Beräknat antal tentander: 32
Antal tentamensteser: 50
Återsänds till: Johan Åström Elteknik
Placeringslistor: Elin Björklund Elteknik

CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Re-Examination

Saturday 3 January 2015, 14:00-18:00, V-building

Examiner: Sonja Lundmark. For any queries arising during examination please telephone Johan at 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 20 jan 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

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1. A shunt connected DC machine is driving a constant load torque of 40N.m and is fed by a 200V battery through a dc-chopper. The armature resistance, $R_{a,}$ is 2 Ohm and the field resistance, R_f, is 200 Ohm. The friction in the machine can be neglected. Ignore any voltage/current harmonics produced due to the dc-chopper.

a) When the dc-chopper has a duty cycle of 70%, the current fed to the machine has a mean value of 20A. Calculate the armature current of the machine and the speed. (6p)
b) The duty cycle of the chopper is increased to 90%. Calculate the new armature current of the machine and the new speed. (6p)
c) Calculate the efficiency of the machine in question (b) (3p)

[15 points]

2. The full-load slip of an 4-pole induction motor at 50 Hz is 0.04. The motor is connected to a load described as $T=b\omega^2$, where the rated torque is reached when the motor is fed with 50Hz :

a) Calculate the frequency needed to operate the motor at 1000rpm, assume that U/f=constant

b) If the load is operated at 100rpm keeping the U/f ratio constant, what can be changed in order to increase the efficiency of the motor. Motivate your answers with expressions for the losses in the motor.

[10 points]

3. You have a motor that operates on its thermal limit. Explain the consequences if you decide to run the motor at 3-times its rated torque for a short period of time and then continue to operate at its rated operation. (Assume that the supply can handle the increase of current and voltage during the peak operation)

[5 points]

4.
a) Explain why the ratio of stator voltage over voltage frequency (V/f) often is kept constant during the variable speed control of an induction machine. [5p]
b) Draw the phasor diagram of a synchronous machine (considering the stator resistance as well), indicating the positive direction of current in the equivalent circuit, the phase angle φ between the grid voltage and the current, and the load angle δ, when it is operating as:
i) underexcited motor, having a lagging power factor (absorbs reactive power from the grid) [3p]
ii) generator with a power factor equal to 1 [2p]

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[10 points]

