CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Examination

Thuesday 28 October 2014, 14:00-18:00, V-building

Examiner:	Sonja Lundmark. For any queries arising during examination please call Johan Åström, 1642
Grading:	Your score from this written examination (maximum 80 points) will be added to your points obtained from laboratory work (maximum 20 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 11 Nov 12:00. Location: 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 constant load torque of 1N.m and is fed by a 12V battery through a dc-chopper. The armature resistance, $R_{a,}$ is 0.1 Ohm and the field resistance, R_f, is 600 Ohm. The friction in the machine can be neglected. Ignore any voltage/current harmonics produced due to the dc-chopper.

a) What do you need to measure in order to obtain the motor constant? (1)

b) What do you need to do in order to reverse the rotation of the motor (motivate your answer)? (4)

c) The motor is connected to a 1Nm constant load, operating at 1000rpm and 10V. What happens with the speed if we increase the voltage to 12V (6p)

d) The motor is now operating at a constant speed and torque. How does the turn on/ and of time (switching frequency) of the dc-chopper affect the resistive losses in the motor winding? Motivate your answer. (4)

[15points]

2. You have an induction motor with the rating of 4kW 1435 rpm 50Hz and 400V.

a) Calculate the slip of the motor (1)

b) Calculate speed if the motor is connected to a constant load of 10Nm (2)

c) Calculate the speed if the frequency is decreased to 10Hz. Do reasonable assumptions regarding the change in voltage. (2)

d) What are the benefits using a frequency converter fed induction motor during the start up (compared to a grid connected IM). (5)

[10 points]

3. You have a PMSM motor with a rating of 4kW at 3000rpm and 92% efficiency. Measurements show that the losses are equally distributed between the iron and copper losses (friction losses can be neglected in this case). Estimate the efficiency at the same operating point if you decide to decrease the length with 10%.

[5 points]

4. 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 use a variable frequency source (inverter). Is it possible to connect several synchronous motors to one inverter, motivate your answer?

c) Draw the torque speed profile of a synchronous machine. Specify the motor and generator operating points on the drawing.

[10 points]

5. 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)

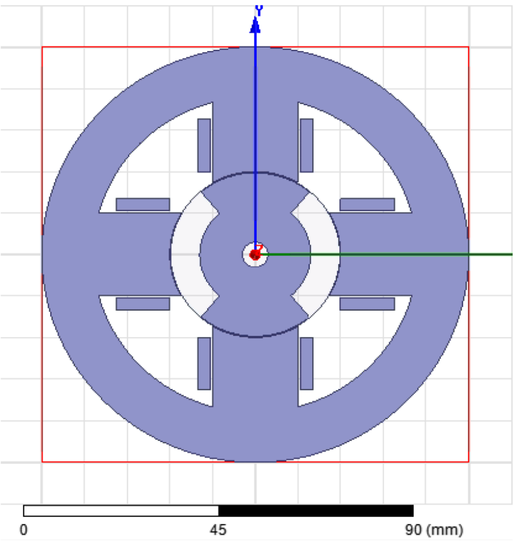
a) Calculate the inductance in aligned and unaligned position and draw the inductance profile (both phase A and B in one graph).

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) In a SRM, the inductance is usually increased linearly from a minimum value to a maximum one. If this increment is not linear, what is the impact on the machine performance? How one can possibly enhance the performance?

[15 points]



$\beta_s = 60^\circ$

$\beta_r = 80^\circ$

Outer Diameter: 100 mm
Stator Inner Diameter: 50 mm
Rotor Diameter: 49.4 mm
Shaft Diameter: 6 mm
Gap length:0.3 mm
Stator back-iron thickness: 12 mm
Rotor back-iron thickness: 14 mm
Stack length: 40 mm

Number of turns per pole: 10 turns
Wire size: as thick as possible
(example: 4*1mm each turn)

