



Mechatronics and Electrical Drives

24.03.2015

Surname:					Student number:																										
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Course of Study:																															
Exercise:	1	2	3																												
(Points)	(21)	(20)	(22)				Total (63)	Grade																							

Duration:
120 Minutes

- Permitted:**
- a non-programmable calculator without graphic display
 - drawing materials (compasses, protractor, ruler, pens ...)

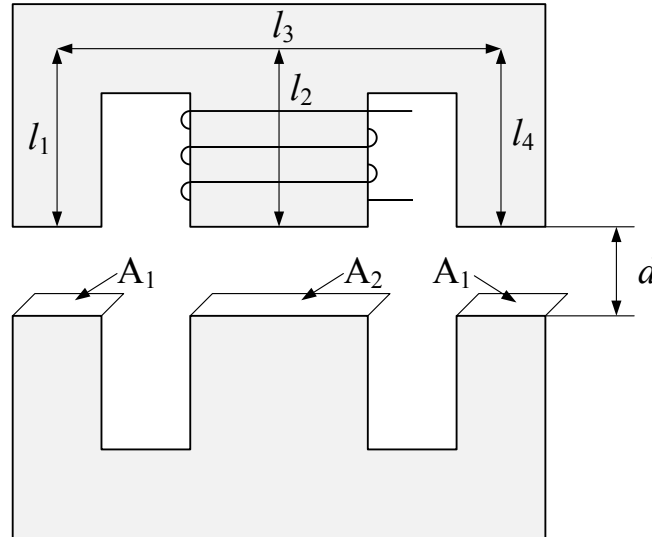
Please note:
 Please prepare your student ID card (with photo) on your desk for the attendance check.
 Please label each exam sheet with your name and student number.
 Use a new exam sheet for each task. Do not use pencils or red pens.
 With numerical calculations, the units must be considered in every step. Not following that rule will result in deduction of points. All solutions must be clearly documented and wherever required explained!
 The entry of a mere final result without any approach will not be counted.

You can only take part in the exam, if you are registered in the PAUL system. If you take part without registration, the exam result will not be considered.

Good Luck!

Aufgabe 1: Magnetic Bearing
(21 Points)

Shown below are two identical E-iron sections with an air-gap $d = 1$ mm. In this case, only the upper core is provided with a winding of $N = 200$ turns. This winding is excited with a constant current $I = 8.5$ A.



$$l_1 = 4 \text{ cm}, l_2 = 4 \text{ cm}, l_3 = 12 \text{ cm}, l_4 = 4 \text{ cm}, A_1 = 350 \text{ mm}^2, A_2 = 700 \text{ mm}^2, \mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}, \mu_r = 1800$$

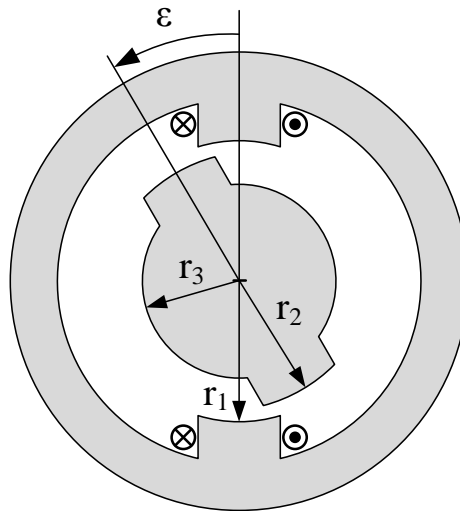
- 1.1 Obtain the magnetic equivalent circuit model and calculate the individual reluctances (5 P)
- 1.2 Calculate the total reluctance that is seen by the MMF source. (3 P)
- 1.3 Determine the flux densities in the air gaps and the inductance of the coil. (4 P)
- 1.4 Calculate the magnetic pressure. The influence of iron can be neglected. (4 P)
- 1.5 Sketch the variation of the magnetic pressure as a function of the air gap d . (2 P)
- 1.6 Explain the process of irreversible demagnetization in a permanent magnet. To do these please refer especially to the remanent magnet flux density (b_r). (3 P)

