CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Re-Examination

Thursday 12 January 2012, 08:30-12:30, M-building

Examiner: Sonja Lundmark. For any queries arising during examination please telephone Sonja Lundmark at: 1651

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 240 V supply and draws an armature current of 23 A at a field current 2 A. The armature resistance is 2.5 Ω. Then, if the field current is suddenly reduced to 1.5 A, calculate the value to which the armature current reaches momentarily.

[7 points]

2. The full-load slip of an 8-pole induction motor at 50 Hz is 0.04. Estimate the **speed** at which the motor will develop rated (full-load) torque if the frequency is reduced to (a) 25 Hz, (b) 3 Hz. Assume that in both cases the voltage is adjusted to maintain full air-gap flux. Calculate the corresponding **slip** in both cases, and **explain** why the very low-speed condition is inefficient. **Explain also** why the full-load rotor currents would be the same in all the three cases.

[10 points]

3. A 1 kW, three-phase, 50 Hz, 400V synchronous motor has a design such as seen in Fig. 1.

a) What is the rated speed?
b) What is the rated torque?
c) **Draw** the equivalent circuit of the synchronous motor at steady state (using **motor reference** and neglecting the resistance), and **draw also** the phasor diagram when the armature current is in phase with the emf; indicate also the load angle (δ).
d) Give one advantage and one disadvantage with having windings in the rotor instead of permanent magnets.
e) Give one advantage and one disadvantage with having the permanent magnets placed on the rotor surface, as in Fig 1, compared to interior mounted permanent magnets.

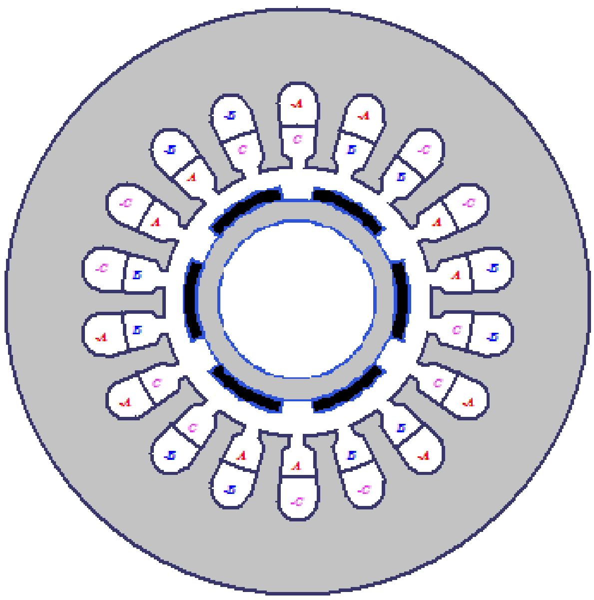


Figure 1

[10 points]

4. a) Sketch a typical (cage rotor) induction motor torque-speed curve with slips between 2 and –1 and indicate: (a) the synchronous speed; (b) the starting torque; (c) the motoring, generating and braking region.

b) Mention, and explain, **one** way of electrical braking of the induction motor.

[10 points]

5. The 3-phase switched reluctance motor shown in cross section in Fig. 2 has six stator poles, each covering an arc of B_s Degrees and four rotor poles, each with an arc of B_r Degrees. The stator inner diameter is 100 mm and the rotor outer diameter is 120 mm. The stator winding with 100 turns per phase, are supplied with a current *i* which is switched to the three series-connected coils (phase a, b and c).

a) The phase inductance (for phase a) versus rotor position is drawn in Fig. 2 where the inductance at the aligned position is L_a and the inductance at the unaligned position is L_u. With the help from Fig. 2, answer to the following question: What are the values of B_s and B_r in Degrees?
b) For the SR motor in Fig. 2, which of the two alternatives shown in Fig. 3 show the correct phase current for motor operation?
c) With the current of 10 A, find the **average power** that can be produced by this motor at a speed of 1000 rpm. The flux linkage-current relations for a typical stator phase are shown in idealized form for the maximum- and minimum-reluctance rotor position in Fig. 4.

