CHALMERS UNIVERSITY OF TECHNOLOGY

Department of Energy and Environment

Electric Drives 1 (ENM055)
Re-Examination

Thuesday 21 August 2012, 08:30-12:30, M-building

Examiner: Sonja Lundmark. For any queries arising during examination please telephone Johan Åström at: 1642

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 DC machine is to operate a load described as $T_L = b\omega$, where $b=0.21$. The armature voltage can be adjusted in the interval $50 \leq U_a \leq 300$ and the current in the magnetizing branch, I_f, can be adjusted in the interval $0.5 \leq I_f \leq 2$. The field resistance is 150 Ω and the armature resistance is $R_a=1$ Ω.

a) The machine is operating at 800rpm, an armature voltage of 200V and an armature current of 8A. Calculate the motor constant k_e and the maximum speed of the machine for the given load, assume that $I_f=1.5$.

b) Calculate the efficiency at the given operating point (800rpm).

c) The efficiency of the machine can be affected by changing the magnetizing current. Explain how and why the different motor loss components are affected when the field current is changed up and down, assume a constant operating point (T, ω).

[10 points]

2. The full-load slip of an 6-pole induction motor at 50 Hz is 0.04. Assume a constant load torque of 50% of the rated value.

a) Calculate the supply frequency needed to operate the motor at 800 rpm. It can be assumed that the voltage/frequency ratio is kept constant.

b) Calculate speed if the voltage is reduced to 95 %, (keeping the same frequency)

[10 points]

3. If the stator of an induction motor is rewound to operate from 220 V instead of 110 V with the same power consumption, how will the new winding compare with the old in terms of number of turns, wire diameter, and physical size?

[5 points]

4. A switched reluctance motor of the form shown in Fig. 1(a) has four rotor poles and six stator poles. The values of the stator pole arc and the rotor pole arc are 30° and 40°, respectively. 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. 2. Each phase winding, consisting of two coils in series, has a resistance of 5Ω. The nominal speed is 3000 rpm.

a) Assuming ideal switching action in a power converter of the form of Fig. 1(b), find the **average power** that can be produced by this motor with a supply current of 3 A.

b) What is the commutation frequency in each phase.

c) Which one(s), if any, of the following is/are correct:

1. The SR motor drive has less manufacturing cost compared to a brushlessdc drive of comparable size.
2. The SR rotor can be of solid iron and need not be laminated.
3. The SR motor drive has higher torque density compared to a brushless-dc

d) How does a decreased air gap, g, (between rotor and stator poles as seen in figure 1 a) influence the phase inductance of the switched reluctance machine, at aligned (L_a) and unaligned (L_u) positions?

[15 points]