Aufgabe 2: Reluctance Motor

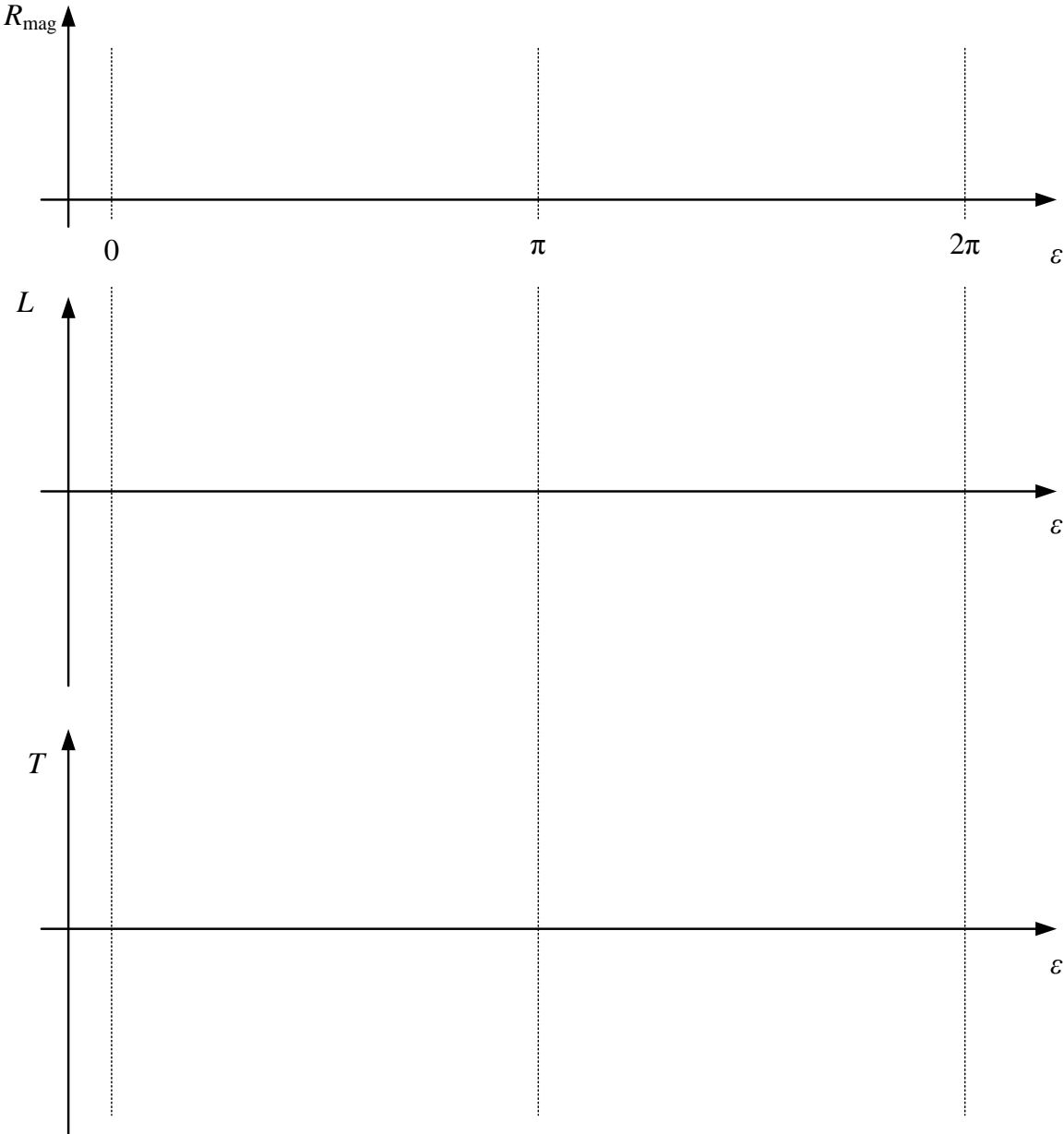
(20 Points)

Given is a switched reluctance motor with two stator and rotor poles of equal area A_p and equal pole width α . The influence of iron can be neglected ($\mu_{r,Fe} \rightarrow \infty$). The stator has two windings with $N = 125$ turns each. Other parameters of the motor can be found in the overview:

$$\alpha = 30^\circ, A_p = 100 \text{ mm}^2, r_1 = 122 \text{ mm}, r_2 = 120 \text{ mm}, r_3 = 80 \text{ mm}, I = 75 \text{ A}, \mu_0 = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}}$$



- 2.1 Calculate the air gap reluctance for the aligned and unaligned case. (5 P)
- 2.2 Calculate the magnetic flux linked for both cases. (5 P)
- 2.3 Determine the power factor. Here make use of a Ψ/i diagram. (5 P)
- 2.4 Sketch in the following charts the variation of the air gap reluctance, the inductance and the torque at a given constant current I . Calculate the corresponding minimum and maximum values. Make sure to complete axis labels! (5 P)