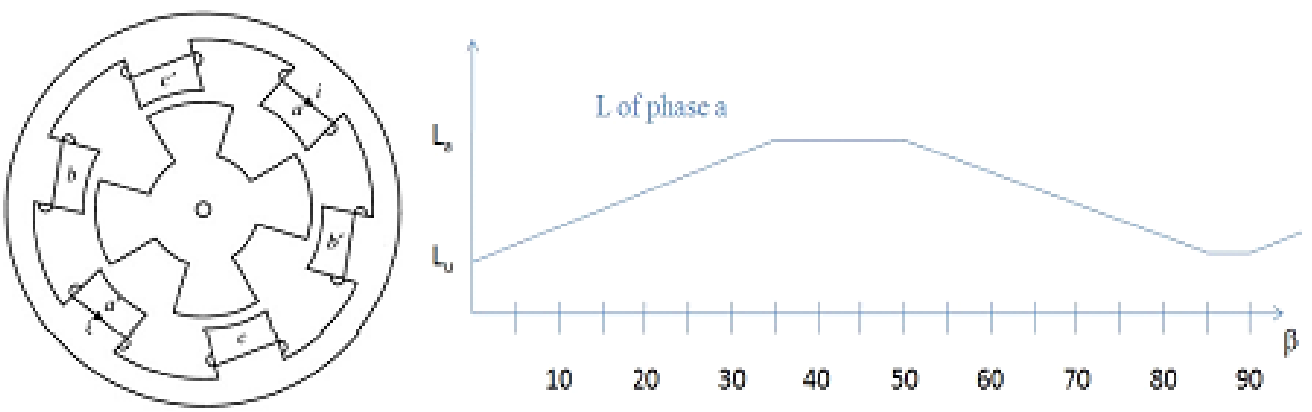
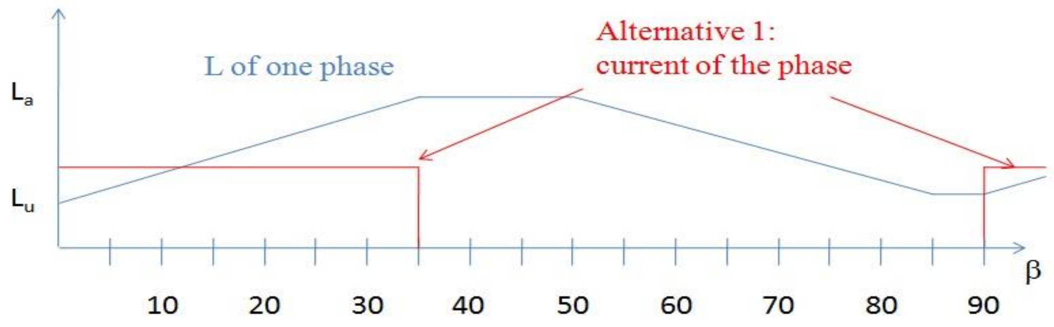