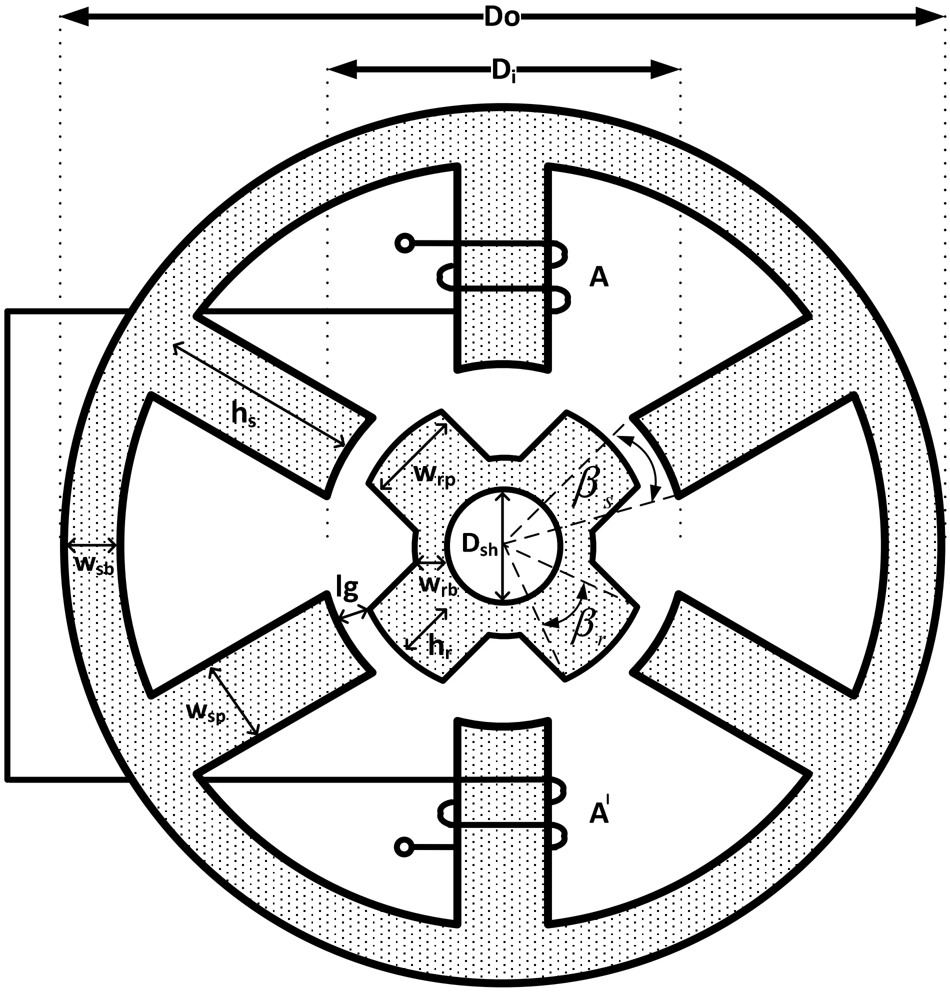

Figure 1: Cross section diagram of a SRM

5. A switched reluctance motor has six stator poles and four rotor poles, like the one in Figure 1. Each stator pole has 40° of arc width while each of the rotor poles has 10° of arc width. The supply current to the stator windings is 5A.

At the minimum reluctance position the flux-linkage (λ) versus coil current (i) relationship is:

$$\lambda_1 = \frac{0.9 \cdot i}{2 + i}$$

while at the maximum reluctance position, the flux-linkage versus coil current relationship is:

$$\lambda_2 = 0.05 \cdot i$$

Assuming ideal switching action in the power converter which is connected to the stator windings:

a) Calculate the inductance of one phase of the SRM for the aligned and unaligned position [2p]
b) Draw the inductance profile for all the three phases of the SRM [6p]
c) Calculate the average total torque of the SRM (not only maximum torque) [7p]

If necessary, you may utilize the following:

$$\int \frac{x}{ax+b}dx = \frac{x}{a} - \frac{b}{a^2}\ln(ax+b)$$

[15points]

6. A 12-pole BLDC motor with surface mounted permanent magnets has a rating of 6kW and 3000rpm. The per phase resistance is 0.325Ω the inductance is 1.2mH and the per phase induced voltage is 200V at the maximum level .

a) Draw the equivalent circuit of the BLDC motor used for steady state calculations. [2p]

b) Calculate the rated torque at 3000rpm [1p]

c) Draw the induced voltage and the current in one phase during one electrical period. Label the x-axis with electrical degrees and point out important angles.[5p]

d) Calculate the rating if we decrease the dc-voltage supply to 100V do reasonable assumptions [12p]

[**20 points**]

7. Are the following statements true or false?

a) The reluctance of an induction machine increases when the airgap between stator and rotor is decreased.
b) The Synchronous Reluctance Machine can not have the same stator as an induction machine.
c) Efficiency is generally lower for low-speed motors.
d) An induction machine operates as a generator if the speed is above its synchronous speed.
e) If we increase the outer dimensions of a motor, we decrease the efficiency of the motor.
f) The PMSM is less efficient than a similar rated induction machine.
g) The power rating of a machine is in general proportional to the electric loading.
h) In a typical (low rotor resistance) induction machine connected to the mains, the maximum stator current occurs at the point of maximum torque.
i) The bandwidth of the current control in a DC machine is approximately 10 times smaller than the bandwidth of the speed control.
j) A PMSM is most optimally designed when the iron losses are at their minimum level.

[5 points]

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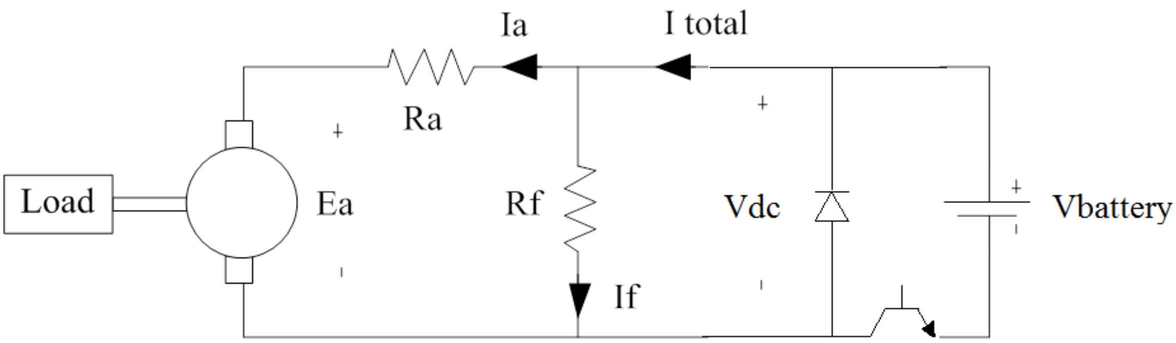
Solutions:

