CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Examination

Tuesday 22 October 2013, 14:00-18:00, V-building

Examiner: Sonja Lundmark. For any queries arising during examination please telephone Johan Åström: 1642

Grading: Your score from this written examination (maximum 80 points) will be added to your points obtained from laboratory work (maximum 30 points) and from the trial exam (maximum 10 points). The grading will then be as follows:

50-64 points G3   65-79 points G4   >79 points G5

Solutions: Solutions will be put on the course home page after the exam.

Review: Time: Tuesday 5 November 12:00-12-30.
Location: Uno lamms room Electric power engineering.

Use of approved calculators (refer to the University's Examination Regulations) is allowed.

Use of Dictionaries and basic mathematics and physics handbook is allowed.

If there is any missing information in the following questions, you can make reasonable assumptions and state them clearly.

Good Luck

1. A shunt connected DC machine is driving a load torque described as $T_L = b \cdot \omega$ (where ω is the speed of the machine) and is fed by a 200V battery. The armature resistance is R_a=1.5 Ohm, the field resistance is R_f=200 Ohm and the load characteristic is b=2. The frictional losses in the machine can be neglected.

a) If the total current which is drawn from the battery is 25A, calculate the armature current of the machine and the speed. (4p)
b) Calculate the flux constant K_b for the previous condition. (1p)
c) The previous machine is connected to the same battery as before and serves the same type of load but the field resistance is increased to 400 Ohm. Calculate the new speed of the machine. (5p)

[10 points]

2. You have **measured** the parameters in the equivalent circuit using **high quality equipment**. The result can be found in table 1 together with the rating of the motor. (Hint: this is probably the most difficult task in the exam ☺)

a) Calculate the phase current at **rated speed** operation using the equivalent circuit parameters. Compare this value with the value given in the table and make some comments. (5p)

b) Calculate the expected loss components, the mechanical output power and the motor efficiency at the **rated speed** operation. Use the equivalent circuit, no approximations is allowed. (12p)

c) The result you obtained in b) differs from the rating 4kW 1455rpm. Discuss what the reason can be for this (even if you have not solved b) comment on why the result differs). (3p)

Table 1

Parameter	**Value**
R_s	1Ω
R_r	0.9 Ω
R_{core}	984 Ω
L_{leaks}	7mH
L_{leakr}	7mH
L_m	0.14H
P_N	4kW
n_N	1455rpm
U	400V
I_N	8.6A
f_N	50Hz

[20points]

3. Explain, in general terms, what limits the continuous output torque AND the peak torque of a motor.

[5 points]

4. a) Explain what asynchronous starting of a synchronous motor is; Why is it used and how does it work

b) Draw the phasor diagram of a synchronous motor when the load current is inductive (indicate the phase angle Θ between the voltage and current, and the load angle

[10 points]

