CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Examination

Thursday 25 October 2012, 14:00-18:00, M-building

Examiner: Sonja Lundmark. For any queries arising during examination please telephone Saeid Haghbin at 1663

Grading: Your score from this written examination (maximum 70 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 13 November 12:00.
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 separately excited DC machine has the following known parameters: armature resistance R_a=1 Ω, motor constant k_e=1.25 and a rated armature current of 15A.

a) The converter feeding the DC machine is connected to a 400V grid. Decide if you need a one phase or three phase supply to the dc rectifier feeding the DC bus, if you are to operate the motor at 2600rpm.

b) Draw the block diagram of a DC motor with a current controller, including feed forward of the back emf. **Write the expressions** inside the blocks.

[10 points]

2. An Induction motor has the following ratings: 4kW, 1455rpm, 50Hz 400V. The rotor resistance is 1Ω and the magnetizing inductance is 0.14H.

a). Derive an expression for the torque as a function of rotor speed, valid for the speed range 1455rpm- 1500 rpm when connected to a 50Hz 400V grid. (Calculate the constant/constants in your expression!)

b) The motor is now fed by a frequency converter with a maximum voltage output of 360V. Calculate the new mechanical output rating of the IM at 50Hz supply frequency. Tip1. Neglect the leakage inductances as well as the stator resistance. (Tip2. This is probably the most tricky task in the exam ☺)

[10 points]

3. a) Draw the equivalent circuit of a synchronous generator and explain how one can measure the parameters?

b) One way of controlling a synchronous motor speed is to change the number of poles in the stator. What are the possible speeds for a motor with a maximum number of 10 poles and minimum of 4 poles at a supply frequency of 50 Hz? Write one advantage and disadvantage of this method for speed control?

[5 points]

4. Figure Q4-1 shows a 4/2 SRM and figure Q4-2 shows the drive circuit for one phase of the SRM. (hint: air gap length at unaligned position, $l_{g,u}$ = stator inner radius - rotor back iron thickness – radius of shaft)

[15 points]

a) Calculate the inductance in aligned and unaligned position and draw the inductance profile (both phase A and B in one graph).

b) Assume that the motor is generating a positive torque by appropriate control of switches in the drive circuit. Draw the command signal to the switches for phase A and phase B of the SRM.

c) For a maximum current of 20 A (peak value), calculate the total SRM torque (positive) for part b.

d) Write down one advantage and one disadvantage of a 4/2 SRM.

