CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Re-Examination

Thursday 17 January 2013, 14:00-18:00

Examiner: Sonja Lundmark. For any queries arising during examination please call Saeid Haghbin: 1633

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.

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 motor runs from 300 V supply and draws an armature current of 20 A at a field current 2 A. The armature resistance is 2 Ω. If the field current is suddenly reduced to 1.5 A, calculate the value to which the armature current reaches momentarily.

[10 points]

2. The full-load slip of an 4-pole induction motor at 50 Hz is 0.04. Estimate the **speed** if:

a) the frequency is reduced to 25 Hz keeping U/f=constant and the torque constant
b) the frequency is increased to 75 Hz, .keeping the same voltage as in the 50Hz case and reducing the load torque to 50%

[10 points]

3. Figure Q3 shows a cross section area of a three-phase ac motor. The aim of the question is to calculate the net magnetic flux in the air-gap, Φ. Assume that the three-phase currents are flowing in the windings as follows:

$$i_{a\acute{a}}(t) = I_M \sin \omega t$$

$$i_{b\acute{b}}(t) = I_M \sin(\omega t - \frac{2\pi}{3})$$

$$i_{c\acute{c}}(t) = I_M \sin(\omega t + \frac{2\pi}{3})$$

Assume that the resulted mmf is sinusoidally distributed in the air gap and is proportional with the currents for each phase. Calculate the total magnetic flux in the air-gap Φ expressed as a function of the amplitude of the flux from one phase, Φ_M. (there is no saliency in the rotor and materials are ideal).

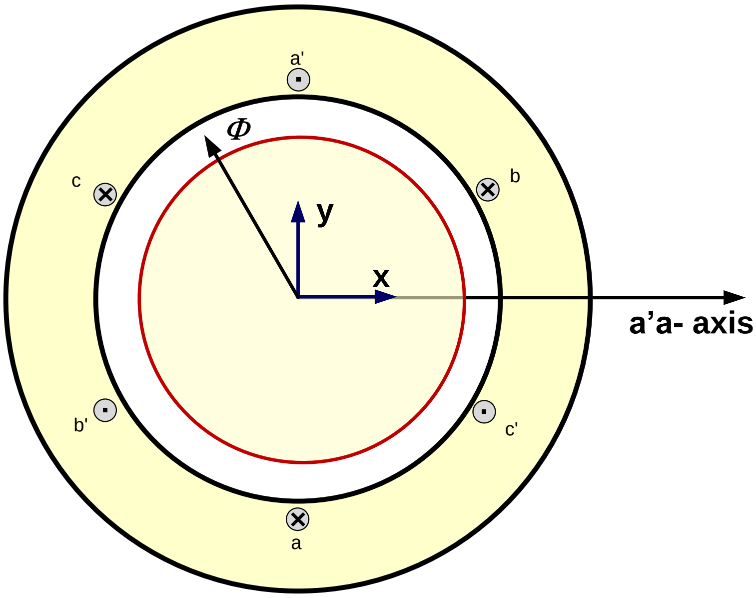


Figure Q3. Cross section area of a stator with three-phase windings

[10 points]

4. a) A 4-phase switched reluctance motor has 8 stator poles and 6 rotor poles, see Fig. Q4 where the coils of phase 1 is shown (but not the coils of phase 2,3, and 4). Draw the phase 1 inductance versus rotor position if the stator pole angle is 20° and the rotor pole angle is 25°. The inductance at the aligned position is L_a and the inductance at the unaligned position is L_u. Draw also the phase 1 current as a function of rotor position. How many times should the phase 1 current be switched on during one rotor revolution (360°)?

a) Give one advantage and one disadvantage with the Switched Reluctance motor drive compared to a synchronous motor drive.

