

## Exam

# Electrical Machines and Drives

Winter 2025/26

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First name:

Last name:

Matriculation number:

Study program:

Instructions:

- You can only take part in the exam, if you are registered in the campus management system.
- Prepare your student ID and a photo ID card on your desk.
- Label each exam sheet with your name. Start a new exam sheet for each task.
- Answers must be given with a complete, comprehensible solution. Answers without any context will not be considered. Answers are accepted in German and English.
- Permitted tools are (exclusively): black / blue pens (indelible ink), triangle, a non-programmable calculator without graphic display and two DIN A4 cheat sheets.
- The exam time is 120 minutes.

Evaluation:

Task	1	2	3	4	$\Sigma$
Maximum score	10	12	7	13	42
Achieved score					

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**Task 1: Design of a single phase transformer**

[10 Points]

An (older) smartphone charger is constructed as shown in Fig. 1. The input (grid) voltage at the transformer is  $U_1 = 230 \text{ V}$ . The output voltage of the charger should have an average voltage of  $U_{\text{out}} = 5 \text{ V}$ . The rectifier causes an average voltage drop of  $U_{\text{rectifier}} = 0.7 \text{ V}$  between  $U_2$  and  $U_{\text{out}}$ . The transformer has a rated apparent power of 100 VA.

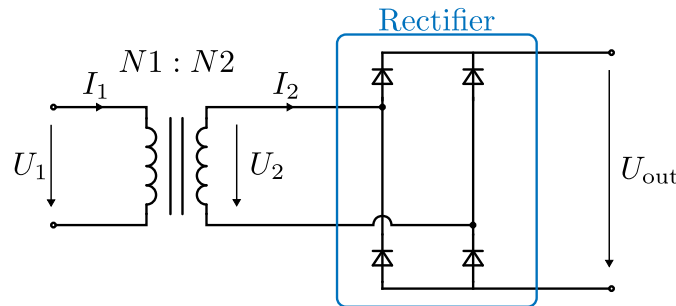


Fig. 1: Simplified sketch of a smartphone charger.

1.1 Calculate the secondary voltage, the turns ratio as well as the primary and secondary current of the transformer for rated and idealized conditions. [2 Points]

Hint: if and only if you are not able to solve this task, use  $I_1 = 0.6 \text{ A}$ ,  $I_2 = 21 \text{ A}$  and  $\ddot{u} = 35$  as substitute results for the subsequent tasks.

1.2 The transformer's geometry and design is to be analyzed in more detail. The laminated core is specified as EI 84/43.5 with a magnetic flux density of  $B_{\text{Fe}} = 1.2 \text{ T}$  in the middle yoke. There are no stray fluxes, and the output voltage remains constant when the transformer is loaded. Calculate the effective cross-sectional area  $A_{\text{Fe}}$  of the iron yoke, the magnetic flux  $\phi_{\text{Fe}}$  and the magnetomotive force  $\theta$ . The geometry and its dimensions are shown in Fig. 2. [3 Points]

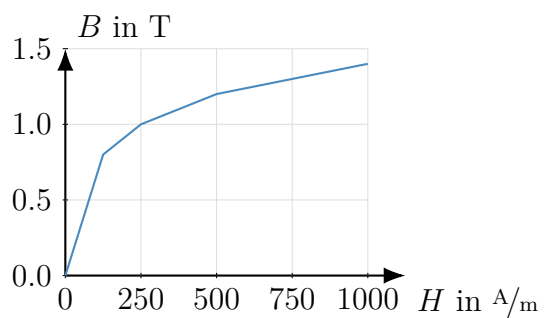
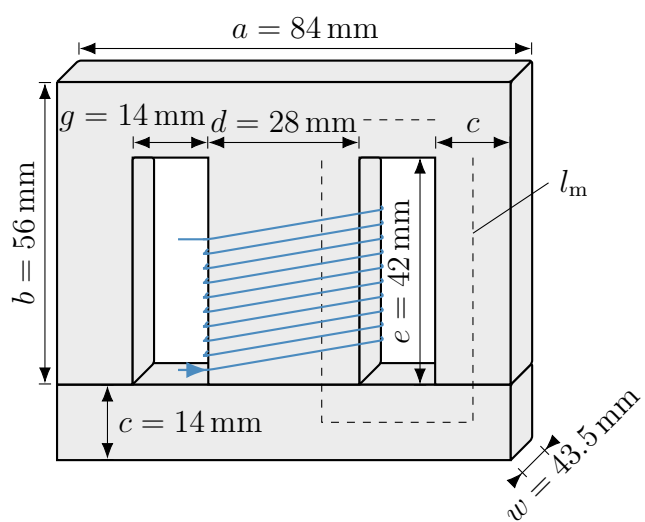
Hint: if and only if you are not able to solve this task, use  $\theta = 100 \text{ A}$  as a substitute result for the subsequent tasks.