Bridge and support thickness: 0.1 mm

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

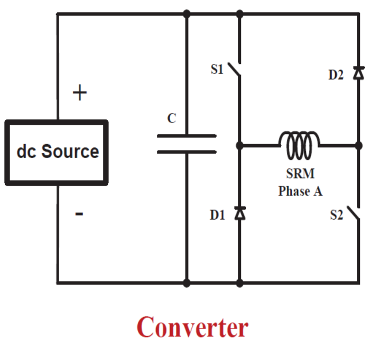


Fig Q4-2: Drive for one phase of an SRM

6. You have a 12 pole, PMSM motor with a rating of 400W, 1000rpm and 3.64A that you want to use as a generator for a small wind turbine. You find the parameters in the equivalent circuit, R_s=2Ohm and L_s=40mH, and the per phase motor constant k=0.35. To simplify things you decide to connect the generator to a resistive load and simply dump the generated power as heat, without any control. The provider of the wind turbine suggests a model that will provide a maximum of 350W at 1000rpm to the motor shaft. (After that speed and power the turbine shuts down so you don't have to think about strong winds). (Hint: This is probably the trickiest task in the exam)

a) Is it safe to say that this will work? Motivate your answer. (No calculation is needed) [5]

b) Make a rough estimation of the load resistance in order to provide a breaking power of 350W at 1000rpm. (Hint: Just a qualified guess might lead you to the correct answer) [8p]

c) Calculate the maximum breaking torque that can be accomplished at 10rpm, (without any control, just passive resistors) [7p]

[**20 points**]

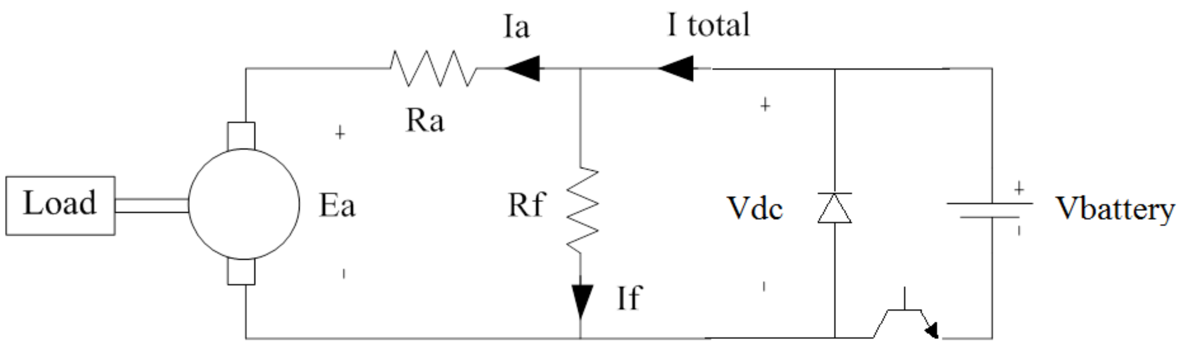
7. Are the following statements true or false?

a) The electric loading in a water cooled motor is often the same as in an air cooled motor
b) If we increase the speed of a motor we can reduce its volume if the output power is constant
c) The number of turns in a winding does not affect the copper losses if the amount of copper (fill factor) remains the same
d) In an IM is fed with a frequency converter we can operate it at its rated torque from zero speed up to its rated speed
e) If we feed an IM with a dc voltage it will work good as a breaker at high speeds
f) The peak torque at low speeds are generally limited by the voltage supply
g) If we double the number of poles in motor with a given volume and speed we approximately double the continuous torque output
h) A BLDC motor can not operate as a Generator
i) If the rotor resistance increases in an induction motor, the starting torque increases.
j) If we scale the diameter of a motor the iron losses will decrease the same amount as the increase in copper losses

[5 points]

Solutions:

Problem 1:



a) Inorder to obtain the motor constant we need to measure the armatrure current or disconnect the load and run it at no load speed.
b) We need to change the direction of the field current without changing the direction of the armature (or the other way around). This can only be done by physically chaninge the winding connections.
c) First we need to calculate the motor constant at 10V supply. Since we know the input and output we can setup an equation to calculate the current

$$P_{in} = P_{loss} + P_{mechanical}$$
$$10I = 0.1I^2 + 1\frac{1000\pi}{30} => I = 11.89A$$

We can now calculate the motor constant for 10V supply
$k = 1/11.89$

If the supply voltage increases so does the field current, with the same proportion. The motor constant at 12V supply then becomes
$$k_2 = \frac{12}{10}\frac{1}{11.89}$$

We still have the same load torque so the current must decrease
$$I = \frac{1}{\frac{12}{10}\frac{1}{11.89}} = 9.91A$$

The speed can now be calculated as
$$w = \frac{U - RI}{k_2} = \frac{12 - 0.1 * 9.91}{\frac{12}{10}\frac{1}{11.89}} 109.1\frac{rad}{s} => 1041rpm$$

d) If the switching frequency changes the current ripple changes. We still control the current to have the same mean value but the RMS value of the current increases with increasing ripple. Hence, the losses in the winding will increase for lower switching frequencies.

