Exam

Electrical Machines and Drives

Winter 2024/25

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 90 minutes.

Evaluation:

Task	1	2	3	4	$\sum$
Maximum score	13	11	8	13	45
Achieved score					

Task 1: Deflecting magnet **[13 Points]**

A dipole magnet with an axial cross-section as shown in Fig. 1 is used to deflect the particle beam of charged heavy ions in a particle accelerator. A rated direct current $I_\mathrm{n} = 5000$ A flows through the two excitation coils. The copper conductors of the coil winding are directly water-cooled due to the high current density of $J = 18$ A/mm^2.

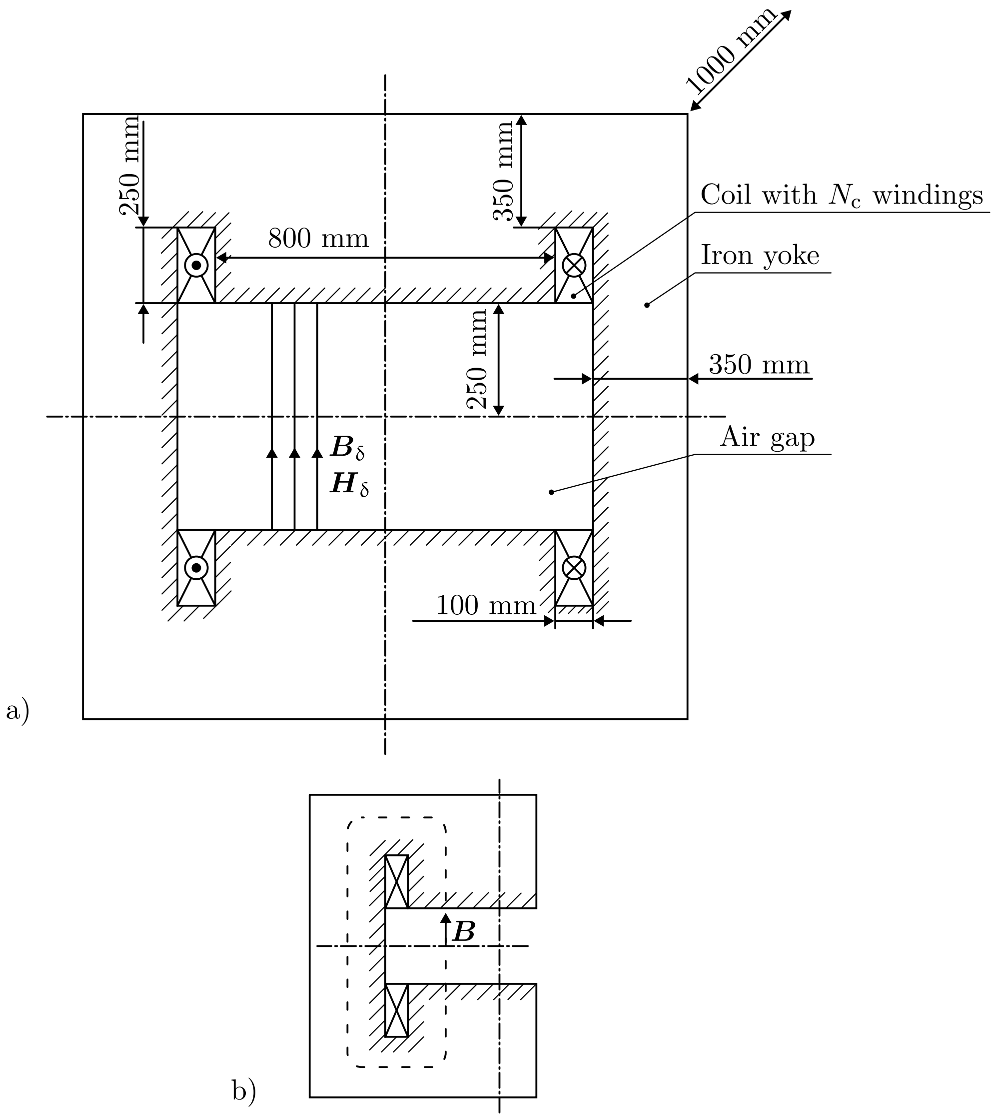

Figure 1: Sketch of the deflecting magnet a) and an idealized field line b).