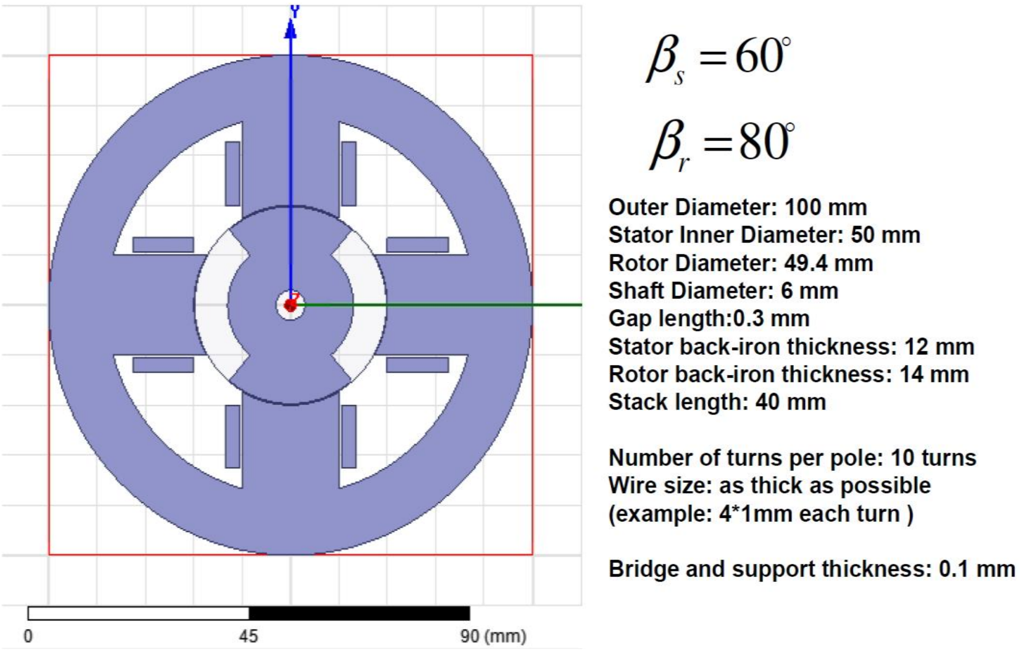


Fig Q4-1: Geometrical information of a 4/2 SRM

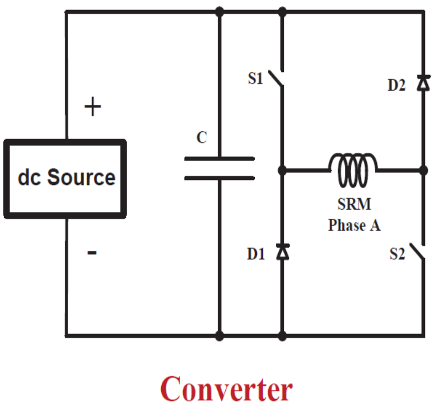


Fig Q4-2: Drive for one phase of an SRM

5. a) Sketch a typical emf waveform of a sinusoidal commutated PM motor and a BLDC motor, together with the phase current for one phase. The x-axis should be labeled with electrical rotor position, marking relevant current transitions.

b) Explain why we don't use a **per phase** equivalent circuit of the BLDC motor

[10 points]

6. You have a motor with the following dimensions:
Diameter = 150mm
Length = 50mm.
The motor is used for an application operating at 3500rpm and 12Nm. Temperature measurements are indicating that the winding temperature is at its maximum.

a) Suggest a new motor size if you need to increase the torque to 24Nm

b) If you could change D or L with 10% in order to increase the efficiency in the original motor. Which parameter would you change? Motivate your answer with respect to copper and iron losses. **[5 points]**

7. Rank three different motor types with respect to:
a) speed range. (All motors can be designed for the same rated torque speed range but different motors have different extended speed range)
b) motor efficiency.
c) power density
d) cost
e) robustness

[10 points]

8. Are the following statements true or false?

a) If we have a motor with two times higher iron losses than copper losses at a certain speed and torque, the efficiency is probably optimized for this point.

b) If we increase the outer dimensions of a motor, we can increase the efficiency of the motor.

c) If a grid connected induction motor can't start a certain load one solution can be to feed the motor with a frequency converter instead

d) A BLDC motor has approximately $\sqrt{2}$ times higher power density than a PMSM

e) The iron losses increases proportionally to the speed (P_{iron} ~ speed).

f) The copper losses increases proportionally to the speed (P_{copper} ~ speed).

g) A series DC motor has a higher starting torque than a shunt DC motor of the same size

h) The main problem of the SRM drive is the converter reliability (the converter is not reliable).

i) The armature reactance in a synchronous motor is mostly because of stator flux leakage.

j) The specific magnetic loading is usually proportional to the rating of a motor

[5 points]

Solutions:

Problem 1:

Solution:
a) The armature voltage can be expressed as

$$U_a = R_a I_a + E_a$$

We know the motor constant so we can calculate the induced voltage at 1500prm expressed as

$$E_a = k_e \omega = 1.252 \frac{2600 \cdot \pi}{30} = 340V$$

If the converter is fed from a 1 phase inverter we cant get a 340V supply to the machine, Hence we need a thee phase supply.

Problem 2:

a)

Since we are to derive an expression valid in the “normal” operating range we can assume a linear relationship between the slip and torque.

Hence, the torque can be expressed as :

$$T(n_r) = k \cdot s = k \frac{n_s - n_r}{n_s}$$

Where n_s is the synchronous speed

We know that the rated torque is produced at 1455rpm. We also know that the rated torque results in 4kW output power.

$$T(1455) = \frac{4000}{(1455\pi / 30)}$$

$$\Rightarrow$$

$$k = T_N \frac{n_s}{n_s - n_r} = \frac{4000}{1455\pi / 30} \frac{1500}{1500 - 1455} = 875.0787$$

So the final expression for the torque, valid for a constant flux and from 0-T_N is

$$T(n_r) = 875\frac{1500 - n_r}{1500}$$

b) If the motor is fed by 50Hz and 360V instead we cant operate the motor at the same torque as before since the current is limited to its rated value.

If we calculate the impedance of the equivalent circuit, neglecting the stator resistance and leakage inductance we get the following:

$$Z = \frac{j\omega L_m \frac{R_r}{s}}{j\omega L_m + \frac{R_r}{s}}$$

If we decrease the voltage to 360V we can allow the slip to increase until we reach the rated current.