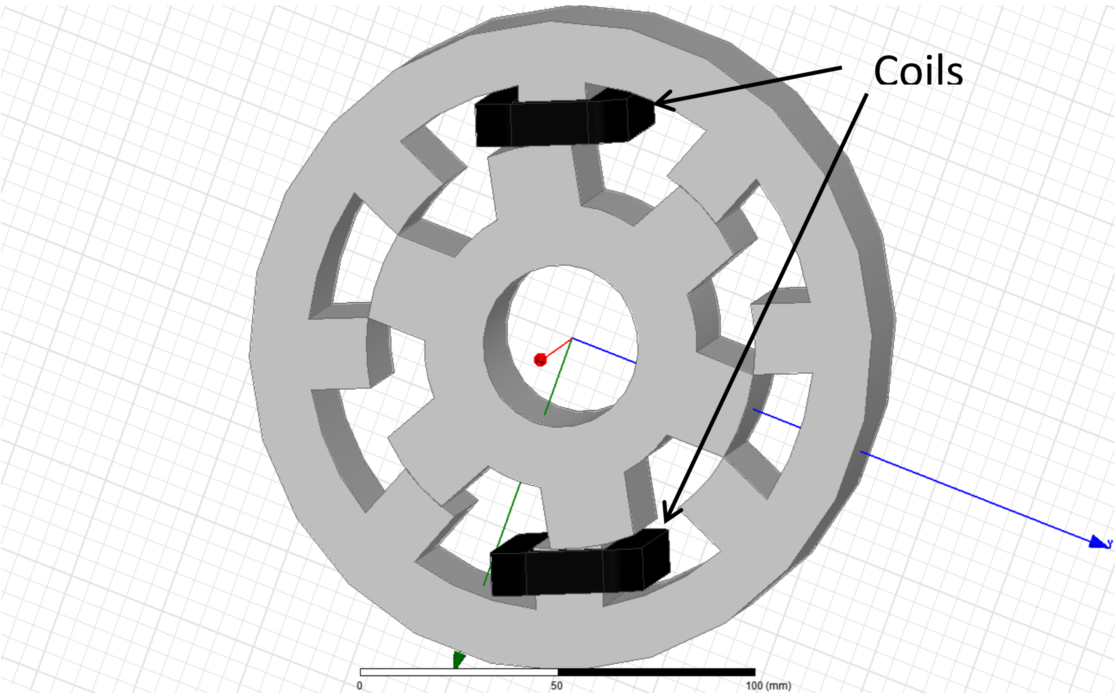


Figure Q4. The stator, rotor and the phase 1 coils of a 4-phase SR motor

[10 points]

5. Consider a synchronous generator with following specifications:

- Phase voltage: 480 Vrms in Y
- Nominal frequency: 60 Hz
- Synchronous Reactance per phase: 1 Ohm
- Number of poles: 6

The armature full current is 60 A in power factor (PF) 0.8 lag. Moreover, in full load condition the mechanical loss is 1.5 kW and core loss is 1 kW. Assume that copper losses are negligible. The field current is adjusted to have a terminal voltage of 480 V in the no load condition. Answer to the following questions:

a) What is the generator speed?

b) What is the terminal voltage in following conditions? Draw a phasor diagrams in each case also.

b1) Full load current with PF=0.8 lag

b2) Full load current with PF=1
b3) Full load current with PF=0.8 lead

c) What is the efficiency of the generator in full load current while PF=0.8 lag?

[**10 points**]

6. A 4-pole brushless-dc motor with surface mounted permanent magnets has a rating of 2kW and 2000rpm. The **per phase** resistance is 0.5Ω and the per phase induced voltage is 120V

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 1000rpm (do reasonable assumptions)

c) Calculate the maximum no load speed of the motor if the available DC-bus voltage is 280V

d) Calculate the instantaneous peak torque at zero speed (neglect any thermal issues that this might cause). Is the result you obtain realistic? Motivate your answer!

[**15 points**]

7. You are about to pick a motor to certain application where you have decided that the induction motor and the PMSM motor is the best candidates. State the main advantages and disadvantage between the two candidates.

[5 points]

Solutions:

Problem 1:
Dc-motor, Ua=300 V, Ra=2Ω, La is assumed zero, Ia= 20 A at If= 2 A gives that
Ea=Ua-Ra*Ia= 300-20*2=260 V.