Aufgabe 3: BLDC

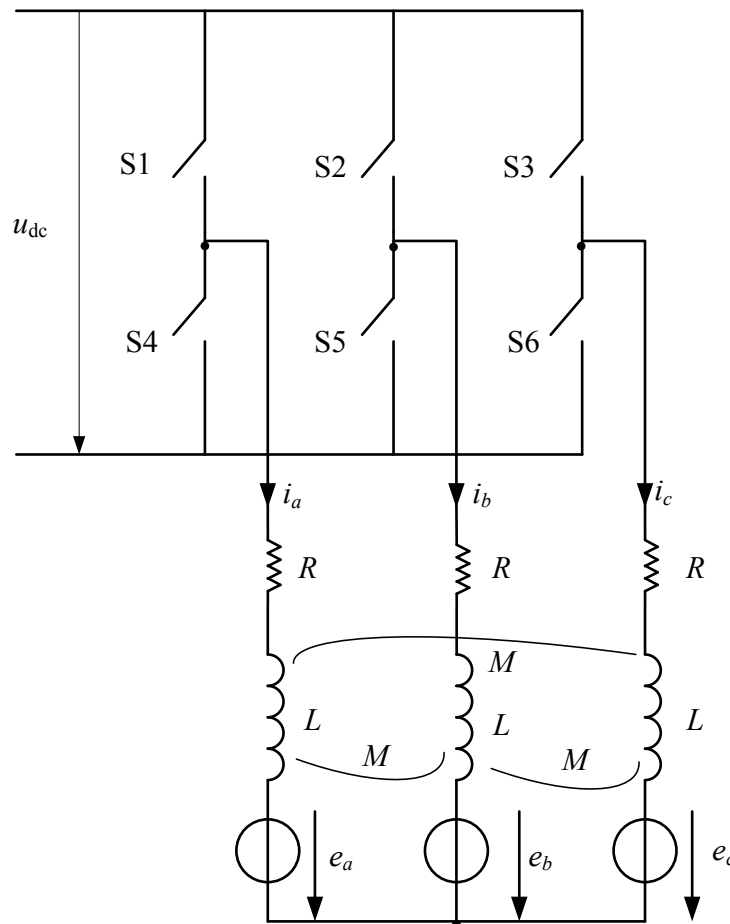
(22 Points)

Consider a symmetrical 3 Phase BLDC Motor operating at $n = 5000 \text{ min}^{-1}$. The motor is delivering a mechanical power $P = 20 \text{ kW}$ to the load. The induced line EMF e_{ab} at the above speed for one electrical cycle is shown in the figure on the next sheet.