The current to the magnetizing inductance will be

$$I_{m1} = \frac{U_1}{jX_m} = \frac{400/\sqrt{3}}{j2\pi 50 \cdot 0.14}$$

$$I_{m2} = \frac{U_2}{jX_m} = \frac{360/\sqrt{3}}{j2\pi 50 \cdot 0.14}$$

The current to the rotor for the two cases will be

$$I_{r1} = \frac{U_1}{R_r/s_1} = 400/\sqrt{3} \cdot 0.03$$

$$I_{r2} = \frac{U_2}{R_r/s_1} = 360/\sqrt{3} \cdot s_2$$

We need to limit the current to its rated value Hence, we can calculate the new maximum slip as

$$I_1 = I_2 =$$

$$\left|\frac{400/\sqrt{3}}{j2\pi 50 \cdot 0.14} + 400/\sqrt{3} \cdot 0.03\right| = \left|\frac{360/\sqrt{3}}{j2\pi 50 \cdot 0.14} + 360/\sqrt{3} \cdot s\right|$$

$$\Rightarrow$$

$$s = 0.0351$$

We now know at what speed we can operate the motor but we still need to determine the torque at this new slip. For the rated flux in the machine we get the following torque at s=0.0351

$$T_1 = T_N \cdot \frac{s_2}{s_1} = 26.24 \frac{0.0351}{0.03} = 30.71$$

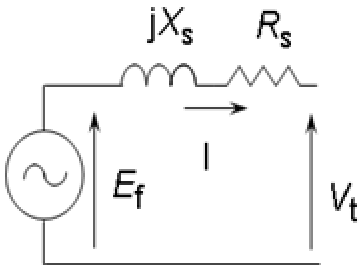
The new torque can be calculated as

$$T_2 = T_1 \left(\frac{U_2}{U_1} \right)^2 = 30.71 \left(\frac{360}{400} \right)^2 = 24.88 Nm$$

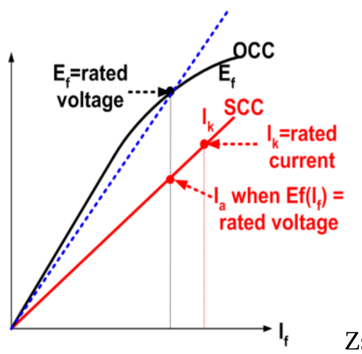
So the new output power is

$$P = T\omega = \frac{1500 - 1500 \cdot 0.0351}{30} \pi \cdot 24.88 = 3770W$$

Problem 3)



a) by using OCC and SCC one can measure the parameters.



Zs=Eoc/Isc

b) Ns = 120 fe/P where for P=4, 6,8 and 10 the speed is: 1500, 1000, 750 and 600 rpm respectively. The speed can not be controlled continuous (just above speeds), and then we need a device to change the machine winding to have the desirable number of poles. The positive point is that we do not need an inverter.

Problem 4)

a) The inductance is $L=N^2/Rg$ where N is the number of turns and Rg is reluctance of the airgap. The iron path reluctance is neglected. For the aligned position the inductance is written as

$$L_a = \frac{N^2}{R_g} = \frac{N^2}{\frac{2\, l_{g,a}}{\mu_O A_g L}} = \frac{N^2}{\frac{2\, l_{g,a}}{\mu_O \frac{D_S}{2} \beta_S L}} = \frac{20^2}{\frac{2*0.3\ mm}{\mu_O \frac{50mm}{2} * \frac{\pi}{3} * 40\ mm}} = 877.28\ \mu\text{H}$$

At unaligned position, the air gap length can be calculated as $l_{g,u}$ = stator inner radius - rotor back iron thickness – radius of shaft = 25-14-3 = 8 mm. Then the inductance in unaligned position can be stated as

$L_u = \frac{l_{g,a}}{l_{g,u}} L_a = \frac{0.3\ mm}{8\ mm} * 877.28\ \mu\text{H} = 32.898\ \mu\text{H}$. The inductance profile is shown in the figure below.

b) The control signals for the phase A and B of the SRM are shown at the following figure.