Then, field current If is reduced to If2=1.5 A and Ea reduce instantaneously a factor (If/If2) while speed change slowly due to inertia. Thus,

Ea=300/(2/1.5)=225 V

Then **Ia**=(Ua-Ea)/Ra=**37.5 A**

(This flux reduction gives increased speed as supplied voltage is constant and flux is proportional to Ua/frequency. Initially, the increased armature current gives increased torque. Then, as speed increase, Ea increase and Ia reduce)

Problem 2:

a) Voltage is adjusted to maintain full air gap flux, so voltage decrease as frequency decrease.

Rotor resistance is assumed constant and core loss is ignored.

p = 4 (number of poles)
s_n = 0.04
f = 50Hz
f' = 25Hz

For frequencies of 50, 25 corresponding synchronous speeds for the 2-pole machine are:

n_s =(2/p)*f*60=1500 rpm
$n_{s'}$ =(2/p)*f'*60=750 rpm

slips in rpm are not changing so the slip can be calculated as

slip=0.04*1500=60 rpm
The rated speed at 25 Hz can now be calculated as

n=750-60=690 rpm

b) The frequency is now increased to 75Hz keeping the same voltage. Hence the flux in the machine will decrease as follows

$\Phi \sim U/f$
$\Phi_2 / \Phi_1 \sim f_1/f_2 = 50/75 = 2/3$

In order to produce 50% of the rated flux at 75Hz it the slip will be higher than 30rpm (which would be that case at rated flux). We need to compensate for the fact that the flux has reduced and that the induced current in the rotor has reduced. Hence the new slip can be calculated from the synchronous speed (2250rpm) as follows

$slip_{75Hz}=(30/2250)/(2/3)^2=0.03$

Finally the speed can be calculated as

2250-2250*0.03=2182.5rpm

Problem 3

- The three phase load currents produce a rotating flux with constant amplitude.
  The produced magnetic flux can be written as:

$$\Phi_{a\acute{a}}(t) = \Phi_M \sin \omega t < 0^o$$
$$\Phi_{b\acute{b}}(t) = \Phi_M \sin(\omega t - \frac{2\pi}{3}) \ < \frac{2\pi}{3}$$
$$\Phi_{c\acute{c}}(t) = \Phi_M \sin(\omega t + \frac{2\pi}{3}) \ < \frac{4\pi}{3}$$

  The amplitude of the total flux is calculated at time t=0 at a point on the magnetic axis of a'a:

$$\Phi(t) = \Phi_{a\acute{a}}(t=0) < 0^o + \Phi_{b\acute{b}}(t=0) < \frac{2\pi}{3} + \Phi_{c\acute{c}}(t=0) < \frac{4\pi}{3} =$$
$$0 + \Phi_M sin\left(-\frac{2\pi}{3}\right) < \frac{2\pi}{3} + \Phi_M sin\left(\frac{2\pi}{3}\right) < \frac{4\pi}{3} = \cdots = 1.5\ \Phi_M < -\frac{\pi}{2}$$

  For an arbitrary point in the stator periphery, the phase shift is compensated by the angle as well.