Problem 2:

a)

The slip can be calculated as (ns-nr)/(ns)
For the rated operation

s=(1500-1435)/1500=0.0433

b) If we load the motor with 10Nm we we can use the known rated slip and torque to calculate the new slip
Trated=4000/(1435π/30)

s=(1500-1435)/1500*10/(4000/(1435π/30)=0.0163

The speed can now be calculated as

nr=ns-ns*s=1475.6rpm

c)The frequency is reduced to 10 Hz. We reduce the voltage with the same magnitude so the flux remains the same. Hence we have the same slope of the Torque-speed curve. The new speed can be calculated as

ns-nslip=300-24.45=275.5rpm

d) If we feed the IM with a frequency converter it is possible to feed the motor with a low frequency. As a result, the starting torque will be higher compared to a grid connected IM. The starting currents will also be smaller since we feed the motor with a lower voltage

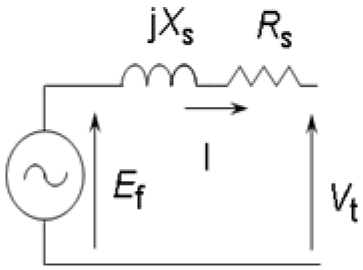
3) The efficiency can be calculated as

Effic=4000/(4000+Piron+Pcu)=92%
Since the losses are of equal magnitude we can calculate them

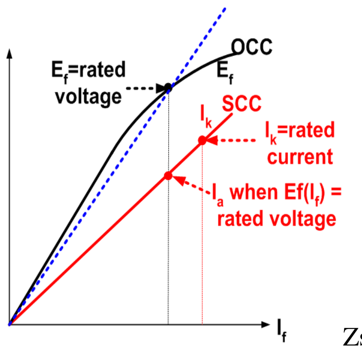
Piron=Pcu=174W
If we decrease the length of the motor the iron losses are expected to decrease with the same amount. The copper losses will increase with the same amount. Since the losses has the same magnitude the efficiency remains the same.

(**However, in practice a decrease will result in a higher temperature in the motor resulting in a higher winding resistance. In addition, a higher N*I term results in slightly higher iron losses compared to the linear assumption. Hence the efficiency will decrease. Since we don’t have more information it is not possible to estimate the difference so the best guess is that the efficiency remains the same since the change is so small.)

Problem 4

a) 

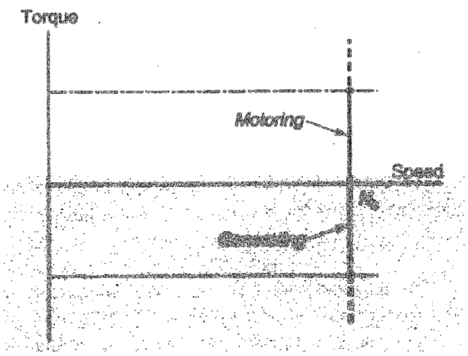
by using OCC and SCC one can measure the parameters.



Zs=Eoc/Isc

b) Yes. Since the motors are using one inverter, the closed loop control can not be performed.

c) Speed-Torque curve:



Problem 5

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

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

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

$L_u = \frac{l_{g,a}}{l_{g,u}} L_a = \frac{0.3\ mm}{8\ mm} * 877.28\ \mu H = 32.898\ \mu H$. 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.

