Version PRP/3

EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 29 April 2014 2 to 3.30

Module 3B4

ELECTRIC DRIVE SYSTEMS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number __not__ your name on the cover sheet.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) (i) What are the benefits of *distributed windings* and *short pitching* in electrical machines? [10%]

(ii) The distribution factor, K_d, and the short pitch factor, K_p, are often written as

$$K_d = \frac{\sin(mp\,\beta/2)}{m\sin(p\,\beta/2)}$$

and

$$K_p = \cos\left(\frac{p\alpha}{2}\right)$$

where p is the number of pole-pairs.

Explain the meaning of the m, β and α terms, and state how the above relationships are used to determine the winding factor K_w of a machine winding. [20%]

(b) A 4-pole induction motor has stator laminations with 24 slots and with equal tooth and slot widths.

(i) If the maximum permitted peak flux density in the tooth is 1.8 T what is the equivalent RMS flux density in the air gap? [10%]

(ii) The delta connected stator winding is three-phase and is to be supplied with 400 V at 50 Hz. Design a suitable single layer distributed winding for this machine giving the number of turns per coil. The stack length is 250 mm and the air gap diameter is 100 mm.

Note

$$E_{rms} = \frac{N_{eff} B_{rms} \ell d \omega}{p}$$

where the symbols have their usual meanings. [35%]

(c) A suitable cage rotor is to be designed for the motor. Suggest:

(i) a suitable form of rotor construction; [5%]

(ii) a possible number of rotor bars; [5%]

(iii) a possible bar shape if a good starting torque is required; [5%]

(iv) what factors determine the acceptable current density in the rotor bars? [10%]

2 (a) Explain how the combination of a cage rotor induction motor and an inverter giving a variable voltage and variable frequency output yields a versatile variable speed drive. [20%]

(b) A simplified expression for the torque available from a three-phase induction motor is:

$$T = \frac{3V_1^2 s}{\omega_s R_2}$$

(i) what assumptions are made to derive this formula? [10%]

(ii) sketch torque-speed characteristics in the normal operating region of a machine which is supplied with a constant V / f ratio. [15%]

(c) A drive uses a 4-pole star connected induction motor rated at 400 V, 50 Hz and 9 A. The motor parameters under rated conditions are

Stator resistance, $R_1 = 1.8\ \Omega$

Stator leakage reactance, $\omega L_1 = 2.5\ \mathrm{j}\Omega$

Referred rotor resistance, $R_2 = 1.6\ \Omega$

Referred rotor leakage reactance, $\omega L_2 = 2.5\ \mathrm{j}\Omega$

Magnetising reactance, $\omega L_m = 108\ \mathrm{j}\Omega$

(i) Determine the rated torque for the drive. [15%]

(ii) Assuming the machine is fully magnetized, what excitation frequency is needed to provide half rated torque at zero speed,? [15%]

(iii) What voltage needs to be applied to the machine terminals to ensure full magnetization at this frequency? [20%]

(iv) What precautions need to be taken if the drive enters into braking mode during operation? [5%]

 (TURN OVER

3 (a) (i) With regard to permanent magnet *Brushless DC* (*BLDC*) motors, explain the terms *sinusoidal* and *trapezoidal* brushless DC. [10%]

(ii) Explain briefly why sinusoidal BLDC motors always have the same number of poles in the stator winding as magnetic poles in the rotor, whereas trapezoidal BLDC motors may not. [20%]

(iii) Give an example application for each, where one type should not be replaced by the other and state your reasons. [20%]

(b) A nominal 24 V three phase trapezoidal BLDC motor has the following characteristics:

Winding resistance (2 phases)	2 Ω,
Winding inductance (2 phases)	8.37 mH,
Rated Torque	0.706 Nm,
Rated current	3 A,
Full load speed at 24 V	500 rpm.

(i) Plot the *torque-speed* curve assuming ideal trapezoidal BLDC operation at rated conditions. [20%]

(ii) Plot the torque speed curve assuming ideal trapezoidal BLDC operation through the point of rated torque and the highest speed at which it can be achieved. [10%]

(c) Consider the effect of winding inductance at high speeds in a back-emf sensing trapezoidal motor. Hence explain why the manufacturer of the motor in part (b) states, "increased performance can be achieved with the use of a sinusoidal drive". Illustrate your answer with a phasor diagram. [20%]

4 (a) (i) A hand held vacuum cleaner uses a *switched reluctance motor* (SRM) with 4 stator poles arranged symmetrically with opposite pairs carrying the same winding. The rotor has three poles. Show by sketching a sequence of cross sectional views how the motor may be operated in the manner of a switched reluctance motor. [20%]

(ii) Write down an equation for the inductance of one winding. Hence obtain an expression for the Torque. If the maximum power at 100,000 rpm is 160 W and the peak winding current is 15 A, estimate the change in inductance of the winding with rotor position. State clearly any assumptions made. [20%]

(b) (i) The SRM motor in part (a) is to be replaced by a two pole *Brushless DC* (BLDC) motor with a single phase winding. State two advantages and two disadvantages of such a motor compared to an SRM. [20%]

(ii) The motor and drive is described as having:

(i) asymmetrically shaped poles;

(ii) a Hall sensor;

(iii) a MOSFET H-bridge;

(iv) a single phase winding wound in parallel.

Noting that the vacuum cleaner is battery powered, sketch the system schematic showing the main control loops. Give a reason for choosing each of (i) – (iv) above. [30%]

(c) For an air hand dryer a power rating of 1600 W is required at 100,000 rpm. Suggest practical changes to the design of the BLDC motor in part (b) such that it will satisfy this requirement. [10%]

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