Figure 2



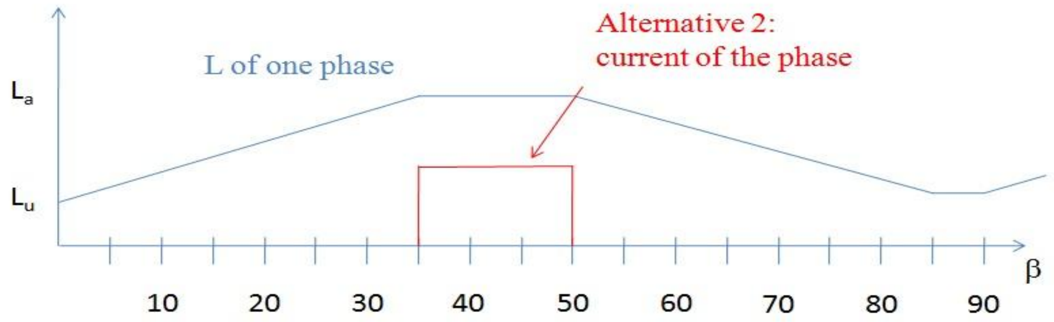


Figure 3

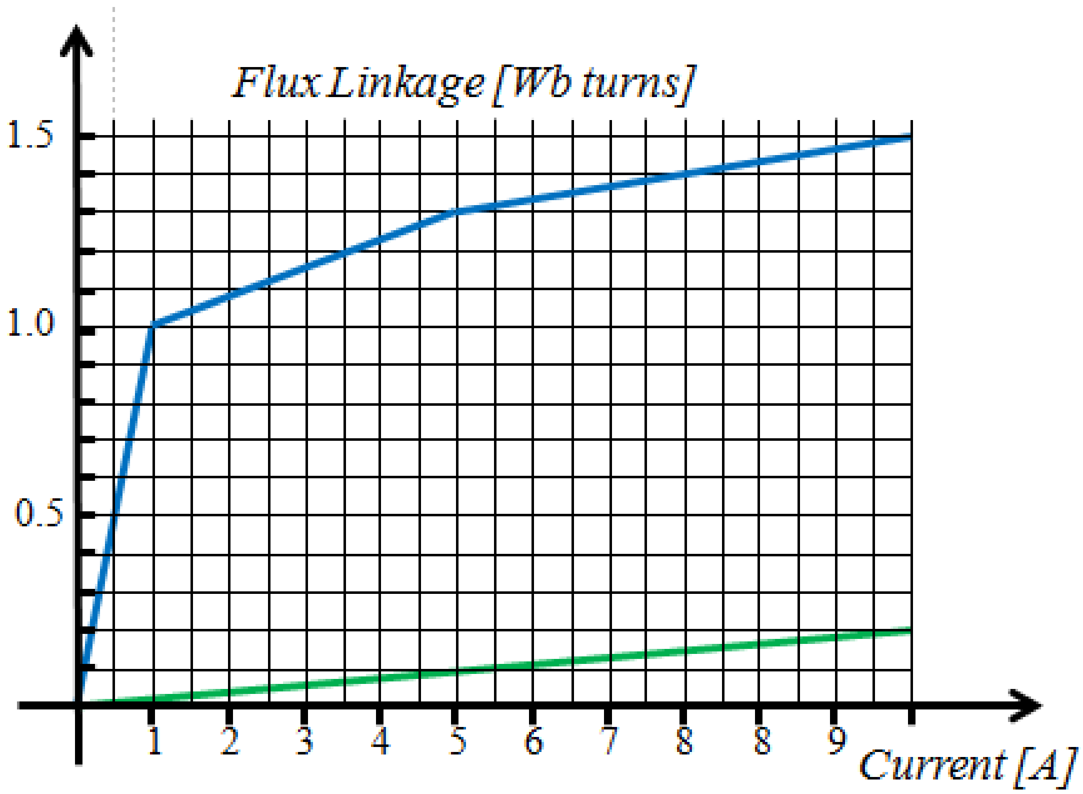


Figure 4

[10 points]

6. A 2-pole brushless-dc motor with surface mounted permanent magnets (as seen in Fig. 5) has a bore radius of r=20 cm, magnet length of l_m=5 mm, magnet arc of θ_m =150° (=2γ in Fig. 5), an air gap of g_e=0.8 mm, and an axial length of l=10 cm. Slotting is neglected and the single full-pitch stator coil has 25 turns per phase. The NdFeB magnet has B_r=1.3T and H_c=850 kA/m. The current in the stator coil is zero.

a) Determine the **waveform** and the **peak value** of the emf induced in the stator coil if the rotor rotates at 3000 rev/min.

b) With a stator current I=3A, and a supply frequency of 50 Hz, what is the mechanical **power** and **torque** produced by the machine? Assume ideal switching action in a power converter of the form of Fig. 3(b). Losses may be ignored.

c) How would the **resistance** and **inductance** of the stator winding change if the motor length were doubled (with all other dimensions kept constant).

