Draft Solution

**ECE321/ECE595 Exam 5**
**Spring 2013**

Notes: You must show work for credit.

This exam has 4 problems and 8 pages.

Note that problem 2 has different specifications depending on if you are in ECE321 or ECE595

**Good luck!**

1 23
23
22
32
100

1.) 23 pts. Consider a single phase reluctance machine. The a-phase conductor density may be expressed

$$n_{as} = N_s \cos\left(\frac{P}{2}\phi_{sm}\right)$$

$c' = -s$
$s' = +c$

The airgap ~~may be expressed~~ is given by

$$g = \frac{1}{c_A + c_B \cos(P\phi_{rm})}$$

The inner stator radius is denoted $r$, and the length of the machine $l$, and the $a$-phase current is denoted $i_{as}$. The mechanical rotor position is $\theta_{rm}$. Derive an expression for torque in terms of $N_s$, $P$, $\theta_{rm}$, $r$, $l$, $c_A$, $c_B$, and $\mu_0$.

$$W_{as} = \frac{1}{2}\int_0^{2\pi/P} n_{as} - \int_0^{\phi_{sm}} n_{as}\, d\phi_{sm}$$

$$\int \cos\left(\frac{P}{2}\phi_{sm}\right) d\phi_{sm} = \frac{2}{P}\sin\left(\frac{P}{2}\phi_{sm}\right)$$

$$W_{as} = \left[\frac{1}{2}\frac{2}{P}\sin\left(\frac{P}{2}\phi_{sm}\right)\Big|_0^{\frac{2\pi}{P}} - \frac{2}{P}\sin\left(\frac{P}{2}\phi_{sm}\right)\Big|_0^{\phi_{sm}}\right] N_s$$

$$= \left[\frac{1}{P}\left[\sin(\pi) - \sin(0)\right] - \frac{2}{P}\left[\sin\left(\frac{P}{2}\phi_{sm}\right) - \sin(0)\right]\right] N_s$$

(8)
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$$= -\frac{2}{P} N_s \sin\left(\frac{P}{2}\phi_{sm}\right)$$

$$L_{masas} = \mu_0 r l \int_0^{2\pi} \frac{W_{as}^2}{S} \, d\phi_{sm}$$

$$= \mu_0 r l \left(\frac{2N_s}{p}\right)^2 \int_0^{2\pi} \sin^2\left(\frac{p}{2}\phi_{sm}\right)\left(C_A + C_B \cos(p\phi_{rm})\right) d\phi_{sm}$$

$$\phi_{sm} = \phi_{rm} + \theta_{rm} \Rightarrow \phi_{rm} = \phi_{sm} - \theta_{rm}$$

$$L_{masas} = \mu_0 \frac{4N_s^2 r l}{p^2} \int_0^{2\pi} \sin^2\left(\frac{p}{2}\phi_{sm}\right)\left(C_A + C_B \cos(p\phi_{sm} - p\theta_{rm})\right) d\phi_{sm}$$

$$= \mu_0 \frac{2N_s^2 r l}{p^2} \int_0^{2\pi} \left(1 - \cos(p\phi_{sm})\right)\left(C_A + C_B \cos(p\phi_{sm} - p\theta_{rm})\right) d\phi_{sm}$$

$$= \frac{2N_s^2 r l \mu_0}{p^2} \int_0^{2\pi} C_A + C_B \cos(p\phi_{sm} - p\theta_{rm}) - C_A \cos(p\phi_{sm}) - \frac{1}{2} C_B \cos(2p\phi_{sm} - p\theta_{rm}) - \frac{1}{2} C_B \cos(-p\theta_{rm}) \, d\phi_{sm}$$

(8) 12

$$L_{masas} = \frac{2N_s^2 r l \mu_0}{p^2}\left[C_A 2\pi - \pi C_B \cos(p\theta_{rm})\right]$$

$$W_c = \frac{1}{2}\left[L_{ls} + \frac{2N_s^2 r l \mu_0 \pi}{p^2}\left[2C_A - C_B \cos(p\theta_{rm})\right]\right] i_{as}^2$$

4

$$T_c = \frac{N_s^2 r l \mu_0 \pi C_B}{p} \sin(p\theta_{rm}) \, i_{as}^2$$

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2.) 23 pts. Consider the buck converter we studied in class. Assuming operation is in continuous mode, derive expressions to answer the questions below in terms of $v_{dc}$, $v_{fsw}$, $v_{fd}$, $L_{AF}$, $L_{AA}$, $L_{FF}$, $r_a$, $r_f$, $d$, and $f_{sw}$.