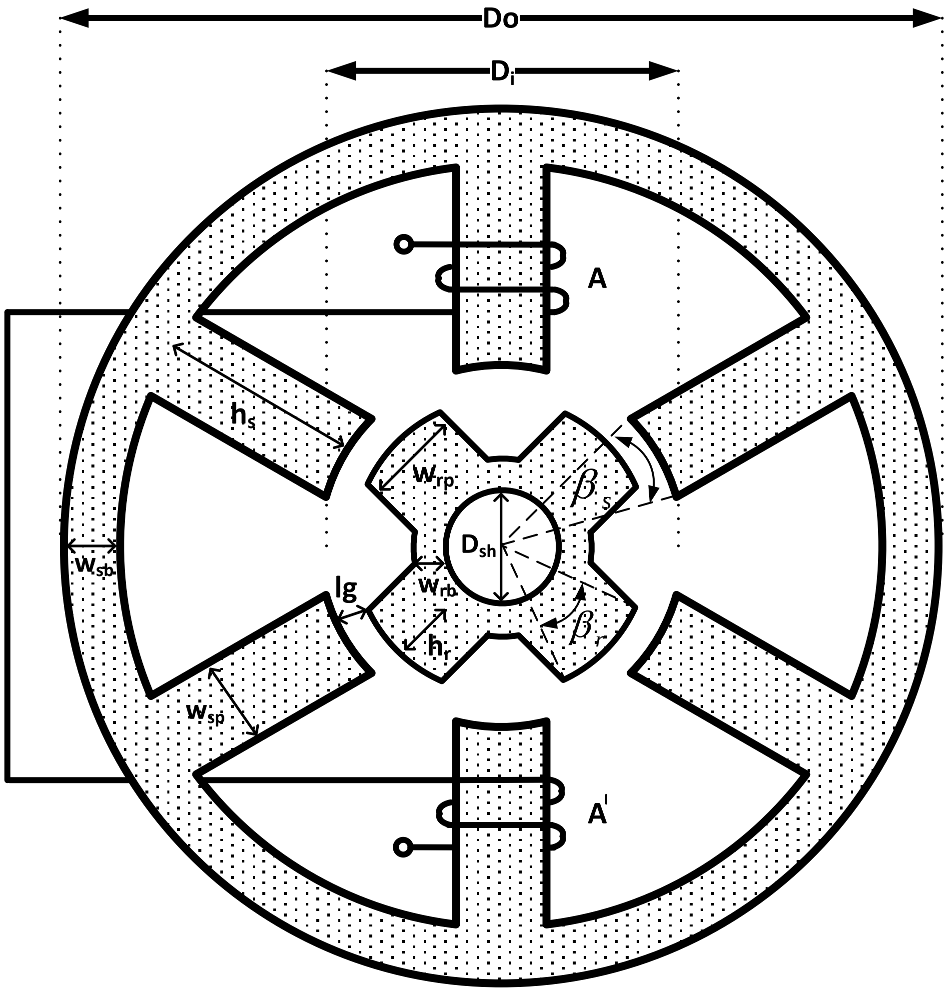


Figure 1: Cross section diagram of a SRM

5. Figure 1 shows the basic diagram of a SRM. Answer to the following questions

a) What is the number of stator and rotor poles?

b) The phase A inductance values are measured to be 100 uH and 600 uH. Which value corresponds to the aligned position and which value is for un-aligned position?

c) Draw the inductance profile for phase A of the SRM if $\beta_r = \frac{\pi}{4}$ and $\beta_s = \frac{\pi}{6}$.

d) Calculate the motor torque if the maximum current in each phase is 10A

[15points]

6. A 8-pole brushless-dc motor with surface mounted permanent magnets has a rating of 1kW and 1000rpm. The per-phase resistance is 0.5Ω and the per-phase induced voltage is 125V. (The motor is fed by a converter providing enough voltage to produce the rated torque at rated speed without any margin).

a) Draw the equivalent circuit of the BLDC motor and **calculate** the value of the parameters used (the inductance can in this case be neglected)

b) Calculate the rated torque at 500rpm (do reasonable assumptions)

c) If you want the motor to operate at 2000rpm, what needs to be done to the motor and/or the motor supply? (no calculation is needed, just make some comments)

d) The motor length is 40mm and the diameter is 100mm. How can you change the motor dimensions in order to increase the output torque with 50%, **give more than one alternative.**

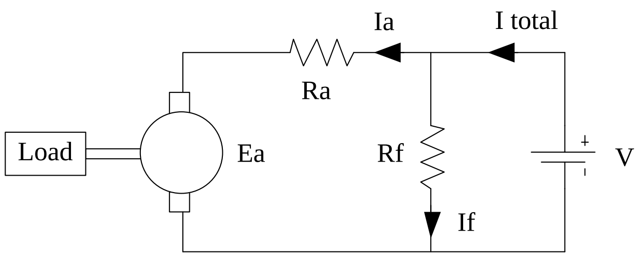
[**15 points**]

7. You are about to pick a motor to certain application with a rated torque speed demand of 10Nm and 2000rpm. You find a PMSM motors from a manufacturer, with 2kW rating and 2000rpm having an efficiency of 91%. Your colleague proudly presents an alternative, a PMSM motor with 94% efficiency and a 2kW rating that is cheaper than your alternative. What can be the reason for this (if we assume that the manufacturers produce motors with the same "quality")?