[**15 points**]

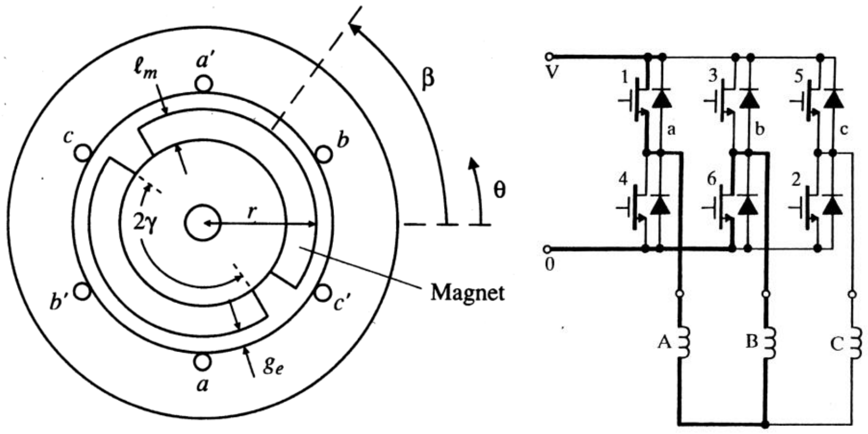


Figure 5

7. Which one of the materials below has the highest product of coercvity and remanence?

Answer with one of the following options:

a) Permendur b) Iron c) NdFeB d) Neon

e) Coal f) Copper g) Al h) Steel i) Alnico

[1 point]

8. What is the difference between hard magnetic materials and soft magnetic materials?

Answer with one of the following options:

a) The coercivity is higher for soft magnetic materials compared to hard magnetic materials.
b) The coercivity is higher for soft magnetic materials compared to hard magnetic materials.
c) Only hard magnetic materials may be used in electrical machines.
d) There is no difference except from the density.
e) Only soft magnetic materials may be used in electrical machines
f) The coercivity is lower for soft magnetic materials compared to hard magnetic materials

[1 point]

9. Are the following statements true or false?

a) For the lamination steel in an induction machine, carbon is an impurity that gives higher coercivity.
b) For the lamination steel in a brushless dc machine, addition of silicon may give higher resistivity.
c) A current density of 3-6 A/mm^2 is reasonable for air-cooled motors.
d) The permanent magnet synchronous machine has a lower efficiency and power factor compared to a same-sized induction motor.
e) Efficiency is generally better for low-speed motors.
f) The commutation frequency in a switched reluctance machine is two times higher than in ac motors with the same rotor pole number.

[6 points]

Solutions:

Problem 1:
Dc-motor, Ua=240 V, Ra=2A, La is assumed zero, Ia= 10 A at If= 2 A gives that
Ea=Ua-Ra*Ia= 240-20=220 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=220/(2/1.5)=165 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:
Similar to problems 1-3, Chapter 8 in book of Hughes
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 = 8 (number of poles)
s_n = 0.04
f = 50Hz
f’ = 25Hz
f’’ = 3Hz
For frequencies of 50, 25 and 3Hz corresponding synchronous speeds for the two-pole machine are:

n_s =(2/p)*f*60=750 rpm
$n_{s'}$ =(2/p)*f’*60=375 rpm
$n_{s''}$ =(2/p)*f’’*60=45 rpm

slips in rpm are not changing so the slip in % are correspondingly;

slip=0.04*750=30 rpm, (s_n=30/750=0.04) (n=750-30=720 rpm)
slip’=30 rpm, s_n’=30/375=0.08 (n=375-30=345 rpm)
slip’’=30 rpm, s_n’’=30/45=0.67 (n=45-30=15 rpm)

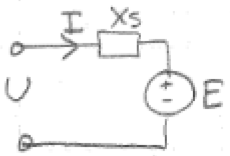
At 50Hz, for slip of s = 0.04 the frequency of the induced current in the rotor is
f_{Irotor} =s_n*f=0.04*50=2 Hz
Likewise,
f_{Irotor} ’=s_n’*f’=0.08*25=2 Hz
f_{Irotor} ’’=s_n’’*f’’=0.67*3=2 Hz