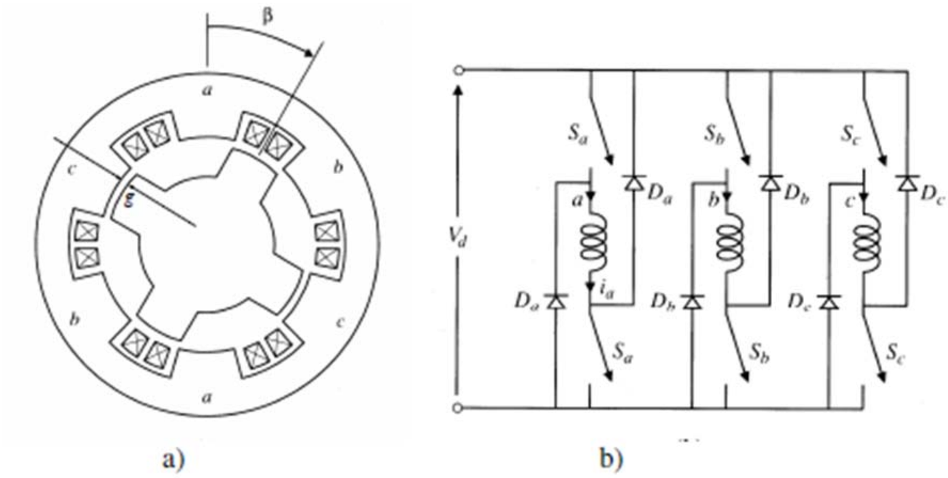


Figure 1

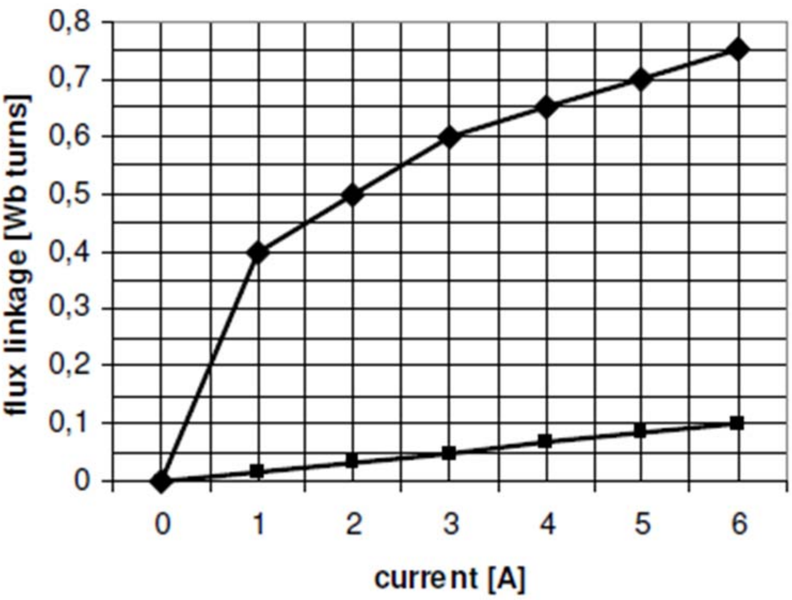


Figure 2

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 the basic current control strategy for the BLDC currents.

[10 points]

6. a) Explain what asynchronous starting of a synchronous motor is; Why is it used and how does it work?

b) Draw the phasor diagram of a synchronous motor when the load current is inductive (indicate also the phase angle θ between phase voltage (V) and phase current (I), and the load angle (δ).

[10 points]

7. Why is the power density in general higher for a permanent magnet motor compared to an induction motor?

[4 points]

8. Are the following statements true or false?

a) The rated torque of a motor is mainly limited by the heat dissipation in the motor windings
b) A distributed winding generates a more sinusoidal induced voltage compared to a motor with concentrated windings.
c) The starting torque of an induction motor will increase if the rotor resistance is increased
d) The output torque of a motor is in general proportional to the square of the motor diameter
e) A series DC-motor runs I the same direction regardless of voltage polarity.
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:

Solution:
a) The armature voltage can be expressed as

$$U_a = R_a I_a + E_a \Rightarrow$$
$$E_a = U_a - R_a I_a = 200 - 8 = 192V$$

The motor constant k_e can be expressed as

$$E_a = k_e \omega = kI_f \omega \Rightarrow$$
$$k_e = kI_f = \frac{E_a}{\omega} = \frac{192 \cdot 60}{800 \cdot 2\pi} = 2.29$$

The maximum speed of the motor is obtained at 300V

$$U_a = R_a I_a + k_e \omega$$
$$T = \frac{E_a I_a}{\omega} = k_e I_a \Rightarrow$$
$$I_a = \frac{b\omega}{k_e}$$

The speed can now be expressed as

$$\omega = U_a \frac{1}{\frac{R_a b}{k_e} + k_e} = 300 \frac{1}{\frac{0.21}{2.292} + 2.292} = 125.9 rad/s$$

b) The input power to the machine can be calculated as

$$P_a = U_a I_a = 200 \cdot 8 = 1600W$$
$$P_f = RI_f^2 = 120 \cdot 1.5^2 = 270W$$
$$P_{tot} = 1870W$$

The efficiency can now be calculated as

$$\eta = \frac{P_{mec}}{P_{tot}} = \frac{I_a E_a}{P_{tot}} = \frac{8 \cdot 188}{1870} = 0.804 = 80.4\%$$

c) The losses in the machine can be manipulated by changing the field in the machine. If the field current is increased the flux will increase and hence the back emf at a given speed increases. As a result, the armature current decreases if the operating point, (T,n), is kept constant. The losses in the armature winding current will decrease but the losses in the field winding will increase. The opposite occurs when the field current is decreased.

Problem 2:
a)

$p = 6$ (number of poles)
$s_n = 0.04$
$f = 50Hz$

$n_s =(2/p)*f*60=1000rpm$

the slip at rated operation is 0.04 so at 50% of rated torque the slip is 0.02, 20rpm

slip=0.04*1000=40 rpm,

If the motor is operated at 800 rpm the synchronous speed needs to be 820 resulting in a supply frequency of

f=820/60*p/2=41Hz

b)
The load torque is constant, so the motor will run at a speed such that its torque is equal and opposite to the load torque.