[5 points]

Solutions:

Problem 1:



a) The field current is:

$$I_f = \frac{V}{R_f} = \frac{200}{200} = 1\ A$$

Therefore the armature current will be

$$I_a = I_{total} - I_f = 25 - 1 = 24\ A$$

In the armature circuit we have:

$$V = I_a R_a + E_a \rightarrow$$
$$V = I_a R_a + K_b \omega \qquad (1)$$

The electrical torque will be equal to the load torque in steady state:

$$T_e = T_L$$
$$K_b I_a = b\omega \rightarrow K_b = \frac{b\omega}{I_a} \quad (2)$$

Then:

$$(1) \overset{(2)}{\rightarrow} V = I_a R_a + \frac{b\omega}{I_a}\omega$$
$$V = I_a R_a + \frac{b\omega^2}{I_a}$$
$$\omega^2 = \frac{(V - I_a R_a)\cdot I_a}{b} \rightarrow \omega = \sqrt{\frac{(V - I_a R_a)\cdot I_a}{b}} = \sqrt{\frac{(200 - 24\cdot 1.5)\cdot 24}{2}} = 44.36\ r/s$$

b) $K_b = \frac{E_a}{\omega} = \frac{V - I_a R_a}{\omega} = \frac{200 - 24\cdot 1.5}{44.36} = 3.697\,\frac{Nm}{A}$

c) The field resistance has now changed. The new field current will be:

$$I_f = \frac{V}{R_f'} = \frac{200}{400} = 0.5\ A$$

We know that the flux constant of DC machines is proportional to the field current, therefore:

$$\frac{K_b}{K_b'} = \frac{I_f}{I_f'} \rightarrow K_b' = K_b \frac{I_f'}{I_f} = 3.697\,\frac{0.5}{1} = 1.848\,\frac{Nm}{A}$$

The electrical and load torques are:
$T_e = T_L \rightarrow K_b' I_a' = b\omega' \rightarrow I_a' = \frac{b\omega'}{K_b'}$ (3)
Then

$$V = I_a' R_a + E_a' \xrightarrow{(3)} V = \frac{b\omega'}{K_b'} R_a + K_b' \omega'$$

$$\omega' = \frac{V}{\frac{b \cdot R_a}{K_b'} + K_b'} = \frac{200}{\frac{2 \cdot 1.5}{1.848} + 1.848} = 57.61\ r/s$$

Problem 2:
3) The parameters in the equivalent circuit are given and the total impedance can be calculated as

$$Z_{rotor} = j\omega L_{leakr} + \frac{R_r}{s}$$

$$Z_{mag} = \frac{j\omega L_m R_c}{j\omega L_m + R_c}$$

$$Z_{rotor}||Z_{mag} = \frac{Z_{rotor} Z_{mag}}{Z_{rotor} + Z_{mag}}$$

$$Z_{tot} = Z_{rotor}||Z_{mag} + R_s + j\ \omega L_{leaks}$$

If we put in the given values, where s is obtained from (1500-1455)/1500 we get the equivalent impedance:

Z_{tot}= 19.97 +j16.17

The stator current can now be calculated as:

$$I_s = U\frac{U_s}{Z_{tot}} = \frac{230}{19.97\ + \mathrm{j}16.17} = \ 6.96\ -\ J5.63 => \ 8.94A$$

The calculated current is higher than the rated value. This means that the impedance of the equivalent circuit is lower if the rated values 1455 4kW are the “true” values. The measurement of the parameters is never 100% correct but we were told that the equipment had high quality so we can’t explain the big deviation on measurement errors.
More important are the operating conditions when the tests were performed. A slight increase in motor temperature will result in higher resistance in the stator and rotor changing the result.
The most likely reason for the difference is that the temperature in the motor was lower for during the tests.

b)The different loss components can be calculated when we know the rotor current and voltage over the iron core resistance

as:

$$I_r = \frac{(U_s - I_s Z_{stator})}{Z_{rotor}} = 7.01A$$
$$Um = (U_s - I_s Z_{stator}) = 210.8V$$

$$P_{stator} = 3I^2 R_s = 3 \times 8.94^2 \times 1 = 239W$$
$$P_{Rotor} = 3I^2 R_r = 3 \times 7.01^2 \times 1 = 132W$$
$$P_{core} = 3\frac{U_m^2}{R_{core}} = 3\frac{210.8}{984} = 135W$$

