Department of Power Electronics and Electrical Drives

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Mechatronics and Electrical Drives

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Surname:	Student number:
First name:	
Course of Study:	

Exercise: (Points)	1 (30)	2 (18)	3 (22)			Total (60)		Grade

Duration: 120 Minutes

Permitted:

• a self-created, handwritten sheet of formulas (1 sheet A4, inscribed on both sides, no copies or prints)

• a non-programmable calculator without graphic display

• drawing materials (compasses, protractor, ruler, pens ...)

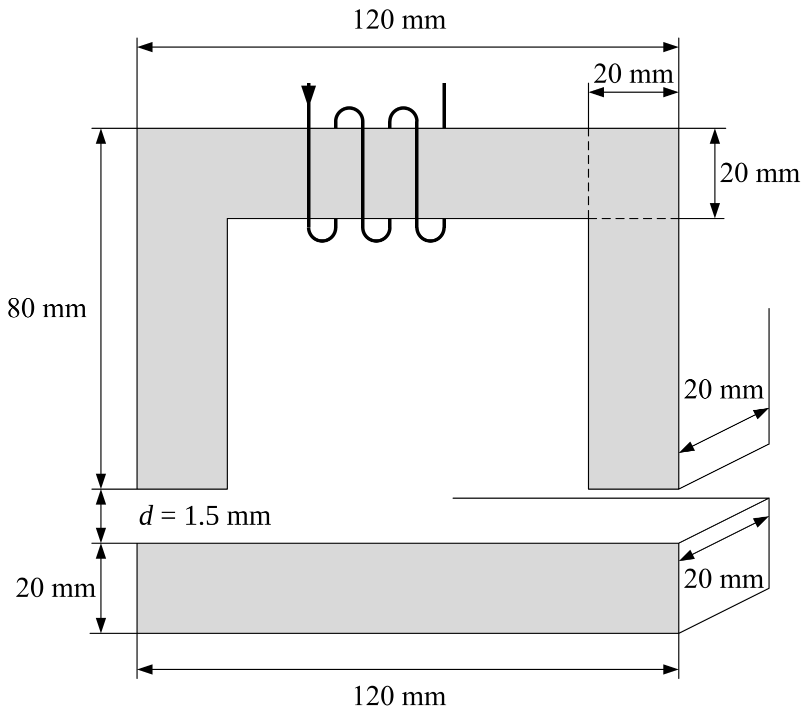
Please note:

- 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.

Good Luck!

Exercise 1: Magnetic bearing **(30 Points)**

In the following magnetic circuit, the coil is made up of 1000 turns and the relative permeability of the core material is 4000.



1.1 Calculate the equivalent length of the magnetic circuit, including the air-gap **(4 P)**

1.2 The coil of the circuit is excited with the voltage waveform U_S, shown in the following figure. Assuming the core material to be non-saturable and the resistance of the coil to be zero. Calculate resulting coil current, the flux and the flux density in the core, all at the end of 500 ms

(10 P)

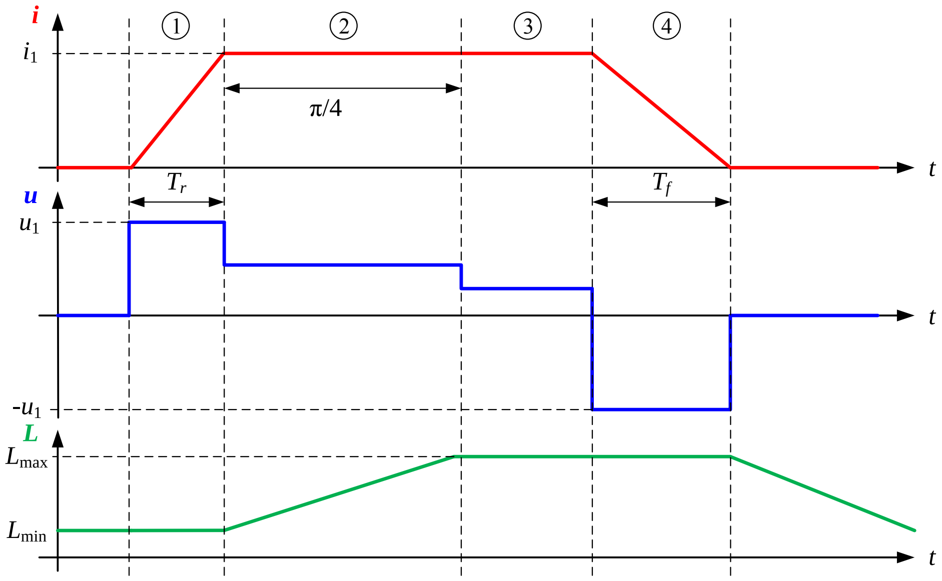
1.3 By how much percent does the flux density change (at the end of $t = 500\ ms$), when the length of the sides of the core are increased from 80 mm to 140 mm? Please consider the excitation voltage to be the same as in question 1.2. **(10 P)**