Problem 1:



a) The dc voltage fed to the dc machine is:
$V_{dc} = V_{battery} \cdot Duty\ Cycle = 200 \cdot 0.7 = 140\ V$

The field current is:
$$I_f = \frac{V_{dc}}{R_f} = \frac{140}{200} = 0.7\ A$$

Therefore the armature current will be

$$I_a = I_{total} - I_f = 20 - 0.7 = 19.3\ A$$

The load torque is equal to:
$T_L = T_e = K_b I_a$
therefore
$$K_b = \frac{T_L}{I_a} = \frac{40}{19.3} = 2.073 \frac{Nm}{A}$$

In the armature circuit we have:
$V_{dc} = I_a R_a + E_a \rightarrow$
$V_{dc} = I_a R_a + K_b \omega \rightarrow$
$\omega = \frac{V_{dc} - I_a R_a}{K_b} = \frac{140 - 19.3 \cdot 2}{2.073} = \frac{101.4}{2.073} = 48.91\ r/s$

b) The duty cycle has increased to 90%
Then:
$V'_{dc} = V_{battery} \cdot Duty\ Cycle = 200 \cdot 0.9 = 180\ V$

The field current is:
$$I'_f = \frac{V'_{dc}}{R_f} = \frac{180}{200} = 0.9\ A$$

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

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$$\frac{K_b}{K_b'} = \frac{I_f}{I_f'} \rightarrow K_b' = K_b \frac{I_f'}{I_f} = 2.073 \frac{0.9}{0.7} = 2.665 \frac{Nm}{A}$$

The load torque is equal to:
$T_L = T_e = K_b' I_a'$

therefore
$$I_a' = \frac{T_L}{K_b'} = \frac{40}{2.665} = 15.01\,A$$

$$V_{dc}' = I_a' R_a + E_a' \rightarrow V_{dc}' = I_a' R_a + K_b' \omega'$$
$$\omega' = \frac{V_{dc}' - I_a' R_a}{K_b'} = \frac{180 - 15.01 \cdot 2}{2.665} = 56.28\,r/s$$

c)
$$Efficiency = \frac{P_{out}}{P_{in}} = \frac{E_a' \cdot I_a'}{V_{dc}' \cdot I_{tot}} = \frac{E_a' \cdot I_a'}{V_{dc}'(I_a' + I_f')} = \frac{K_b' \omega' I_a'}{V_{dc}'(I_a' + I_f')} = \frac{2.665 \cdot 56.28 \cdot 15.01}{180 \cdot (15.01 + 0.9)}$$
$$= \frac{2251.29}{2863.8} = 0.79 = 79\%$$

Problem 2:
a)
the rated speed can be calculated as
$n_N = n_s - n_s * s = 1440$

If we reduce the speed to 1000rpm the torque will be reduced as follows:

$T_{1000rpm}$=TN*(1000/1440)^2=0.48

We can assume a constant U/f ratio resulting in a constant slip of the T-n curve. As a result the slip must be
$S_{100rpm}=0.48*s_N$

And the shyncronous speed and finally the frequency can be obtained as

$n_{s2}=1000/(1-0.48*s_N)=1019.67$
fs= ns/60*p=1019.67/60*2=33.99Hz

b)
If we run at 100rpm the load torque has reduced to (100/1500)^2=0.004. Hence it is no need for keeping the flux level at its rated level. If we decrease the voltage, the current will decrease (at first) resulting in lower copper losses in the stator winding ($P=3R_sI^2$) since the majority of the current in the stator is reactive at this point. Theiron losses (Piron≈$3UR_{iron}$) will also decrease. The losses in the rotor will increase since the slip increases (this will in turn increase the active part of the stator current but not as much as the decrease in reactive current).