The output power cannot be assumed to be 4kW. For the given operating point we get

$$P_{out} = 3(I_r^2 \left(\frac{R_r}{s} - R_r\right) = 4289W$$

The efficiency can now be calculated as

$$effic = \frac{4289}{9844289 + 239 + 132 + 135} = 89.4\%$$

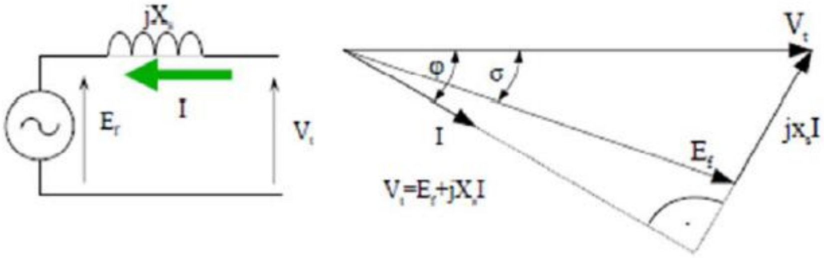
c) Similar discussion as in a). Since the output power is higher this means that we operate at a slightly higher slip. One likely reason for this is that the temperature in the motor (rotor) is lower than the rated temperature. We have also neglected friction and windage losses which also contribute to the error.

*Furthermore we have a component called stray losses that is not accounted for but this is nothing that we have discussed in the course

Problem 4

SM cannot start on its own unless asynchronous starting is used; the rotor is then constructed in a such way (i.e with damper windings or with dolid pole shoes =sp that currents are induced in the rotor and the motor starts as an IM)

b)

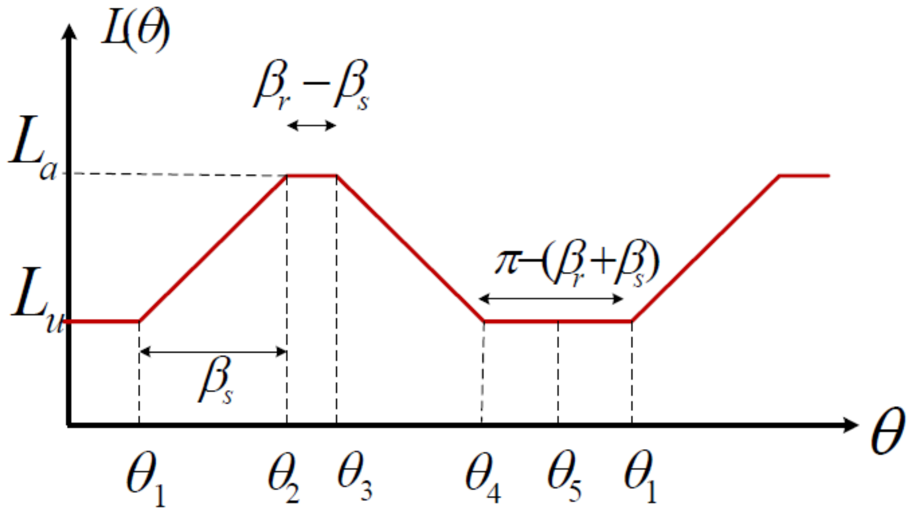


Problem 5

Answer:

a) Ns=6 and Nr=8
b) Aligned position inductance is 600 uH and inductance for un-aligned position is 100 uH

c) Refer to this picture.



d) The torque is $T_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$. For this motor the value is $\frac{1}{2} 10^2 \frac{(600-100)\,uH}{\frac{\pi}{6}} = 0.4774$ Nm.

Problem 6

Eq circuit see course material

The task gave us numbers of the per phase resistance and induced voltage. However, the eq. circuit of the BLDC motor represents two phases in series so the resistance will be 1Ω and the induced voltage 240V

b) We can assume that the rated torque is the same for 500rpm as it is at 1000rpm. Hence the rated torque can be calculated as

T=P/ω=1000/(1000π/(30)=9.55Nm

c) If the speed is doubled we need more voltage for the same motor. Either we change converter provided that the winding can handle higher voltage or we need to rewind the motor (or if possible connect the windings in a different way)

d) We can use the relation that the torque is prop to D^2L and just increase that term 50%.

Problem 7

What your colleague has most likely missed is that the rated speed is different. If the motor speed is higher (for the same output power) the size of the motor is reduced which results in a lower cost. In addition, higher speed motors usually (of course not always…) have higher efficiency.