



Mechatronics und Electrical Drives

28.03.2014

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Course of Study:								
Exercise:	1	2	3	4		Total		Grade
(Points)	(25)	(25)	(25)	(25)				

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 bring your student ID card (with photo)!

Please label each exam sheet with your name and student number. Use for each task a new exam sheet. 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!

Aufgabe 1: Basic Magnetics**(25 points)**

- 1.1** For the magnetic circuit shown in Figure 1.1, draw the waveforms of the flux ϕ in the core, flux density B and current i in the winding, for the duration from 0 to 1 s. The voltage $u_s(t)$ is given and has a waveform as shown in Figure 1.2. The magnetization curve for the core material is shown in Figure 1.3. As shown, the magnetization curve is broken down into three piecewise linear regions with different slopes.

Neglect the winding resistance. Assume that all the flux generated is confined to the core and the initial flux is zero.

NOTE: Please fill in the waveforms only in the sheets provided for this purpose

- 1.2** Calculate the internal energy stored in the magnetic circuit at $t = 500$ ms
- 1.3** Define the term “inductance” and comment about this term in the present case.
- 1.4** Calculate the value(s) of the inductance(s).

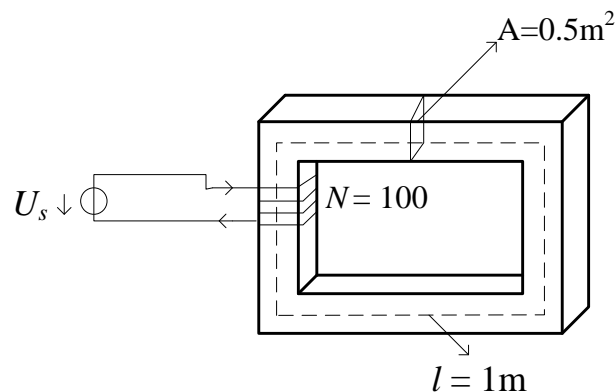


Figure 1.1 Magnetic circuit

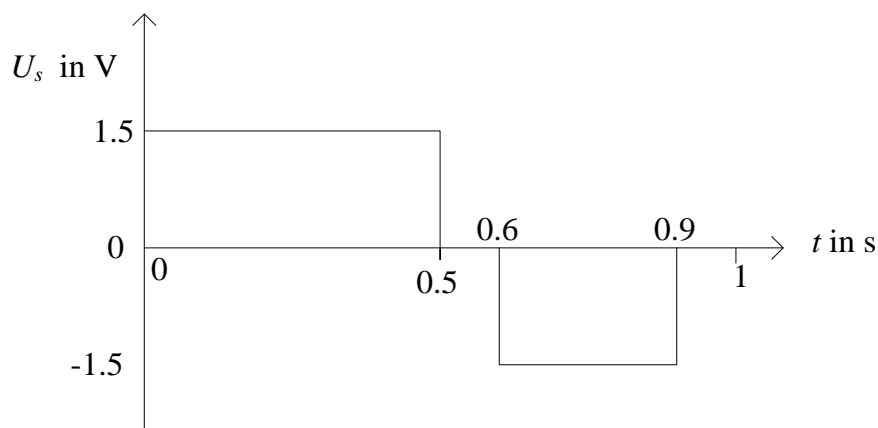


Figure 1.2 Input voltage waveform

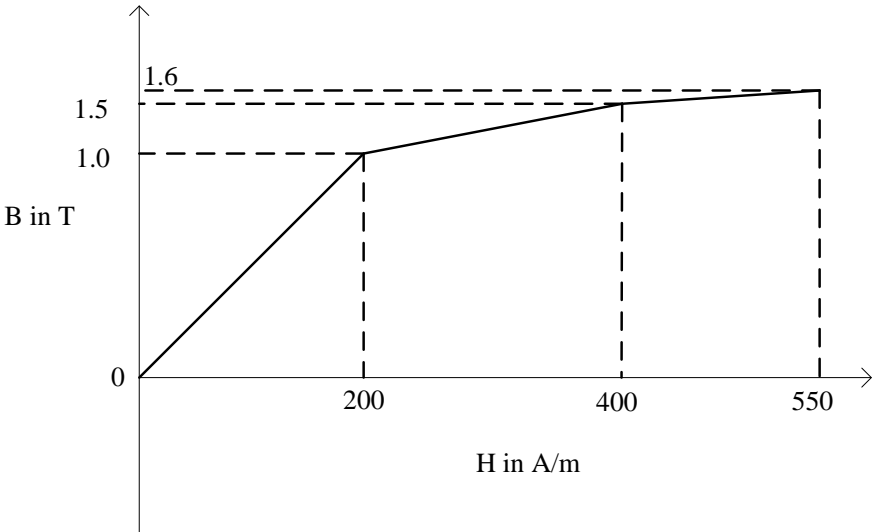
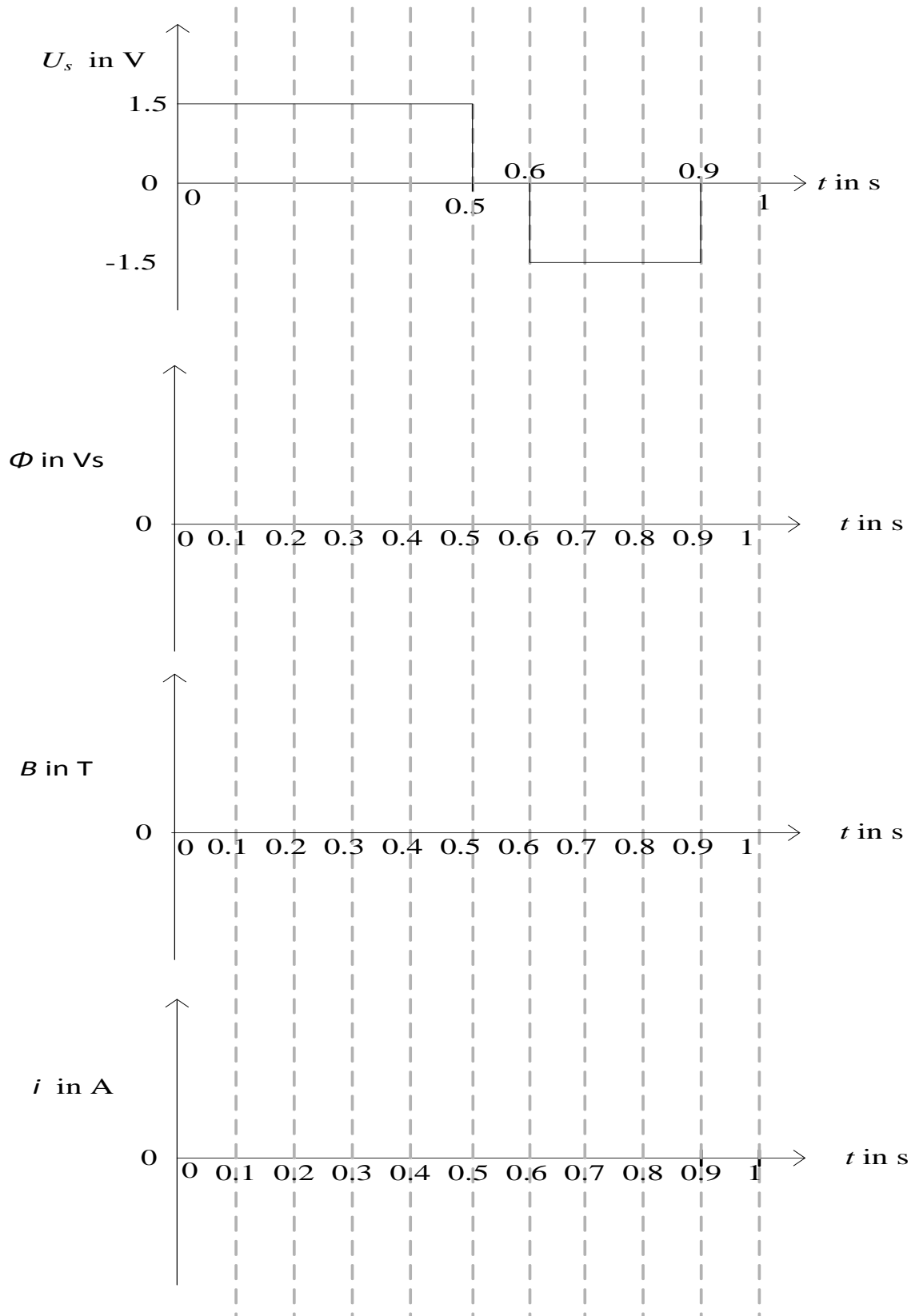