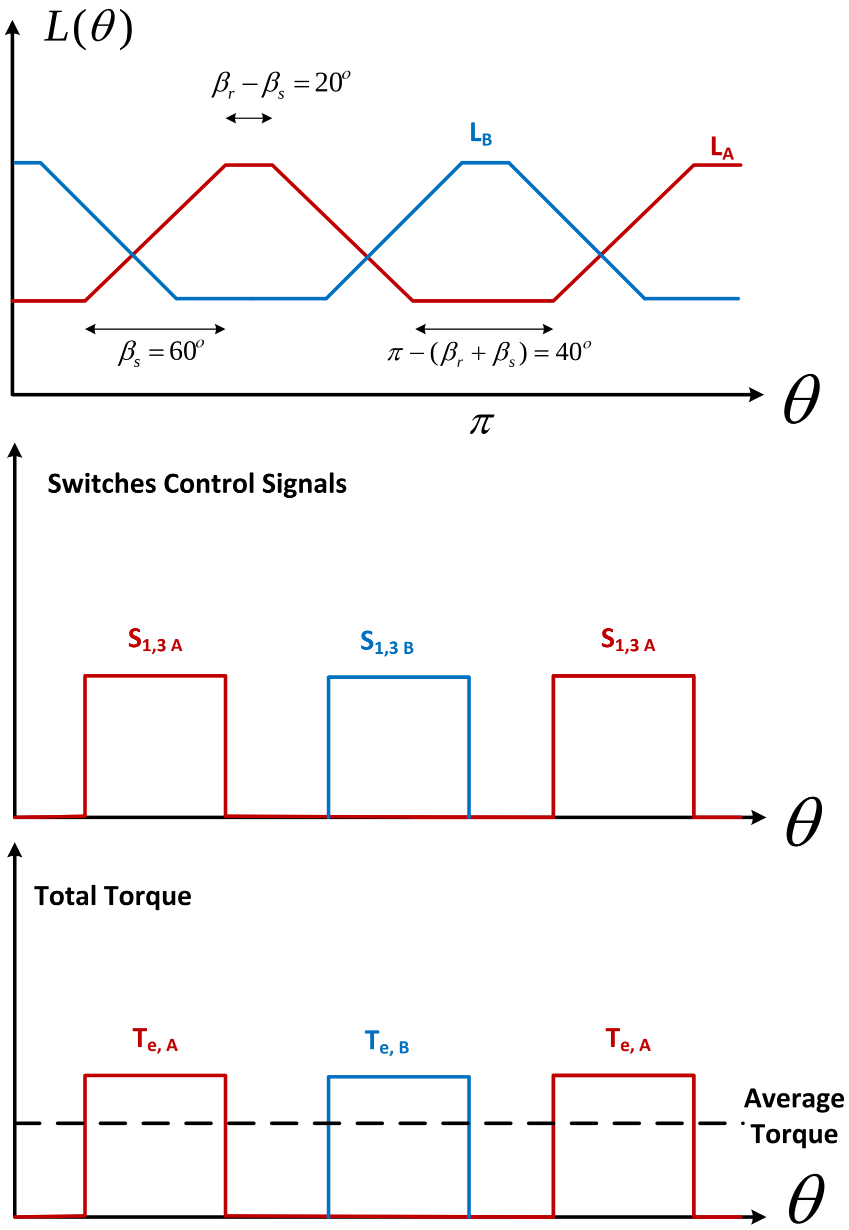
c) The torque of one phase can be calculated as $T_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$. For the phase A, for example, the torque for the duration that the switch is on can be written as

$$T_{e,A} = \frac{1}{2}\ i^2 \frac{dL}{d\theta} = \frac{1}{2}\ i^2 \frac{L_a - L_u}{\theta_u - \theta_u} = \frac{1}{2}\ 20^2 \frac{877.28\ \mu\text{H} - 32.898\ \mu\text{H}}{\frac{\pi}{3} - 0} = 0.1613\ Nm$$

The calculated value for phase A, is exactly the same for the phase B as well. The last part of the figure shows that to calculate the total machine torque we need to calculated the average value of the torque for the phas A and B as

$$T_{e,total} = Average(T_{e,A} + T_{e,B}) = \frac{\frac{\pi}{3}}{\pi}\ (0.1613 + 01613) = \ 0.1075\ Nm.$$

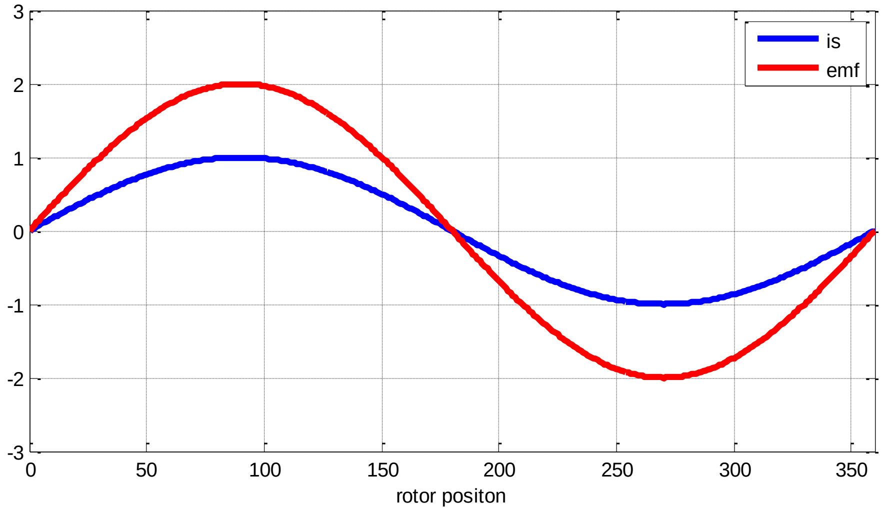
d) Disadvantage is start up problem (in some position the SRM can not start up and the advantage is lower losses in the motor due to lower supply frequency make it suitable for the high speed application.