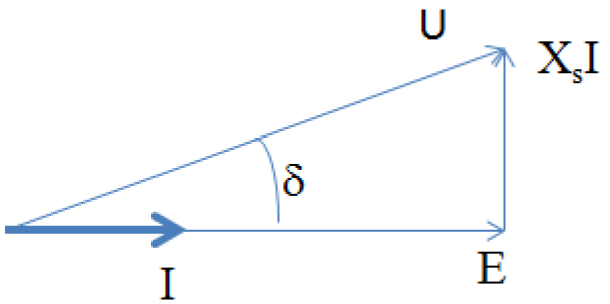
At 3 Hz the voltage is very low and the voltage drop over Rs is relatively high, giving a low efficiency. The load currents are the same for all three cases as rotor frequency and rotor resistance and the load torque are the same and flux is constant.

Problem 3:

SM, Pn=1 kW, f=50Hz, 3-phase, Un=400 V

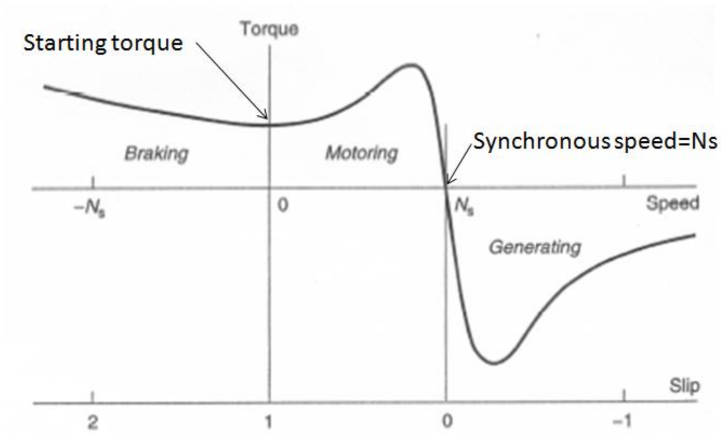
a) Number of poles =6 (seen in fig. 2)
   n_s =(2/p)*f*60=1000 rpm=rated speed
b) Rated torque, Tn=P/w=1000/(2π*1000/60)=30/π=9.55 Nm
c) See figure:





d) Advantage with winding: easier to field weaken
   Disadvantage with windings: Copper losses in the rotor give lower efficiency

Problem 4:



a)

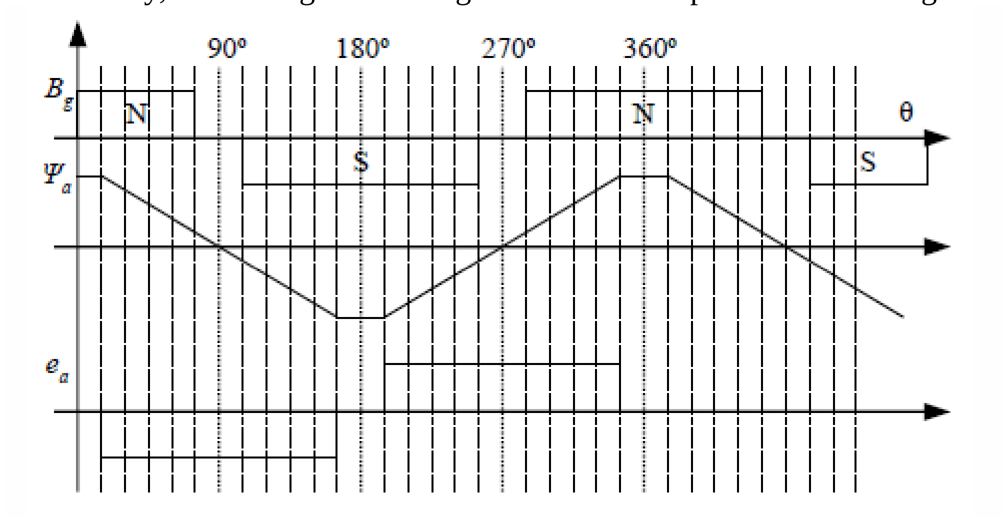
b) Plugging (changing two of the phases) and injection braking (supply dc-voltage to two of the phases)

