Mock-up Exam

Electrical Machines and Drives

Summer 2024

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	8	12	9	13	42
Achieved score					

Task 1: Fundamentals **[8 Points]**

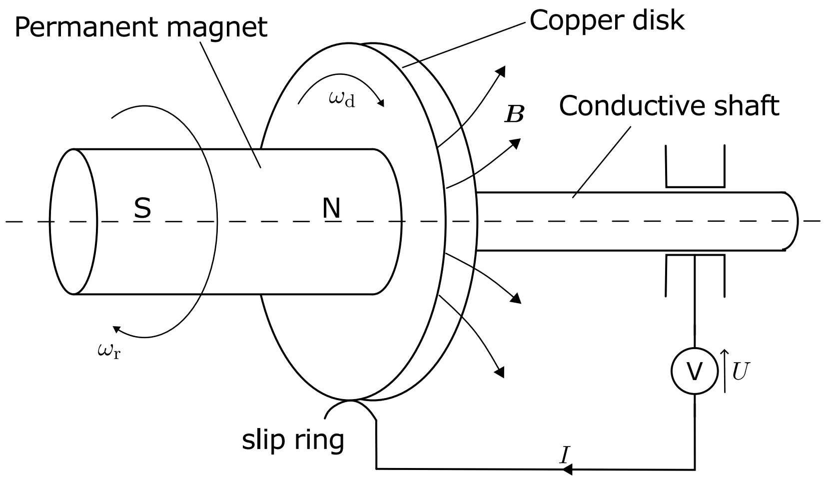

Figure 1: Faraday's disk (rotating copper disk in a homogenous magnetic field)

1.1 The disc from Fig. 1 has a diameter of $d = 60$ cm and is rotating with the circumferential speed $v_\mathrm{d} = 100\ \frac{\mathrm{m}}{\mathrm{s}}$. What is the rotational speed and angular velocity of the copper disk? [2 Points]

1.2 Assuming that the permanent magnet is not rotating ($\omega_\mathrm{r} = 0$) while delivering a homogenous and constant magnetic field with $B = 1.8$ T, what is the measured induced voltage U? [2 Points]

1.3 Assume that the volt meter is exchanged for a resistor with $R = 1\ \Omega$. How big are the resulting current I and electrical power P? Is the disc operating as a motor or generator? [2 Points]

1.4 Discuss the three following cases regarding the presence of an induced voltage: [2 Points]

- The disc is at standstill, but the permanent magnet is rotating.
- The disc and the permanent magnet are rotating, but with different speeds.
- The disc and the permanent magnets are at standstill, but the electrical circuit is rotating.

Task 2: DC machine **[12 Points]**

2.1 What are the three main connection types for DC machines? Draw the equivalent circuit diagrams and add the respective current and voltage equations in the steady state. [3 Points]

2.2 Now consider a DC machine with the parameters given in Tab. 1. To which of the above connection type can the parameter set belong? [1 Point]

Table 1: Characteristics of the given DC machine.

Symbol	Description	Values
$U_{\mathrm{a,n}}$	Nominal armature voltage	230 V
$I_{\mathrm{a,n}}$	Nominal armature current	20 A
$U_{\mathrm{f,n}}$	Nominal field voltage	230 V
$I_{\mathrm{f,n}}$	Nominal field current	1.1 A
R_{a}	Armature resistance	1.2 Ω
R_{f}	Field resistance	42.0 Ω
P_{n}	Nominal power	4.1 kW
n_{n}	Nominal speed	1500 $\frac{1}{\mathrm{min}}$

2.3 Calculate the nominal torque T_{n}. [2 Points]

2.4 Determine the nominal efficiency η_{n} of the entire machine. [2 Points]

2.5 Calculate the armature starting current $I_{\mathrm{a,0}}$ and the resulting starting torque T_0. [2 Points]

2.6 Discuss potential operation issues of the found starting torque and current values compared to the machine's nominal operation. Propose potential remedies to address these issues. [2 Points]

Task 3: Induction machine **[9 Points]**

3.1 Draw and label the stationary equivalent circuit diagram of the general induction machine. What simplification can you make if the machine is at standstill ($\omega_\mathrm{r} = 0\ \frac{1}{\mathrm{s}}$)? [1 Point]

3.2 From now on consider a **squire cage induction machine** with the parameters from Tab. 2. Calculate the no-load speed n_0. [2 Points]

Table 2: Characteristics of the given induction machine.