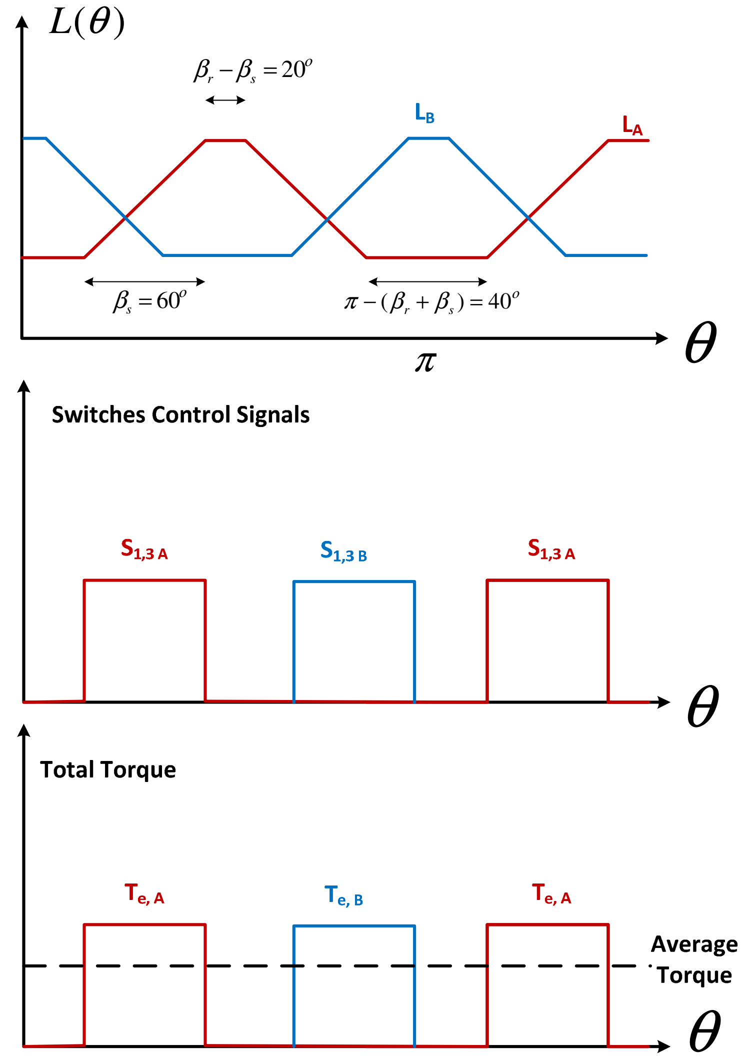
c) The torque of one phase can be calculated as $T_e = \frac{1}{2} i^2 \frac{dL}{d\theta}$. For the phase A, for example, the torque for the duration that the switch is on can be written as

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

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) The torque function will not be constant anymore. Depend on the type of nonlinearity; there will be torque ripple with a constant current drive strategy. One can change the constant current strategy to an enhanced waveform to improve the torque ripple.



Problem 6

a) The rating is stated for motor operation with proper motor control. In order to run a motor (or generator) in an efficient way we need to keep track of the rotor positon all the time and control the current so that the load angle is more or less optimal, 90 degrees for a surface mounted PM motor. If we simply connect the motor to a resistive load we have no control of the current and it is safe to say that we will not operate at an optimal load angle, since we always have inductance in the motor. As a conclusion we should be aware of the fact that the rating of the motor needs to be higher if this is going to work. We can know for sure without calculations but it is definitely not safe to say that it will work.

b) In order to solve this question lets start with a "wild guess". The Impedance of the motor at 1000rpm is

X=2+j2π100*40e-3=2+j25

The induced voltage at this speed is
E=kw=0.35*1000/30* π=36.35V

We need 350/3=116.7W breaking power in each phase

3.64A was the rated current and in order to dissipate 116.7W in a resistive load with this current we get
$R=116.7/3.64^2=8.8$Ohm

If we calculate the current obtained by connecting a 8.8Ohm resistance we get

$$I = \frac{E}{Z} = \frac{36.6}{2 + j2\pi 100 * 0.04 + 8.8} = 1.33A$$

Hence, we need to increase the current more by having an even lower resistance

But… since the inductive part is so dominant we cant achieve this… even if we short circuit the motor.

So the answer is it will not work!

c) In order to maximize the torque at 10rpm we can simply short circuit the motor terminals maximizing the current.

The current can then be calculated as

$$I = \frac{E}{Z} = \frac{36.6/100}{2 + j2\pi 0.04} = 0.18A$$

We also need to consider the phase angle between the induced voltage and current which in this case becomes 7.1 degrees.

The torque can now be calculated as

$$T = 3kIcos(\varphi) = 3 * 0.35 * 0.18 * \cos(7.1) = 0.19Nm$$

At higher speeds the phase shift increases and at a certain point it might be needed to add a resistance (similar reasoning as we have in the induction motor at start)

Problem 7

a) **F**
b) **T**
c) **T**
d) **F**
e) **F**
f) **F**
g) **F**
h) **F**
i) **T**
j) **F**