1.3 Calculate the integer number of winding turns on the primary and secondary side. [1 Point]

1.4 Determine the ohmic winding losses and wire diameters of the primary and secondary sides. First calculate the winding cross-sections assuming a current density of  $J = 3 \text{ A/mm}^2$ , an average turn length of  $l_w = 0.25 \text{ m}$ , and an electrical conductivity of  $\kappa_{\text{Cu}} = 50 \cdot 10^6 \frac{\text{S}}{\text{m}}$ . [3 Points]

1.5 To also charge a laptop with a battery voltage of 12 V, which transformer type would allow one charger to provide both output voltages? [1 Point]

Hint: This task is independent of the previous tasks and can be solved qualitatively without reference to the previous results.



(a) EI-84/43.5 core geometry.

(b) Magnetization curve.

Fig. 2: EI-84/43.5 core and electrical steel magnetization curve.

Task 2: Working principle of a DC machine

[12 Points]

Fig. 3 shows a simplified DC machine cross section. The symbols  $\bullet$  and  $\times$  indicate technical conductor current directions (out of / into the drawing plane). Assume that the drawn field lines represent the complete air-gap field, i.e., no additional field lines exist to the left and right of the shown field region. Thus, outside the depicted air-gap field region the flux density is assumed to be zero.

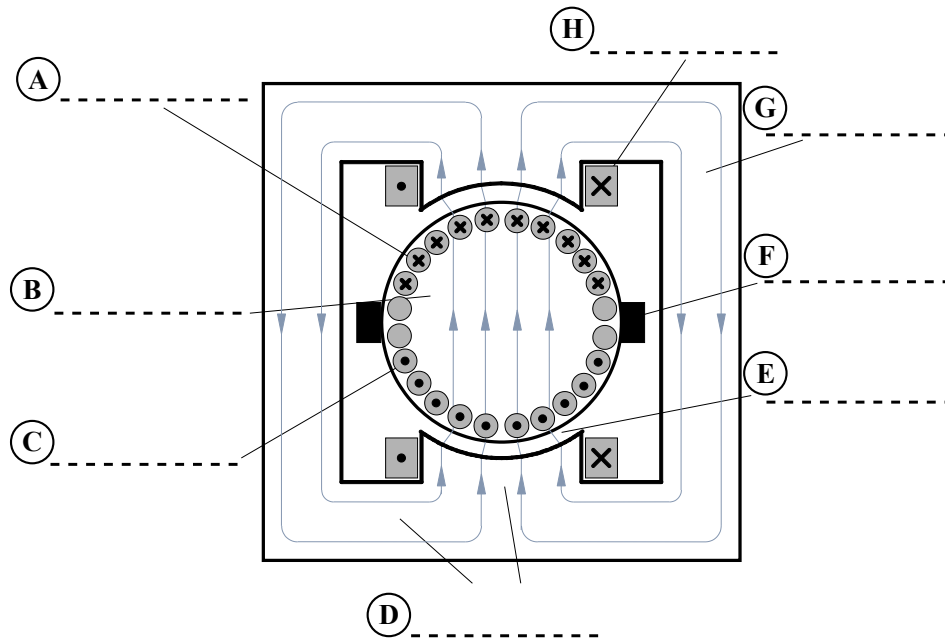


Fig. 3: DC machine cross section with missing component labels.

For the calculations, assume a homogeneous and block-shaped air-gap flux density  $\hat{B}_\delta$  within the pole coverage. Use the data from Tab. 1 for the following calculations.

Tab. 1: Given DC machine parameters.