Symbol	Description	Values
U_n	Nominal voltage	400 V
$f_\mathrm{s,n}$	Nominal frequency	60 Hz
P_n	Nominal power	20 kW
n_n	Nominal speed	$1700\ \frac{1}{\mathrm{min}}$
p	Pole pair number	2
R_s	Stator resistance	0 Ω
R'_r	Rotor resistance	2 Ω
M	Mutual inductance	70 mH
$L_{\sigma,\mathrm{s}}$	Stator leakage inductance	2 mH
$L'_{\sigma,\mathrm{r}}$	Rotor leakage inductance	2 mH

3.3 Calculate the nominal torque T_n and nominal slip s_n. [2 Points]

3.4 Determine the nominal electrical power $P_\mathrm{el,n}$ and the efficiency η_n. For this purpose neglect the impact of the stator leakage inductance. [2 Points]

3.5 Determine the maximum possible torque T_max of the machine. Which speed n_max corresponds to that operating point? [2 Points]

Task 4: Synchronous machine **[13 Points]**

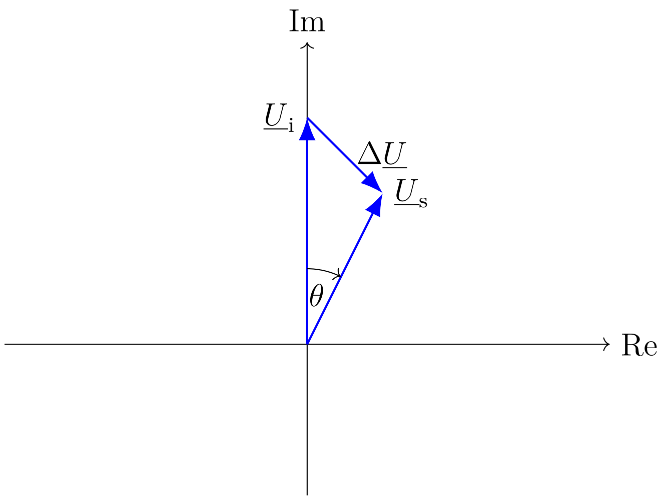

Figure 2: Phasor diagram of a synchronous machine with scaling 1 kV = 1 cm and 1 kA = 1 cm.

4.1 Determine the operating mode of the machine characterized by Fig. 2. [2 Points]

4.2 An experiment revealed the short-circuit current $I_{\mathrm{s,sc}} = 1.33$ kA for a nominal field excitation current $I_{\mathrm{f}} = 100$ A. Insert the short-circuit current into the above sketch and calculate the synchronous reactance X_{s}. [2 Points]

4.3 Determine the stator current $\underline{I}_{\mathrm{s}}$, the power factor $\cos(\varphi)$ and the corresponding angle φ. Add those into the above diagram. The nominal active power is $P = -4$ MW while the ohmic stator resistance can be neglected. [3 Points]

4.4 Determine the apparent power S and the reactive power Q. [2 Points]

4.5 What torque T is associated with the above operating point for a pole pair number $p = 3$? What is the theoretical maximum torque T_{max} for the given stator voltage operating at a grid frequency of $f = 50$ Hz? [2 Points]

4.6 Determine a modified field excitation current I_{f} which delivers the same active power but reduces the reactive power to zero. Which load angle θ results? [2 Points]