1.4 Obtain the equation for the Co-energy, as a function of the gap-length d. Use the data given in the question 1.3. **(3 P)**

1.5 At what value of the gap-length is the Co-energy maximum? What is the value of the corresponding Co-energy? Use the data given in the question 1.3. **(3 P)**

Aufgabe 2: Reluctance motor (18 Points)

The profiles of voltage, current and inductance of a reluctance motor are shown below. The magnetization of the material can be assumed to be linear.

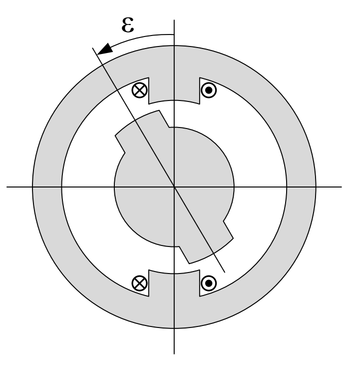


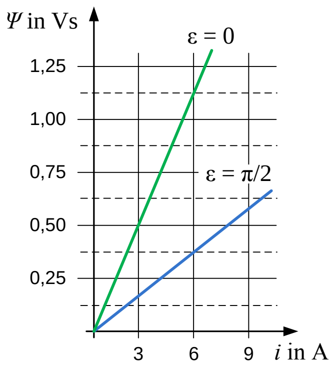
2.1 Calculate the magnetization and demagnetization times T_r and T_f. **(6 P)**
Consider the following: u_1 = 250 V, i_1 = 35 A, L_{min} = 1 mH, L_{max} = 2,75 mH, ω = 120 π/s. The ohmic resistance can be neglected in this case.

2.2 Calculate the values of the applied voltage $\boldsymbol{u}$ to the motor during section 2 and 3.
The ohmic resistance is R = 0,1 Ω. **(6 P)**

The following questions are independent of the machine configuration and can be answered without results from the previous task!

The magnetization curve of a switched reluctance machine having a pair of poles for the positions $\varepsilon = 0$ and $\varepsilon = \pi$ are shown below. The windings have 320 turns each and are fed by a maximum current $I_{\mathrm{Max}} = 6$ A. The permeability of the iron is $\mu_{\mathrm{r}} = 1750$. Note: The electrical and mechanical losses are negligible.





2.3 What is the maximum mechanical work W_{mech} that can be delivered during an electrical period? **(3 P)**

2.4 Calculate the mean torque (averaged over the angle) in a period? **(3 P)**

Aufgabe 3: Brushless DC Machine **(22 Points)**

Consider a symmetrical 3-Phase BLDC Motor operating at n = 1000 min^{-1}. The motor is delivering a power of P = 10 kW to the load. The induced EMF for the B phase e_b at the above speed for one electrical cycle is shown in the figure 3.1. (next sheet).