Figure 1.3 Magnetization curve for the core material

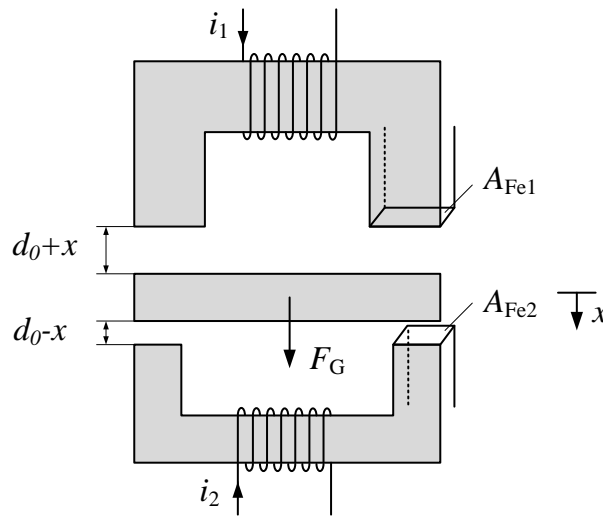
Answer sheet for question 1



Aufgabe 2: Magnetic Bearing

(25 points)

Shown below is a structure of a magnetic bearing to suspend a shaft using two yokes.



The yokes have windings with turns $N_1=N_2 =1250$. The current through the upper winding is $i_1 = 25$ A. The cross-sectional areas shown in the figure are $A_{Fe1} = 100$ mm² and $A_{Fe2} = 0,9 A_{Fe1}$. The desired resting position of the shaft is defined by $d_0 = 3$ mm and $x = 1$ mm. The weight of the shaft amounts to $F_G = 1500$ N. **Please use the assumption $R_L \gg R_{Fe}$**

- 2.1 Calculate the current i_2 needed to keep the shaft in the resting position.
- 2.2 Calculate a modified number of turns N_2 in order to hold the shaft in the resting position with $i_2 = i_1 = 25$ A.

The following questions can be answered without any reference to the above tasks and are therefore independent!

- 2.3 Assume that the windings are each fed by 4-quadrant converter. Does the supply voltage of the 4-quadrant converter have any influence on the generated magnetic force? Please give reasons for your answer!
- 2.4 Does a bias magnetization make sense in a two-yoke construction? Please give reasons for your answer. Also comment on the idea of a bias magnetization in an arrangement with only one yoke.
- 2.5 The control structure for the position control of the magnetic bearing is sketched in Figure 2.1. Identify the blocks marked '1' to '6' and also the variables 'a' to 'g'. Explain **in detail** the function and the importance of the respective blocks!