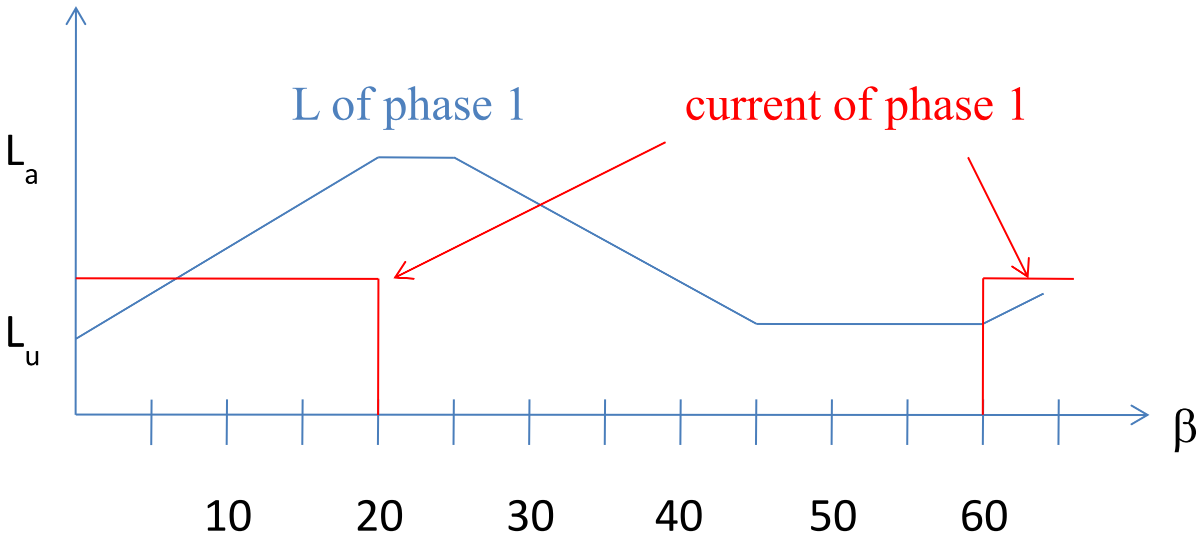
Problem 4

a) A 4-phase switched reluctance motor has 8 stator poles and 6 rotor poles, see Fig. 1 where the coils of phase 1 is shown (but not the coils of phase 2,3, and 4). Draw the phase 1 inductance versus rotor position if the stator pole angle is 20° and the rotor pole angle is 25°. The inductance at the aligned position is L_a and the inductance at the unaligned position is L_u. Draw also the phase 1 current as a function of rotor position. How many times should the phase 1 current be switched on during one rotor revolution (360°)?

b) Give one advantage and one disadvantage with the Switched Reluctance motor drive compared to a synchronous motor drive.

Solution:

β_s=20°, stator gap=25°, β_r=25°, rotor gap=35°, 8 stator poles and 6 rotor poles



Current should be switched on 6 times per revolution.

c) Example of advantages: Low cost, fault tolerant. Example of disadvantages: Low efficiency, noisy.

Problem 5

The generator is Y connected and the Phase voltage, V_φ, is: $V_\varphi = \frac{V_T}{\sqrt{3}} = 277\ v$ where V_T is terminal voltage that is 480 v in this case. Since the terminal voltage is adjusted in no load condition, it will be generator internal voltage without armature reaction. So the internal voltage is E_A=277 v.

a) The generator mechanical speed can be calculated as: $n_m = \frac{120 f_e}{P} = 1200\ rpm.$