Symbol	Description	Value
$\hat{B}_\delta$	Air-gap flux density (block-shaped)	0.8 T
$I_c$	Conductor current (per conductor)	218.75 A
$l_z$	Axial length	0.25 m
$d_a$	Armature diameter	0.24 m
$p$	Pole pairs	1
$\alpha_p$	Pole coverage factor	0.65
$n$	Nominal rotational speed	2500 $\frac{1}{\text{min}}$
$N_{\text{act}}$	Number of active conductors (4 forward + 4 return)	8
$a$	Number of parallel armature paths	1

2.1 Add the missing component labels (A–H) in Fig. 3.

[2 Points]

2.2 In Fig. 3, draw the resulting Lorentz force on one exemplary forward conductor ( $\bullet$ ) and one

return conductor ( $\times$ ). Also, indicate the resulting torque direction at the shaft. [2 Points]

2.3 Calculate the Lorentz force  $F_c$  acting on one active armature conductor assuming a perpendicular field penetration through the air gap. [1 Point]

2.4 Calculate (i) the torque contribution  $T_c$  of one active conductor and (ii) the resulting shaft torque  $T$  from all active conductors. [2 Points]

2.5 Compute the maximum flux linkage per armature coil  $\hat{\phi}_c$ . [2 Points]

2.6 Determine (i) the induced voltage magnitude  $\hat{u}_{i,c}$  per active conductor at the nominal speed and (ii) the total induced armature voltage magnitude  $\hat{u}_i$ . For the latter assume that the voltage induction per conductor loop is roughly identical for all loops. [3 Points]

## Task 3: Transformer model parameterization

[7 Points]

The transformer designed in task 1 has been manufactured, and experimental tests must be carried out to determine its T-type equivalent circuit model parameters.

Hint: if you are not able to solve task 1, use  $\ddot{u} = 35$  as substitute results for the subsequent tasks.

3.1 Draw the equivalent circuit diagram for the open-circuit test (incl. labeling of components, voltages and currents). [1 Point]

3.2 In the open-circuit test,  $U_{1,o} = 230$  V,  $P_{1,o} = 10$  W, and  $S_{1,o} = 15$  VA were measured. Determine the iron loss resistance  $R_c$  and the mutual inductances  $M'$  and  $M$  (referred to the primary side and un-referred). Neglect ohmic losses and stray inductances. [3 Points]

3.3 During a follow-up short-circuit test with  $U_{1,s} = 3.4$  V,  $I_{1,s} = 0.5$  A and  $P_{1,s} = 1.6$  W were measured. Determine  $R_1 = R'_2$  and the untransformed  $R_2$ , as well as  $L_{1,\sigma} = L'_{2,\sigma}$  and the untransformed  $L_{2,\sigma}$ . Neglect the mutual inductance. [3 Points]

**Task 4: Stationary operation of a permanent magnet synchronous machine [13 Points]**

Fig. 4 shows the mechanical rotor angle  $\varepsilon_r(t)$  and the three-phase stator currents  $i_{s,a}(t)$ ,  $i_{s,b}(t)$ ,  $i_{s,c}(t)$  of a permanent magnet synchronous motor (PMSM). The rotor angle sensor is aligned for  $\varepsilon_r = 0$  with the  $a$ -phase winding current vector. Assume steady-state operation (constant speed) and a symmetric star-connected stator (zero-sequence-free currents). The PMSM parameters are given in Tab. 2. Neglect iron losses, friction/windage, and converter losses. Consider only stator copper losses via  $R_s$ .

Tab. 2: Given PMSM parameters.

Symbol	Description	Value
$R_s$	Stator resistance	30 m $\Omega$
$L'_{s,d}$	d-axis inductance	0.25 mH
$L'_{s,q}$	q-axis inductance	0.40 mH
$\psi_{pm}$	PM flux linkage	0.12 Vs