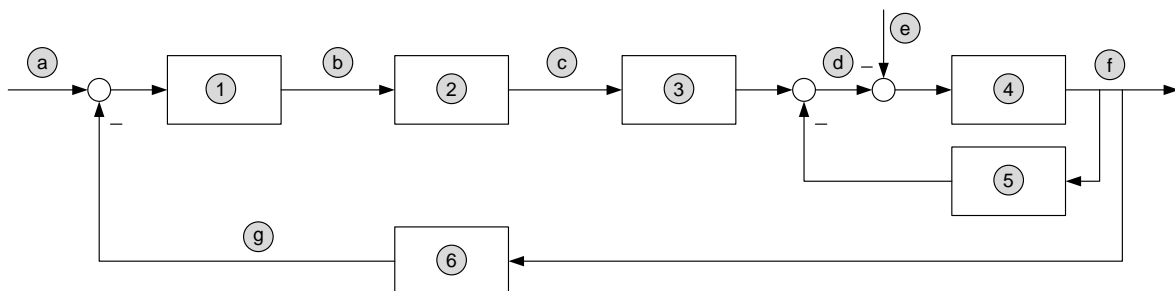


Figure 2.1: Control Structure of a two yoke magnetic bearing

Aufgabe 3: Reluctance motor**(25 points)**

Consider a two-pole reluctance motor, made of linear dynamo sheet steel, fed by an asymmetric half-bridge converter. The number of turns in each pole winding is $N = 62$. The maximum supply voltage is $U_{\max} = 250$ V and the maximum current is $i_{\max} = 75$ A. The motor is operated with a small angular velocity of $\omega = 10 \pi$ /s. The ohmic resistance is $R = 0.125 \Omega$.

The reluctance of the magnetic circuit is known and is given as:

$$R_{\max} = 958603.5 \text{ A/Vs} \quad R_{\min} = 444611.5 \text{ A/Vs}$$

3.1 Sketch the following profiles of the following variables on the next page and select the appropriate axis scales.

Note: For $\frac{9\pi}{10}$ to $\frac{11\pi}{10}$ the reluctance is constant.

a) Inductance $L(\varepsilon)$

b) Differential inductance $\frac{dL(\varepsilon)}{d\varepsilon}$

c) Current $i(\varepsilon)$ (**Please Note:** The current $i(\varepsilon = 0) = 0$ A, the ohmic resistance can be neglected for the magnetization and demagnetization phase)