EE321: If the converter is connected to a series connected dc machine. Derive an approximate expression for the peak-to-peak current ripple

EE595: If the converter is connected to a shunt connected dc machine. Derive an approximate expression for the peak-to-peak torque ripple. Note, for this problem variation, it is acceptable to have the average armature current $\bar{i}_a$ and average field current $\bar{i}_f$ in your answer, in addition to those quantities listed above.

Solution is same as Exam 2, Problem 5.

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3.) 22 pts. A three-phase wye-connected brushless dc machine is open-circuited, and is spun using a dynamometer. The b- to c- phase voltage measured from an oscilloscope if found to be sinusoidal. The waveform has a peak-to-peak voltage of 240 V, and a frequency of 82 Hz. Next, with the machine open-circuited and stationary the impedance between two connections is measured. At 100 Hz the impedance measured between two line connections is 0.1+j1 Ohms (with the third line connection open-circuited). Determine ~~X~~, $\lambda_m$, $r_s$, and $L_{ss}$.

$$V_{bc} = \sqrt{3}\,\omega_r \lambda_m \cos(\omega_r t + \phi)$$

$$\omega_r = 2\pi 82$$

$$\lambda_m = \frac{240}{2\sqrt{3}\,\omega_r} = .1345$$

$$\omega = 2\pi 100$$

$$Z = 2(r_s + j\omega_e L_{ss})$$

$$r_s = \frac{0.1}{2} = 0.05\,\Omega$$

$$L_{ss} = \frac{\mathrm{Imag}(Z)}{2\omega_e} = \frac{1}{2\omega_e} = \sout{1.4\,mH}$$

$.796\,mH$

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32 pts

4.) The following are worth 2 points each.

a) What is the main purpose of the machine variable induction motor model?
starting point for other models

b) Would the co-energy approach to finding torque be applicable to a machine which is highly saturated? Yes

c) Why is the fact that the flux linkage equations are a function of mechanical position important to society? ↳ Allows torque production, electromechanical devices, generators

d) Consider a generator where the mechanical source is slow. Would you expect the machine to have a large number of poles or a low number of poles? (large #)

e) Name an advantage of induction machines over permanent magnet ac machines.
Can operate off of line; more robust

f) Name an advantage of permanent magnet ac machines over induction machines.
more torque dense

g) Name an advantage of permanent magnet ac machines over dc machines. ~~more efficient~~
no brushes

h) Name an advantage of dc machines over permanent magnet ac machines.
less power electronics, easier control

i) Name an advantage of separately excited dc machines over permanent magnet dc machines. Field weakening ⇒ larger capability curve.

j) Name an advantage of permanent magnet dc machines over separately excited machines. Simpler, don't need a field. More efficient

k) What simplification do we always obtain by going to qd variables regardless of choice of reference frame (rotor versus stationary)? eliminate rotor position dependent inductances.

l) Name one reason why having a T-equivalent circuit of an induction motor is advantageous with respect to identify parameters. We can find the referred parameters - not the original

m) Why is the start up of an induction machine often a relatively violent transient?
low starting torque

n) What is significant about having a lossless field in terms of energy storage which was important to our methods of computing force.
~~[illegible]~~ Stored energy is only a function of state

o) Would it make sense to have a 4-phase variable reluctance stepper motor?
Yes

p) Why are transformers of key importance in modern society?
allow smaller conductors in transmission lines through use of high voltages