3) If we first operate the motor at its thermal limit (rated torque and speed) and increase the load, the temperature in the motor will increase, which in turn increases the resistive losses in

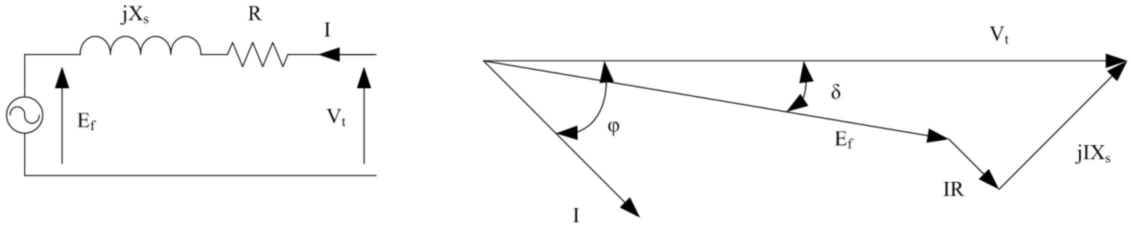
the motor. This is often ok if we only run for a short period of time. However, if we return to its rated torque, the temperature increase will lead to a much longer time period of high temperature in the motor and needs to be considered.

Problem 4

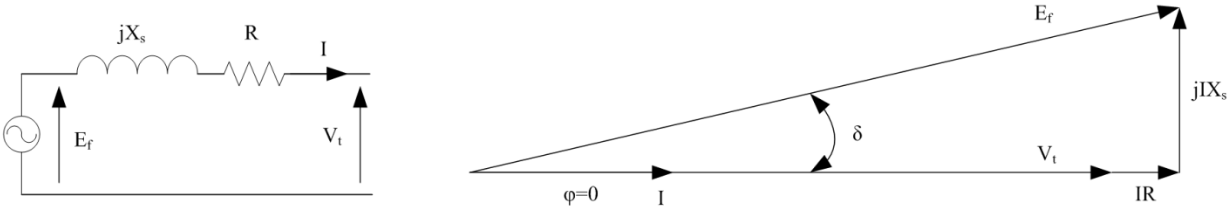
a) The torque of an induction mahine is proportional to the flux of the airgap. Therefore it is important to have as much flux as possible in the whole range of operation of the machine. As a result it is desired to operate at the maximum field current all the time (there is a maximum value to the field current because for higher values than that, the machine enters saturation and the field current cannot produce more flux).
Accordingly, the field current is proportional to the stator voltage and convercely proportional to the frequency. Hence, it is proportional to V/f and since the field current is desired to be kept at a constant maximum value, the ratio V/f must also be kept constant during the frequency change due to the speed control.

b)

i)



ii)



Problem 5

a) The aligned position corresponds to maximum inductance or minimum reluctance.
Hence,

$$L_a = \frac{\lambda_1(i)}{i} = \frac{0.9 \cdot 5}{2+5} \cdot \frac{1}{5} = 128.6mH$$

The unaligned position corresponds to minimum inductance or maximum reluctance.
Hence,