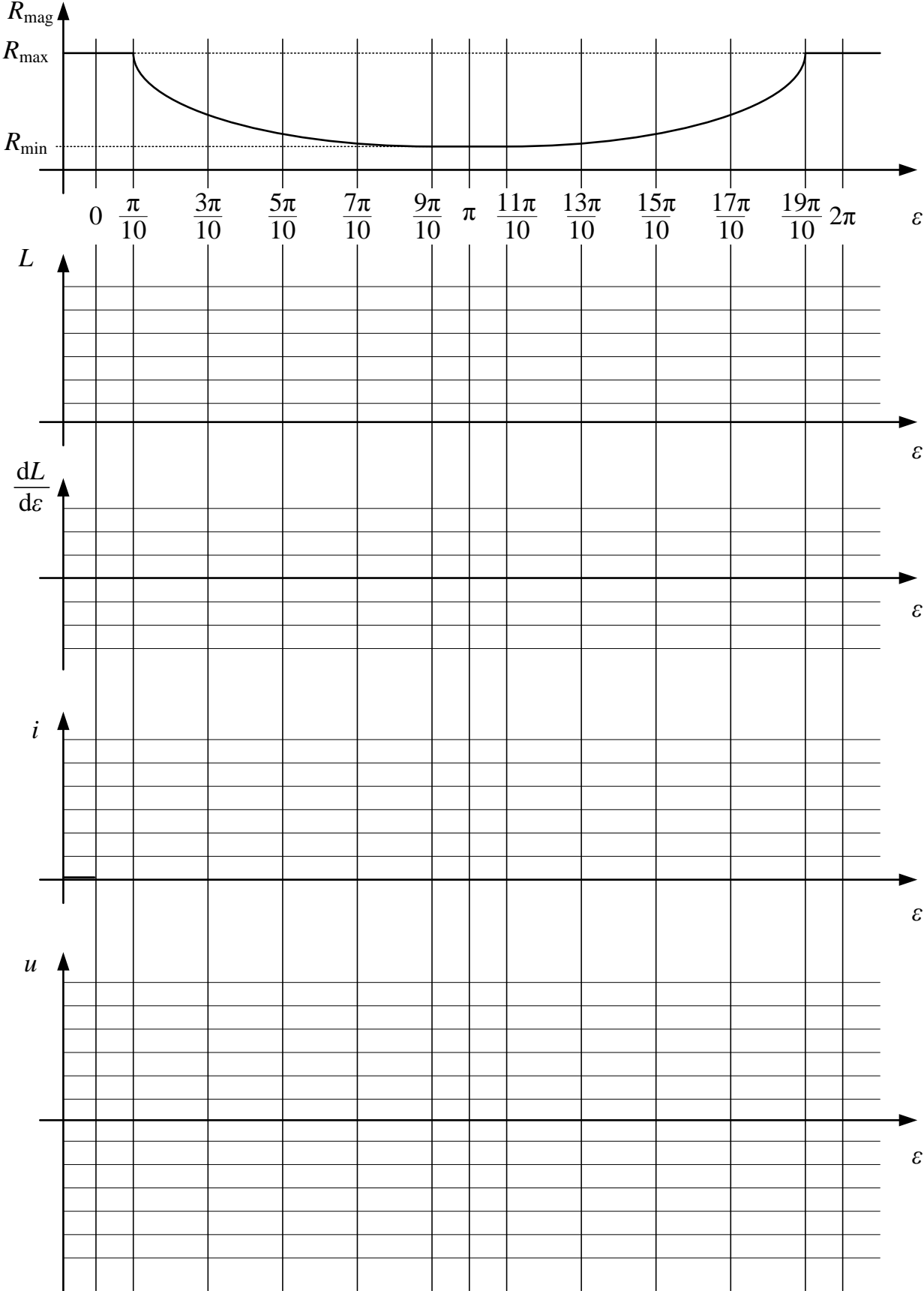
d) Voltage $u(\varepsilon)$

3.2 What is the maximum torque (peak value) T_{\max} that can be obtained from the reluctance motor?

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

3.3 Name three features that are observed at very high speed operation of a reluctance motor.

3.4 Given a reluctance motor capable of generating a maximum torque of 18 Nm with a maximum current of 100 A. Since the converter is not capable of feeding this current to the motor, the maximum current has to be reduced by 15%. What structural changes may have to be made to the motor to deliver a maximum torque of 18 Nm?



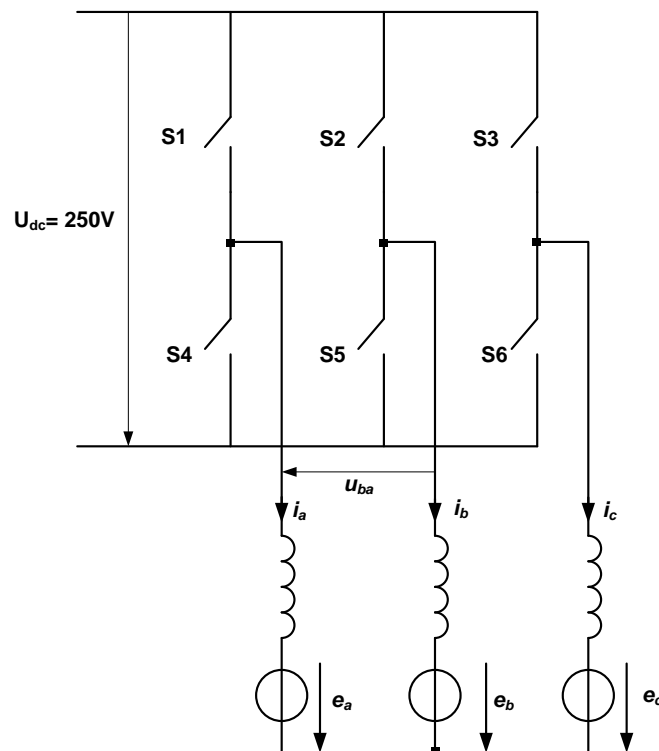
Aufgabe 4: Brushless DC Machine**(25 points)**

