approx. 10 % of a 120-minute written test, SS2024)

2. For a series RLC circuit, the impedance Z is given by $Z = R + j\omega L - j/\omega C$. The resonance frequency f_r is the frequency where the voltage across the capacitor is equal to the voltage across the resistor. What is the resonance frequency f_r in the shown circuit?

Path

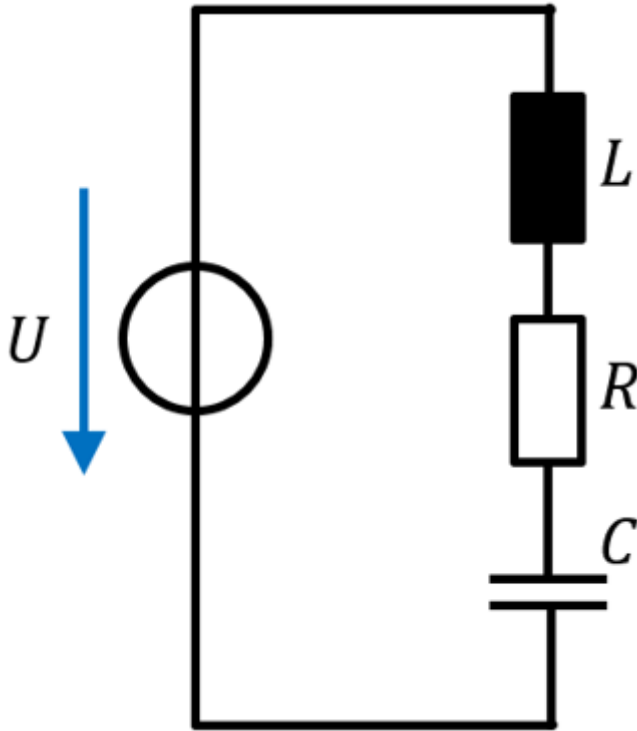
$U_C = 100 \text{ V}$

- $f_r = 83.0 \text{ m}\Omega$
- $Z_{RLC}(f_r) = 20.0 \text{ m}\Omega$

The formula for the resonance frequency f_r is:
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

The voltage across the capacitor is the input voltage by the Q -factor increased U_C
$$U_C \cdot Q = U_C \cdot \frac{\omega L}{R} = 100 \text{ V} \cdot \frac{2\pi \cdot 83.0 \cdot 10^{-3} \text{ s} \cdot 1.6 \cdot 10^{-9} \text{ H}}{10 \text{ }\Omega} = 100 \text{ V}$$

The impedance at resonance is purely the resistor $Z = R = 10 \text{ }\Omega$



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 $X_{LC} = \text{j} \cdot (X_L - X_C)$:
$$\underline{Z}_{RLC} = R + \text{j} \cdot (X_L - X_C) = R + \text{j} \cdot (\omega L - \frac{1}{\omega C}) = R + \text{j} \cdot (2\pi f \cdot L - \frac{1}{2\pi f \cdot C})$$

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

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

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

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

electrical_engineering_and_electronics:task_yh4srwxu1bo1rdy4_with_calculation
 resonance, impedance, resonant circuit, exam ee2 ss2024

Exercise E1 Magnetic Circuit
(written test, approx. 10 % of a 120-minute written test, SS2024)

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

L1

- $|Z_{RL}| = 5.90 \Omega$

L2

- $S = 22.775 \text{ kVA} / 3$

L3

- reactive power

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

The active power is
$$P = S \cdot \cos \varphi = 26.898 \text{ kVA} \cdot 0.84673 = 22.775 \text{ kW}$$

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

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

Path

The phase φ is given by:
$$\varphi = \arctan \left(\frac{X_L}{R} \right) = \arctan \left(\frac{2\pi \cdot f \cdot L}{R} \right) = \arctan \left(\frac{2\pi \cdot 50 \text{ Hz} \cdot 10 \cdot 10^{-3} \text{ H}}{5 \Omega} \right) = 0.5609 \dots \hat{=} +32^\circ$$

With this, the $\cos \varphi$ becomes
$$\cos \varphi = \cos(0.5609 \dots)$$

$$Z = 0.84673 \dots \Omega$$

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

[electrical_engineering_and_electronics:task_d9io924n0e3du21g_with_calculation](#)
resonance, impedance, resonant circuit, exam ee2 ss2024

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