1.1 How large is the magnetic field in the air gap, when there is a homogeneous magnetic flux density of $B_\delta = 3.141$ T? How many windings per coil N_c are necessary? Neglect the magnetization effort of the iron yoke. [3 Points]

Hint: If you have not found a solution for the number of winding turns in this subtask, continue with $N_\mathrm{c} = 140$.

1.2 How lare is the magnetic flux in the air gap? [1 Point]

1.3 Calculate the magnetic flux density B_{Fe} in the iron yoke. Therefore, neglect magnetic leakage fluxes. [1 Point]

1.4 The average length of the iron yoke is given with $l_{\mathrm{Fe}} = 1.2$ m. How large is the magnetization effort of the iron yoke, when the permeability $\mu_{\mathrm{Fe}} = 126\mu_0$? Is the assumption of zero magnetization effort from subtask 1 correct? [2 Points]

1.5 How lage is the electrical resistance of the excitation coil at 50 °C with an average winding length $l_{\mathrm{w}} = 4$ m and an electrical conductivity of $\kappa_{\mathrm{Cu}} = 50 \cdot 10^6\ \frac{\mathrm{S}}{\mathrm{m}}$? [2 Points]

1.6 Calculate the necessary voltage U and the excitation losses P_{l}. [2 Points]

1.7 Calculate the flux linkage ψ_{coil} of one coil. [1 Point]

1.8 How large is the inductivity L, when the two coils are connected in series? [1 Point]

Task 2: Series DC machine **[11 Points]**

Electric vehicle drives were used in mines at an early historic stage in order to avoid exhausts from combustion engines in the tunnels. Historically, series DC machines were used for this purpose, such as the machine with the parameters summarized in the following table.

Table 1: DC machine parameters.

Symbol	Description	Values
U_n	Nominal voltage	440 V
I_n	Nominal armature current	500 A
T_n	Nominal torque	1407 Nm
R_a	Armature resistance	0.02 Ω
R_f	Field resistance	0.025 Ω
L_a	Armature inductance	2 mH
L_f	Field inductance	8 mH

2.1 Draw the equivalent circuit diagram of the series DC machine. [1 Point]

2.2 Determine the effective field inductance L'_f and the effective flux linkage ψ'_f for the nominal steady-state operating point. [2 Points]
<u>Hint:</u> if and if only you are not able to solve this task, use $L'_\mathrm{f} = 8$ mH and $\psi'_\mathrm{f} = 4$ Vs as a substitute result for the subsequent tasks.

2.3 What is the machine's nominal speed n_n and efficiency η_n? [2 Points]

2.4 Due to a fault in the cooling system, the dissipated power losses must be reduced to 1/4 of the nominal rating to prevent overheating. What are the achievable torque and mechanical power in this scenario assuming that the ohmic losses dominate the machine's loss characteristic? What mechanical issue could occur in this new operating point? [3 Points]

2.5 What steady-state starting current can be expected when the nominal machine voltage is applied from the stall position? After what time interval ΔT is 95 % of this steady-state value reached when starting from an entirely currentless, non-rotating machine? [2 Points]

2.6 What dropping resistor must be added to the machine's circuit to limit the starting current to twice the nominal value? [1 Point]

Task 3: Transformer **[8 Points]**

A single-phase 50 Hz transformer with a rated apparent power of 3 kVA for a welding application was delivered without further information regarding its operation characteristics. Hence, experimental tests need to be conducted to identify its T-type equivalent circuit diagram parameters.