Consider a symmetrical 3-phase BLDC motor operating at a speed of $n = 2000 \text{ min}^{-1}$. The motor is delivering a constant torque of $T = 10 \text{ Nm}$ to the load. At the mentioned speed, the induced EMF for the C phase e_c is shown for one electrical cycle in the figure 4.1 (next sheet).

4.1 Calculate the following:

- The mechanical power delivered by the motor to the load at this condition.
- Assuming block-shaped currents in the motor, calculate the magnitude of three phase currents.
- Sketch the induced phase EMFs e_a , e_b and the line-to-line induced back EMF e_{ab} (in the next page). Choose appropriate scalings of the axes.
- Sketch the corresponding block-shaped currents i_a , i_b and i_c (in the next sheet). Choose appropriate scalings of the axes.

4.2 The motor is fed by a three phase inverter as shown below (idealized circuitry).



Consider the following case. $i_a = -i_b$ and $i_c = 0 \text{ A}$ and $U_{dc} = 250 \text{ V}$.

- Which of the switches among S_1 to S_6 have to be closed to ensure this condition?
- What is the voltage u_{ba} at this condition?



Figure 4.1 Induced EMF and currents in a BLDC motor

- 4.3** The simplified control structure for the current control of the BLDC motor is shown in Fig. 4.2. The controller, plant and the sensor transfer functions are $G_c(s)$, $G_s(s)$, and $G_{se}(s)$ respectively with $R = 1\Omega$, $\tau = 0.3\text{ ms}$, $\tau_d = 50\text{ }\mu\text{s}$.

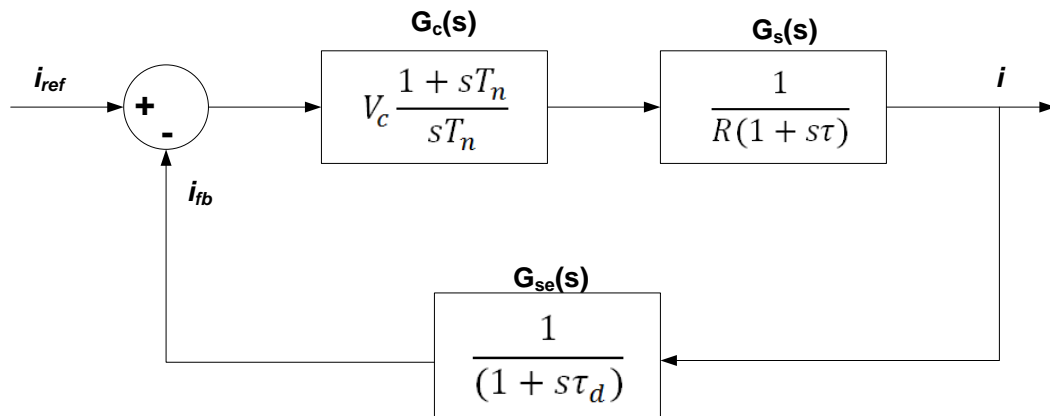


Figure 4.2 Control structure of the current controller of a BLDC motor

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

- The value of the controller reset time T_n .
- The open-loop transfer function
- The closed-loop transfer function $\frac{I(s)}{I_{ref}(s)}$
- Magnitude of the controller gain V_c if the damping factor of the closed loop should result as $d = \frac{1}{\sqrt{2}}$