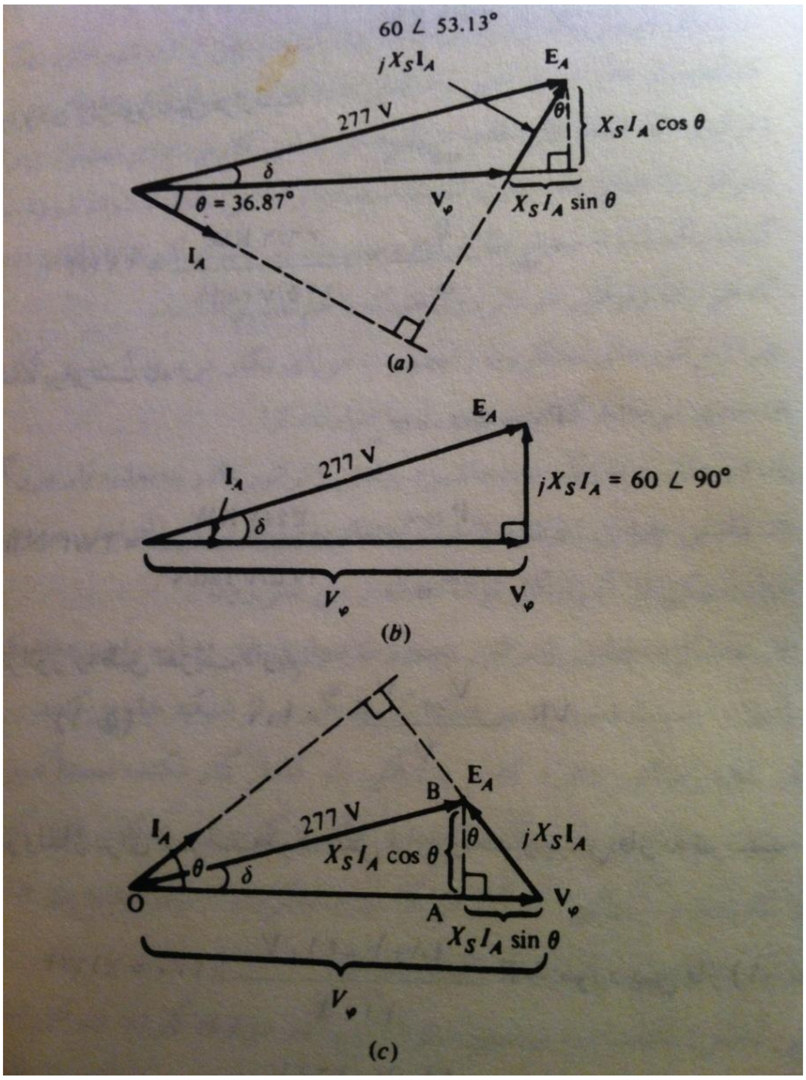
b) The phasor diagram is shown in the following diagram for different cases consequently. The figure shows how to calculate the voltage by using the triangle.
The voltage equation is:

$$E_A = V_\varphi + jI_A X_s$$

$where$ I_A is phase current and X_s is synchronous reactance. The phase voltage, $V_\varphi, is\ the\ reference\ vector$, a phasor with 0 angle. The current angle is known from the PF. So the unknowns are the internal voltage angle that is δ and the phase voltage magnitude V_φ.

1) $E_A^2 = (V_\varphi + X_s I_A sin\theta)^2 + (X_s I_s cos\theta)^2 \rightarrow V_\varphi = 236.8\ v \rightarrow V_T = 410 v$
2) $V_T = 468.4 v$ and $V_\varphi = 270\ v$
3) $V_T = 535 v$ and $V_\varphi = 309\ v$

c) In PF=0.8 lag and I_A=60 A the output power is: $P_{out} = \sqrt{3} V_T I_A\ cos\theta = 3 V_\varphi I_A\ cos\theta$ = 39.9 kW.
The input power that is mechanical power can be written as:
$P_{in} = P_{out} + P_{elec\ loss} + P_{core\ loss} + P_{mech\ loss}$= 33.9 kW+ 0 +1 kW+ 1.5 kW=42.4 kW
Efficiency is $\eta = \frac{P_{out}}{P_{in}} = \frac{39.9}{42.4} \times 100 = 94.1\%$



Problem 6

Eq circuit sees 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 1000rpm as it is at 2000rpm. Hence the rated torque can be calculated as

T=P/ω=2000/(2000π/(30)=9.55Nm

c) The available voltage is 280V and we can assume that the maximum speed will be reached when the induced voltage is 280. Hence the maximum speed can be calculated as max speed = 280/240*2000=2333rpm

d) If we neglect any thermal or saturation issues we can assume that the output torque is proportional to the current. At zero speed (zero induced voltage) we get a current of

I=280/1=280A.

We also know the induced voltage at rated operation so we can calculate the motor contant and the current that provides rated torque

$K_e=E_a/w_r=240/(2000\ \pi\ /30)=1.146$
$I_a=T/k_e=9.55/1.146=8.33A$

The torque zero speed can now be calculated as:

9.55/8.33*280=320Nm

NOTE that this is not realistic in practice since we will reach saturation in the iron long before this..

Problem 7
If we compare the two motor types:

PMSM:
- **+ efficiency**
- **+ power density**
- **- Cost**
- **- robustness**

IM:
- **+Cost**
- **+Robustness**
- **-efficiency**
- **-power density**