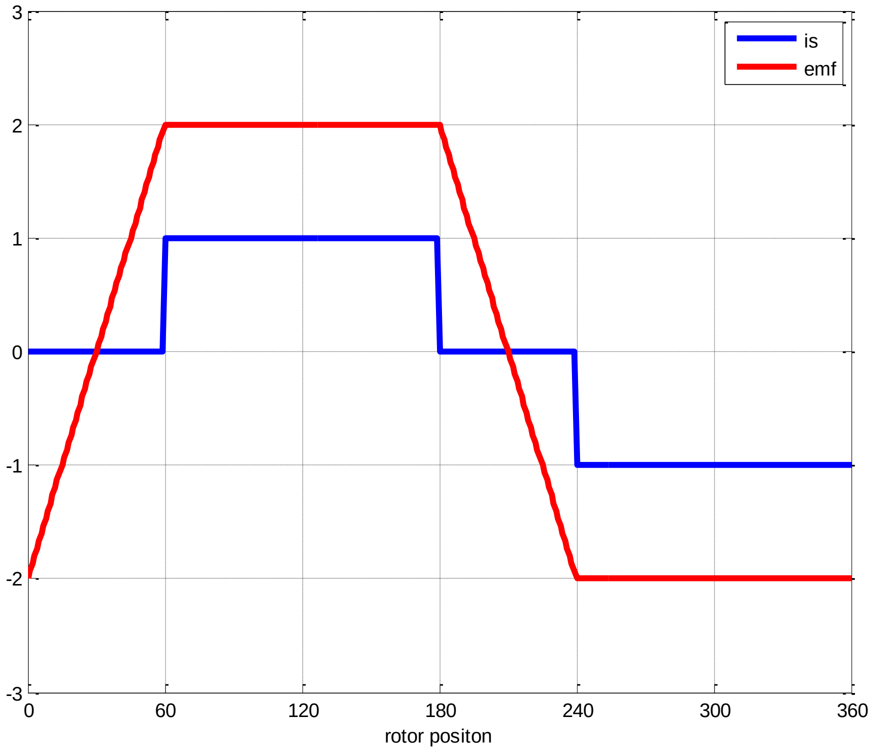
$L(\theta)$
$\beta_r - \beta_s = 20^o$
L_B
L_A
$\beta_s = 60^o$
$\pi - (\beta_r + \beta_s) = 40^o$
θ
π
Switches Control Signals
$S_{1,3\ A}$
$S_{1,3\ B}$
$S_{1,3\ A}$
θ
Total Torque
$T_{e,\ A}$
$T_{e,\ B}$
$T_{e,\ A}$
Average Torque
θ

Problem nr 5)
A typical emf and current waveform can be seen in the figure below

PMSM



BLDC



b) Since only two phases are active at every time instant (except for the time when two phases commutates), The equivalent circuit of the BLDC motor can be represented by two phases in series all the time.

Problem 6) a) In order to increase the toque with a factor of two we can simply increase the length of the motor with the same factor. However, this might not be the optimal solution. If we instead scale L and D equally we need to increase the size as follows

$$T \propto LD^2$$

$$\Rightarrow$$

$$scale = \sqrt[3]{2} = 1.26$$

b) The best alternative is to increase the diameter with 10%. This will result in a decreased NI needed with the same factor. We will also decrease the stator resistence since we can increase the amount of copper in the stator slot. In total, we can expect the copper losses to decrease with a factor of:

$$1/D^4 = 1/1.1^4 = 0.68$$

Problem 7)a) SRM, IM/DC IPM PSMS/BLDC

b) PMSM/BLDC/IPM SRM IM/DC

c) PMSM/BLDC/IPM, SRM IM/DC

d) IM DC/SRM BLDC PMSM/IPM

e) IM SRM PMSM/BLDC/DC

Problem 8

a) False, b) True , c) True

d)False

e) False

f) False

g) True

h) False

i) False

j) False