We must make the reasonable assumption that the motor is operating with a small slip in which case the induced rotor current is proportional to the magnitude of the air-gap flux wave and to the slip. The torque is proportional to the product of the induced rotor current and the air-gap flux.

The air-gap flux is proportional to the applied stator voltage, so if the voltage is reduced by a factor of 0.95, the flux will reduce to 0.95 of its original value. To produce the same torque the current will therefore have to increase by a factor of 1/0.95 or 105.3%.

The induced current in the rotor is proportional to the air-gap flux and to the slip. We have discovered that in order to produce the same torque when we reduce the voltage, we need the rotor current to increase by a factor of 1.053. If the flux had remained the same, this would have called for an increase of slip by a factor of 1.053. But the flux is now only 0.95 of what it was, so the slip has to increase yet more, by a factor of $1.053 \times 1/0.95 = 1.108$. The new slip is therefore $20/820 \times 1.108 = 2.7\%$. resulting in a new motor speed of 820-820*0.027=797.8rpm

Problem nr 3)
Since the power is the same the current can be reduced to 50% since the voltage is doubled. In order to keep the same mmf the number of turns needs to be doubled. Furthermore, since the current is two times smaller, the area of each conductor is halved the current density will remain the same as will the resistive losses.

Problem 4:

$p_r = 4$
$p_s = 5$
$\Theta r = 40$
$\Theta s = 30$
$R = 5\Omega$/phase
$n = 3000$

a)

$i = 3A$ average power => $Pav = \omega T_{av}$. Since one phase at the time is producing tourque, the average torque Tav is equal to the maximum torque produced in one phase.

$$T_{av} = T = \frac{\Delta W}{\Delta \theta}$$
$$\Delta W = \frac{0.4 \cdot 1}{2} + 0.4 \cdot 2 + \frac{0.2 \cdot 2}{2} - \frac{0.05 \cdot 3}{2} = 1.125J$$
$$T_{av} = \frac{1.125}{\frac{\pi}{6}} = 2.15Nm => P = \omega T_{av} = \frac{\pi n T_{av}}{30} = 675W$$