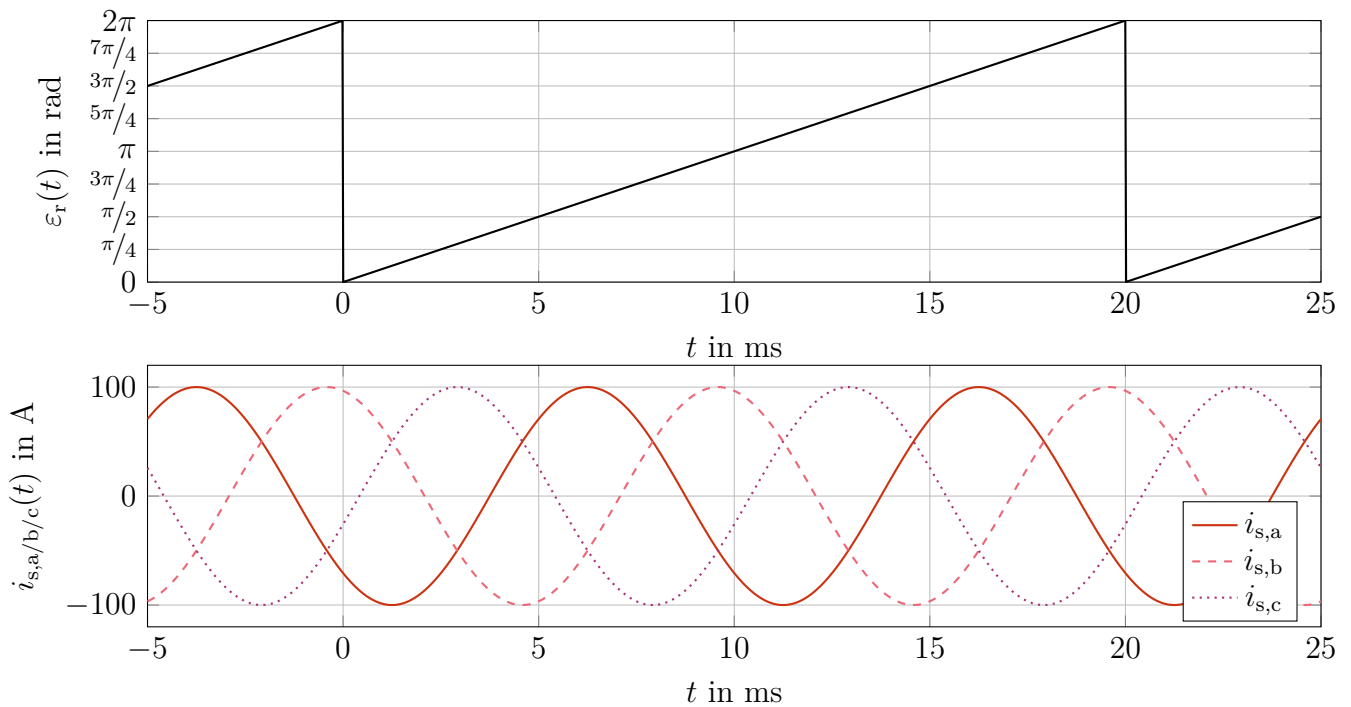


Fig. 4: Measured mechanical rotor angle  $\varepsilon_r(t)$  and three-phase stator currents  $i_{s,a}(t)$ ,  $i_{s,b}(t)$ ,  $i_{s,c}(t)$ .

4.1 Determine the pole pair number  $p$  as well as the mechanical and electrical rotational frequencies  $f_r$  and  $f_{r,el}$  from Fig. 4. [3 Points]

Hint: If and if only you are not able to solve this task, use the following alternative values for the following tasks:  $p = 3$ ,  $f_r = 25$  Hz,  $f_{r,el} = 75$  Hz.

4.2 Determine the electrical load angle  $\theta$  from Fig. 4, i.e., the angle between the rotor flux linkage and the stator current space vector. [2 Points]

Hint: Due to the visual uncertainty, only an approximate estimate is expected. If and if only you are not able to solve this task, use the following alternative value for the following tasks:  $\theta = 225^\circ$ .

4.3 Determine the steady-state dq-current components  $i_{s,d}$  and  $i_{s,q}$ . [1 Point]

Hint: If and if only you are not able to solve this task, use the following alternative values for the following tasks:  $i_{s,d} = -70.71$  A,  $i_{s,q} = -70.71$  A.

4.4 Calculate the electromagnetic torque  $T$  and the mechanical output power  $P_{me}$ . [2 Points]

Hint: If and if only you are not able to solve this task, use the following alternative values for the following tasks:  $P_{me} = -8.64$  kW.

4.5 Calculate the electrical input power  $P_{el}$  and the efficiency  $\eta$ . [3 Points]

4.6 The PMSM is overheated above the Curie temperature, causing permanent demagnetization of the magnets. Qualitatively discuss the effect on torque and mechanical power at the same operating point. Is electromagnetic energy conversion still possible? [2 Points]

Hint: This question is largely independent of the previous tasks and can be answered based on the general understanding of PMSMs and the torque equation.