Problem 5:

a) B_s=35°=35*π/180 rad, stator gap=25°, B_r=50°, rotor gap=40°, 6 stator poles and 4 rotor poles
b) Alternative 1
c) 10 A, 1000 rpm
Tav= ΔW'/B_s. P=ωT
The co-energy change at 10A is ΔW'=1*1/2+1*4+0.3*4/2+1.3*5+0.2*5/2-0.2*10/2=11.1 J which gives power per phase, P_{ph}=(1.125/(35*π/180))*1000*2*π/60 =(11.1/35)*6000 =1.9kW

Problem 6:
p = 2
r = 0.20 m
l = 0.10 m
$\phi_m = 150^\circ$
$g_e = 0.8 * 10^{-3}$ m
$l_{mag} = 5 \;\; * 10^{-3}$ m
$N_s = 25$
n = 3000rpm
I = 3A
$B_r = 1.3$T
$H_c = 850$ kA/m

Flux density, flux linkage and voltage waveforms are presented in the figure:



Induced voltage in the stator windings can be calculated using following formula:

$$e = \frac{d\psi}{dt} = \frac{d\psi}{d\theta}\frac{d\theta}{dt} = \omega\frac{d\psi}{d\theta}$$

$$\psi = N_s\phi = N_s B_g A_g$$

Where flux linkage varies as λ=ψ*180°*β/75°π for 0< β <75° and β=θ+270° in the figure above.

$$A_g = A_m = 150\frac{\pi}{180}rl$$

Thus, $e = \omega\psi*180/75\pi = N_s * B_g\ \omega*180/75\pi*(150\ \pi/180)*rl = N_s * B_g\ \omega*2*rl$
We need to calculate B_g to obtain e. We use the PM design formulas:

$$H_m l_m = K_r H_g l_g \quad B_m A_m = K_l B_g A_g \quad B_m = B_r - \frac{B_r}{H_c} H_m \quad => \quad K_l = 1, K_r = 1, A_g = A_m \quad H_g = \frac{B_g}{\mu_0}, l_m = 2l_{mag}, l_g = 2g_e \quad => \quad 2H_m l_{mag} = 2\frac{g_e B_g}{\mu_0} \quad B_m = B_g \quad B_m = B_r - \frac{B_r}{H_c} H_m$$

$$=> B_g = B_r - \frac{B_r}{H_c} \frac{g_e B_g}{\mu_0 l_{mag}}$$

$$=> B_g = \frac{B_r}{1 + \frac{B_r}{H_c} \frac{g_e}{\mu_0 l_{mag}}}$$

With the given values, B_g = 1.09 T

$$=> \psi = N_s \phi = N_s B_g A_g =$$

=7.12 Wb

Which gives the emf,

*e= $N_s * B_g\ \omega$*2 *rl=25*1.09*314.16*2*0.2*0.1=342 V*

b) Since windings are connected in "wye" or star connection, two phases lead current of 3A at any time instant, which means that at any time instant two phases are producing torque

P = 2Pphase = 2eI = 2.05 kW => *T =P/ω=6.54 Nm*

c) Resistance and inductance will the double.

For resistance we can write

$$\left\{ \begin{array}{l} R = Z\rho \frac{l_{cond}}{A_{cond}} \\ l_{cond} = l \end{array} \right\} => l' = 2l => R' = Z\rho \frac{l'}{A_{cond}} = Z\rho \frac{2l}{A_{cond}} = 2R$$

For inductance we can write

$$\left\{ \begin{array}{l} L = \frac{\psi}{I} = \frac{N\phi}{I} = \frac{NB_g A_g}{I} \\ A_g = \theta r l \end{array} \right\} => \left\{ \begin{array}{l} l' = 2l \\ A'_g = \theta r l' = 2A_g \end{array} \right\} => L' = \frac{NB_g A'_g}{I} =>$$

$$L' = \frac{2NB_g A_g}{I} = 2L'$$

Problem 7: c
Problem 8: f
Problem 9: a, b, c, and f are True, d and e are false