$$L_u = \frac{\lambda_2(i)}{i} = 0.05 \cdot 5 \cdot \frac{1}{10} = 25mH$$

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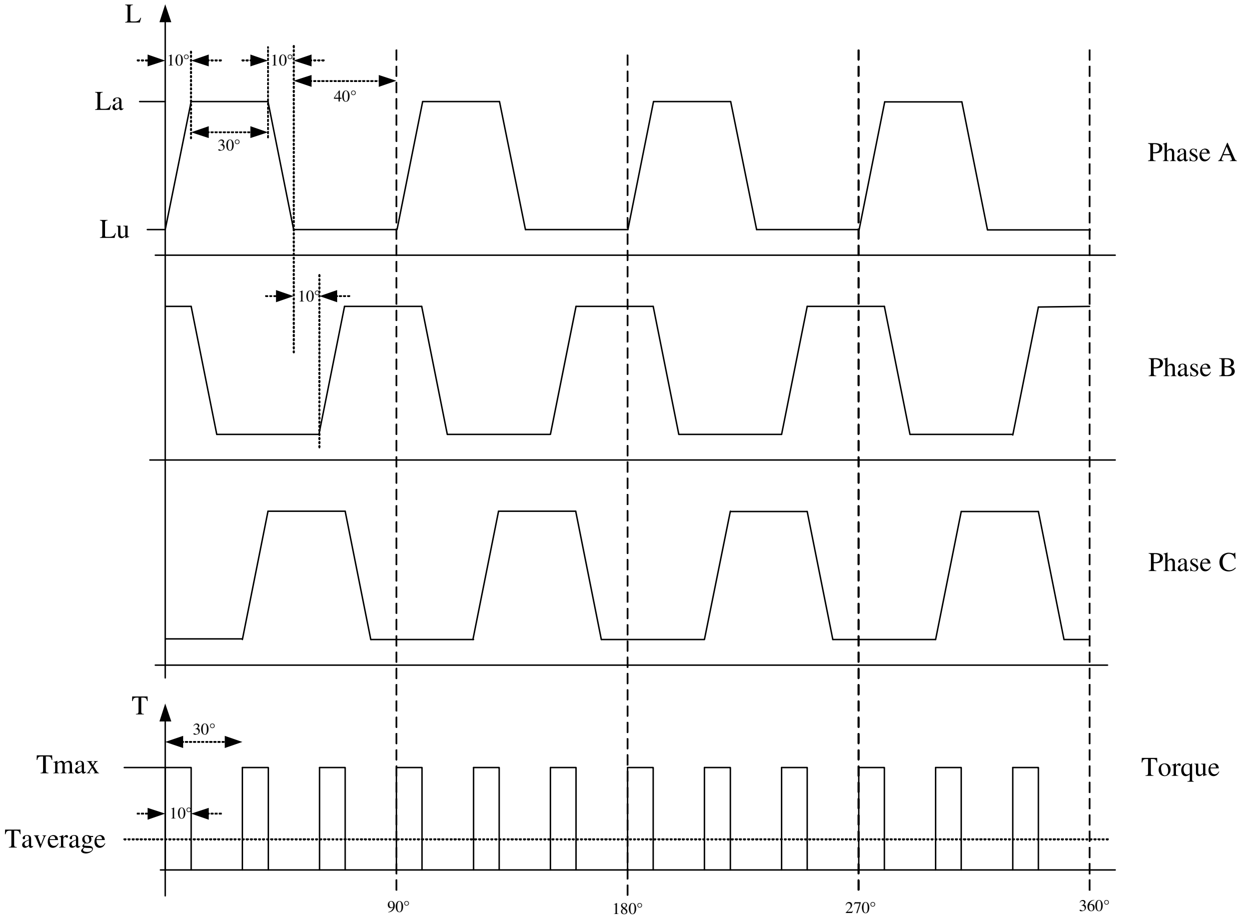
b) The following graph shows the inductances and torque. The torque is not necessary for this question but is needed for the understanding of question c.



c) The torque from all the phases of the machine is shown in the previous diagram. Each pulse of torque has a magnitude calculated as:

$$\int \frac{x}{ax+b}dx = \frac{x}{a} - \frac{b}{a^2}\ln(ax+b)$$

$$T_{\max} = \left.\frac{dW'}{d\zeta}\right|_{I=const}$$

$$dW' = \int_0^5 (\lambda_1 - \lambda_2)di = \int_0^5 \left[\frac{0.9i}{2+i} - 0.05i\right]di = \int_0^5 \frac{0.9i}{2+i}di - \int_0^5 0.05i \cdot di =$$

$$= 0.9\int_0^5 \frac{i}{2+i}di - 0.05\int_0^5 i \cdot di = 0.9\left[\frac{i}{1} - \frac{2}{1^2}\ln(i+2)\right]_0^5 - 0.05\int_0^5 i \cdot di =$$

$$= 0.9\left[i - 2\ln(i+2)\right]_0^5 - \frac{0.05}{2}\left[i^2\right]_0^5 = 2.245 - 0.625 = 1.62$$

$$T_{\max} = \left.\frac{dW'}{d\zeta}\right|_{I=5A} = \frac{1.62}{10 \cdot \frac{\pi}{180}} = 9.2819 Nm$$

The average total torque will be:

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$$T_{average} = \frac{1}{30 \cdot \frac{\pi}{180}} \int_0^{10 \cdot \frac{\pi}{180}} T_{\max} d\theta = \frac{10 \cdot \frac{\pi}{180}}{30 \cdot \frac{\pi}{180}} T_{\max} = \frac{T_{\max}}{3} = 3.094 Nm$$

Problem 6

Eq circuit sees course material

b) The rated torque can be calculated as

T=P/ω=6000/(3000π/(30)=19Nm

c) Refer to the course material

d) Since the motors often are limited by the amount of current it is probably safe to assume that we can run the same current and hence the same torque, 19.1Nm. In practice it is porbably possible to run a slightly higher current since the iron losses has decreased significantly. However we are not able to estimate this effect so our best guess is that we can keep the current constant.

The voltage is decreased so we need to reduce the speed until we can operate the motor at 19.1Nm having 100V supply.

Ua=Ea+RI=k*w+R*I

The term R*I is assumed to be the same as before (same current), Hence the speed needs to be half from before to operate at 19.1Nm

The new rating becomes 1500rpm 3kW

Problem 7

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