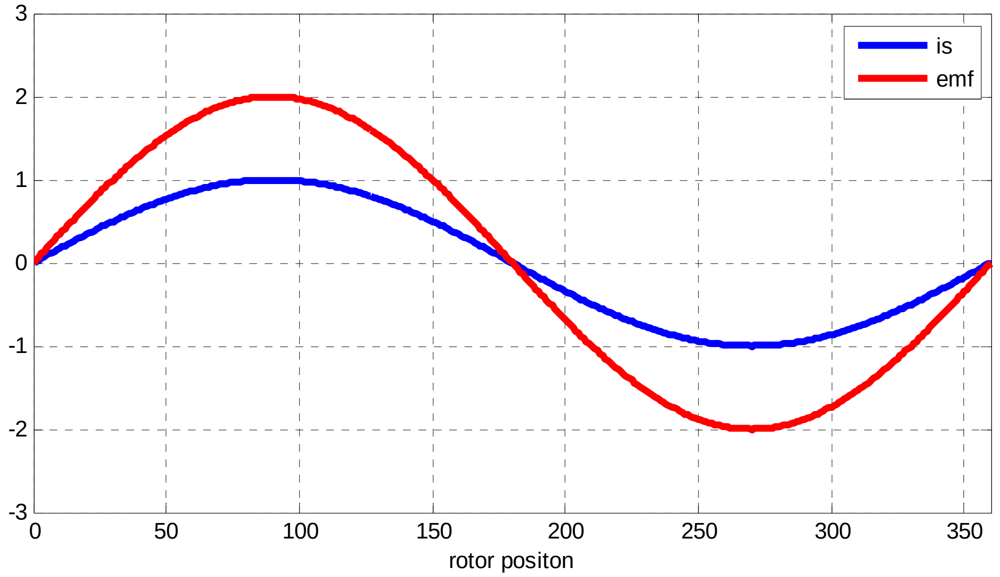
b)
$fc = n*60/p_r = 200Hz$

c)
1

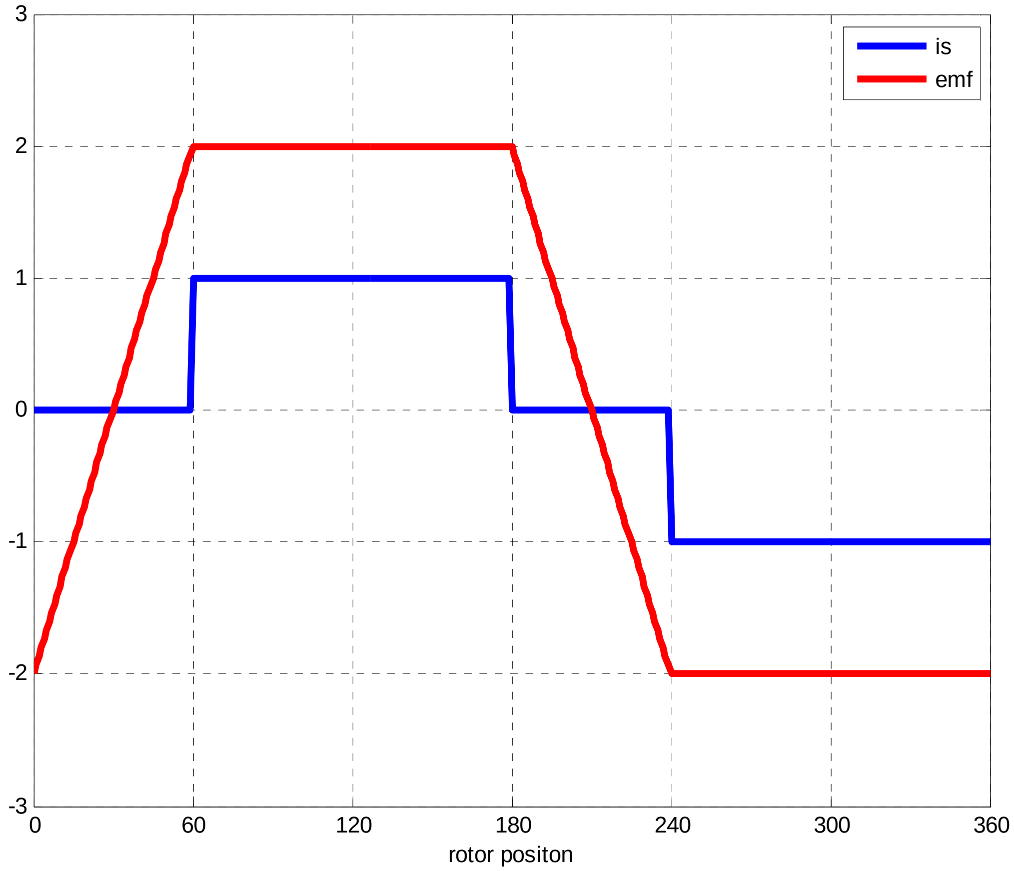
d)
Reluctance of the machine R is directly proportional to the air-gap. Inductance L is reversely proportional to the air gap which means that when the air-gap decreases, the inductance increases proportionally. However, since for un-aligned position, the air-gap is very large, L_u will not increase proportionally with decrease of air-gap as it is the case with L_a.

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

PMSM



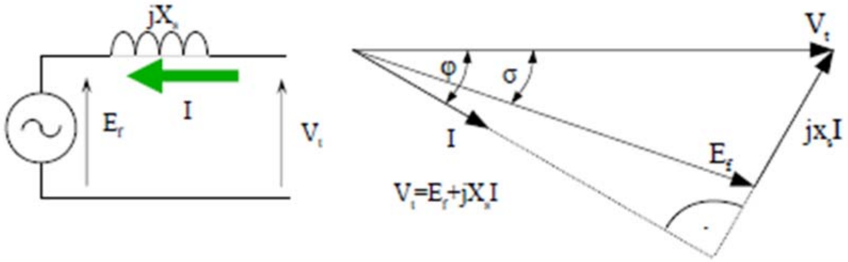
BLDC



b) In order to have produce a constant torque the current in each phase is controlled to be constant during the time period when the emf is constant. As a result, the current will flow through two phases and be zero in one phase at each time instant (except when tow phases commutates). Hence the current in the motor can be controlled by measuring only one current at each time. The current is positive in one phase for 120 electrical degrees, turned off for 60 electrical degrees negative for 120 degrees and finally turned of for 60 degrees as the above figure shows.

6) Sm canot start on its own unless asynchronous starting is used; the rotor is then constructed in a such way (i.e with damper windings or with solid pole shoes= sp that currents are induced in the roltor and the motor starts as an IM.

b)



Proble 7:Since a PM motor is magnetized by its permanent magnets, no magnetixing current is needed. Hence, the power factor of a PM motor is higher. As a result, the same current magnitude will generate a higher power in a PM motor compared to a IM.

Problem 9: a, b, c, d e f are all True