3.1 Calculate the following: **(11 P)**

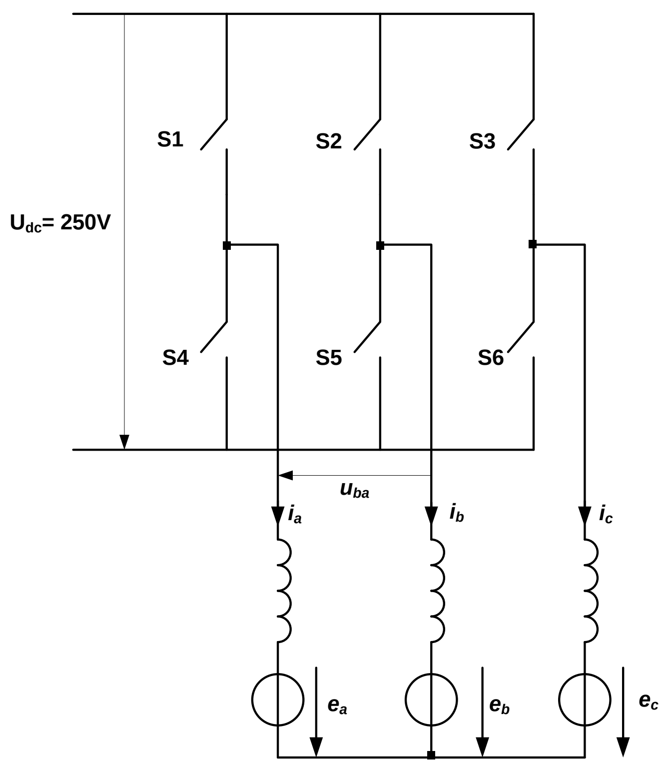
a) The torque delivered by the motor to the load at this condition.

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 the line-line induced back EMF e_{ab} (in the next page). Indicate the appropriate values.

d) Sketch the corresponding block shaped currents i_a, i_b und i_c (in the next sheet). Indicate the appropriate values.

3.2 The motor is fed by a three phase inverter as shown below. **(4 P)**



Consider the following case: $i_a = -i_c$, i_b = 0 A und u_{dc}= 250V.

a) Which of the switches among S_1 bis S_6 have to be turned on to ensure this condition?

b) What is the voltage u_{ca} at this condition?