3.1 Calculate the following: (12 P)

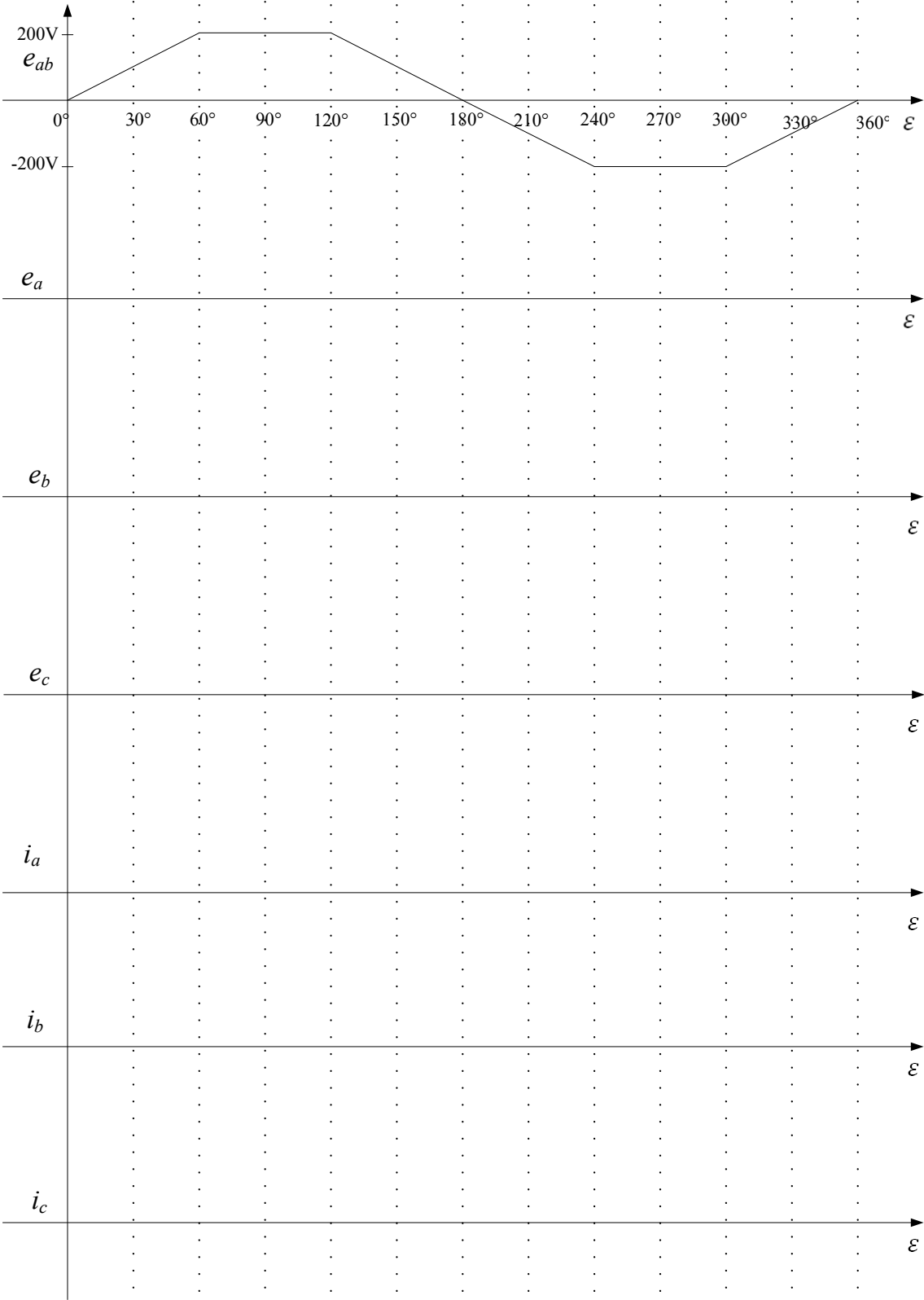
- a) The torque delivered by the motor to the load at this condition.
- b) Assuming block shaped currents in the motor, calculate the currents in the three phases A, B and C.
- c) Sketch the variation of the induced phase EMFs e_a , e_b and e_c (in the next page). Indicate the appropriate values.
- d) Sketch the corresponding block shaped currents i_a , i_b and i_c (in the next sheet). Indicate the appropriate values.

3.2 The motor is fed by a three phase inverter as shown below: (3 P)

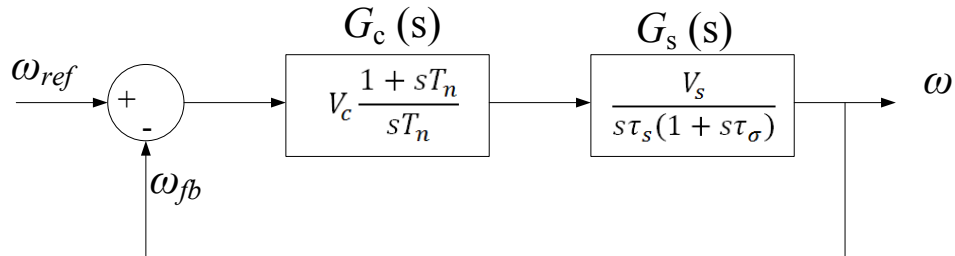


Consider the following case. $i_a = -i_c$ and $i_b = 0$.

- a) Which of the switches among S_1 to S_6 have to be turned on to ensure this condition?
- b) Define the differential equations which governs the behavior the motor.



- 3.3** The simplified control structure for the speed control of the BLDC motor is shown in figure below. The speed controller along with a simplified transfer function (which includes the current controller and plant) are represented as $G_c(s)$ and $G_s(s)$ respectively with $\tau_s = 0.2$ s, $\tau_\sigma = 5$ ms and $V_s = 0.1$. (7 P)



If the controller is assumed of PI-type (G_c) and is designed using symmetric optimum method, obtain the following:

- The open-loop transfer function.
- Controller reset time T_n if the desired crossover frequency is $\omega_c = 100$ s⁻¹.
- The closed-loop transfer function $\frac{\omega(s)}{\omega_{ref}(s)}$
- Magnitude of the controller gain V_c .