3.1 During an open-circuit test with $U_{1,\mathrm{o}} = 230$ V, a secondary voltage of $U_{2,\mathrm{o}} = 5.476$ V is measured. Estimate the transformation ratio as well as the nominal primary and secondary current. [2 Points]

3.2 During the same open-circuit test, an active input power of $P_{1,\mathrm{o}} = 60$ W and apparent power of $S_{1,\mathrm{o}} = 90$ VA were measured. Neglecting ohmic power losses and stray inductances, determine the iron loss resistance R_c as well as the mutual inductance M' and M (transformed to primary side and untransformed value). [3 Points]

3.3 During a subsequent short-circuit test with $U_{1,\mathrm{s}} = 20$ V, the following measurements have been obtained: $I_{1,\mathrm{s}} = 13$ A, $P_{1,\mathrm{s}} = 100$ W. Determine $R_1 = R_2'$ as well as the untransformed R_2. Likewise, find $L_{1,\sigma} = L_{2,\sigma}'$ as well as the untransformed $L_{2,\sigma}$. Neglect the mutual inductance's impact. [3 Points]

Task 4: Steady-state operation curves of an induction machine [13 Points]

The paramters of a six-pole three-phase induction machine are shown in Tab. 2. The nominal stator current is given with $I_{\mathrm{s,n}} = 22.5$ A at a power factor of $\cos(\varphi_{\mathrm{n}}) = 0.8$.

Table 2: Parameters of the induction machine.

Symbol	Value	Symbol	Value	Symbol	Value
$P_{\mathrm{me,n}}$	11 kW	U_{n}	400 V	$f_{\mathrm{s,n}}$	50 Hz
s_{n}	0.0444	R_{s}	0.42 Ω	R_{r}'	0.459 Ω
$L_{\sigma,\mathrm{s}}$	5.1 mH	$L_{\sigma,\mathrm{r}}'$	2.4 mH	M	53.2 mH

4.1 Calculate the nominal rotational speed n_{n} and the nominal torque T_{n}. [2 Points]

4.2 Calculate the nominal electrical power $P_{\mathrm{el,n}}$ and the efficiency η_{n}. [2 Points]

4.3 Determine the leakage coefficient σ. [1 Point]

4.4 Calculate the nominal slip frequency ω_{slip} and the maximum angular frequency ω_{max}. [2 Points]

4.5 Determine the torque and mechanical power for different slip ratios and use these support points to draw the torque and power curves in Fig. 2. [4 Points]
Hint: The torque equation is given with: $T = T_{\mathrm{max}} \frac{2}{\frac{s}{s_{\mathrm{max}}} + \frac{s_{\mathrm{max}}}{s}}$.

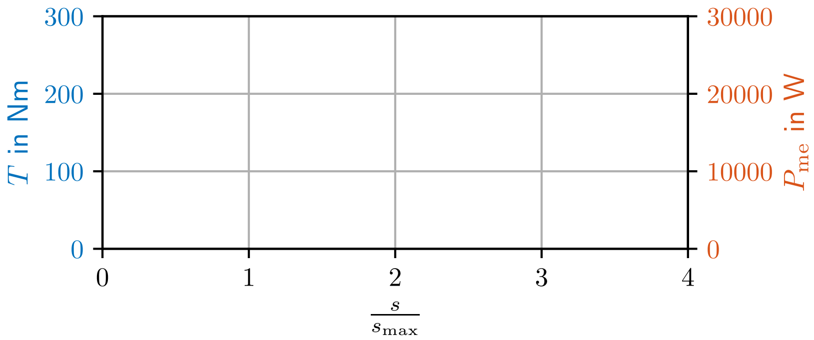

Figure 2: Given template to draw the curves for the torque and mechanical power.

4.6 Is the mechanical power zero for a theoretical consideration of an infinitely large mechanical speed (negative and positive speed values)? [2 Points]