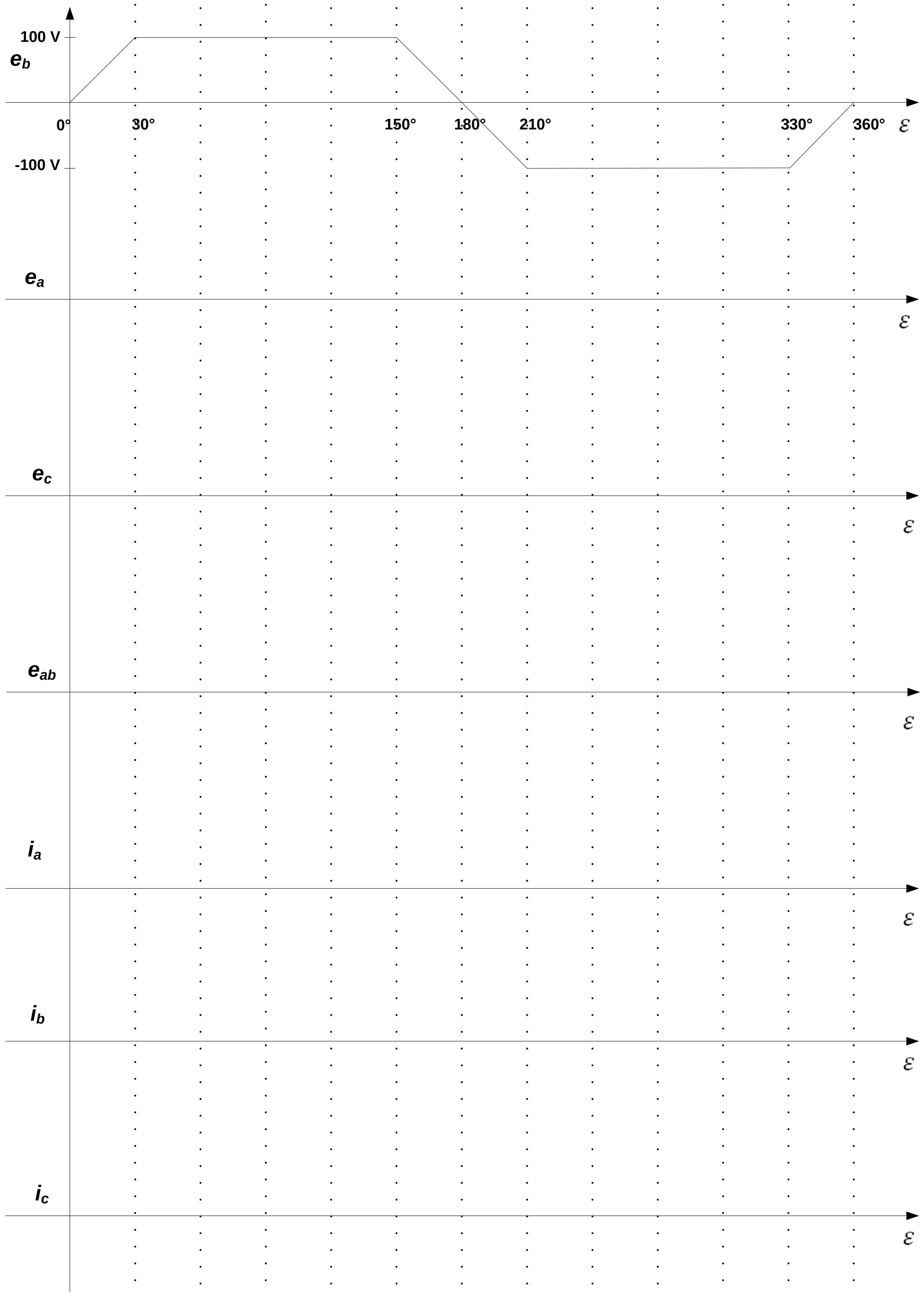


Fig 3.1 Induced voltages and currents of the BLDC Motor

3.3 The simplified control structure for the current control of the BLDC motor is shown in Fig. 3.2. The controller, plant and the sensor transfer functions are $\boldsymbol{G_c(s)}, \boldsymbol{G_s(s)}$ and $\boldsymbol{G_{se}(s)}$ respectively with $\boldsymbol{R = 1\ \Omega, \tau = 0.5\ \mathrm{ms}, \tau_d = 100\ \mu s}$. **(7 P)**

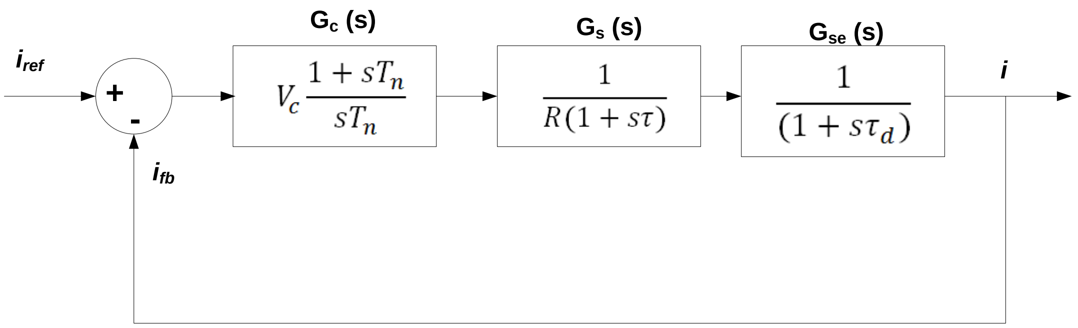


Fig 3.2 Control structure of the current controller of a BLDC motor

If the controller is assumed of PI-type and is designed using pole-zero cancellation method (magnitude optimum), obtain the following:

a) The value of the controller reset time T_n.

b) The open-loop transfer function

c) The closed-loop transfer function $\frac{I(\mathrm{s})}{I_\mathrm{ref}(\mathrm{s})}$

d) Magnitude of the controller gain V_c if the damping factor of the closed loop should result as $d = 1$