ENGINEERING TRIPOS PART IIA

Monday 26 April 2010 9 to 10.30

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.*

There are no attachments.

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book CUED approved calculator allowed

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

Final Version

1 (a) The voltage rating and current rating of an electrical motor do not separately affect the overall volume of the machine. However, the speed of rotation is known to have an inverse proportional effect. State the physical mechanisms which apply to each of these ratings and explain how they are coupled to give a machine size. [30%]

(b) Induction motors commonly have a small airgap. Permanent Magnet (PM) motors typically have a large airgap and come in several types. One such *in runner salient pole* motor, with concentrated windings around a simple pole structure is shown in Fig. 1. Sketch the magnetic equivalent circuit for the PM system and show that a small airgap is not necessary to maximise the airgap energy. Contrast this fact with that for the induction motor. [40%]

(c) A *pancake* PM Motor for a solar racing vehicle is designed such that the flat winding is encapsulated in a plastic resin and all the magnetic material rotates. State one advantage and one disadvantage of such a design. The motor has 12 magnetic poles which produce a flux of 0.5 T in the airgap, with an outer rotor diameter of 400 mm, and an inner diameter of 300 mm. For a simple 12 pole three-phase winding, find the number of turns required for 32 V peak per phase, assuming the wheel rotates at 1080 rpm. State any assumptions made. [30%]

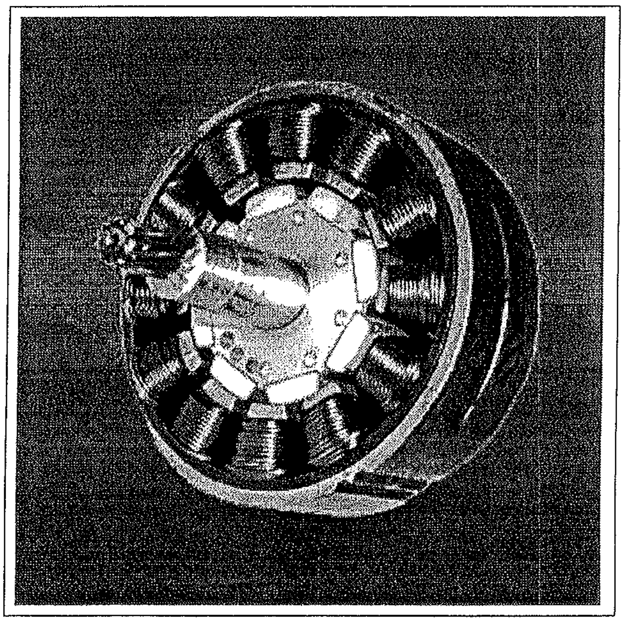

Fig. 1

2 (a) The magnetising inductance carrying the magnetising current of the motor accounts for the main flux linking the rotor and the stator in the conventional three phase induction motor. By consideration of the per-phase equivalent circuit or otherwise explain carefully why the magnitude of the torque produced is proportional to the main flux and the component of the referred rotor current which is 90° out of phase with the magnetising current. [35%]

(b) A microprocessor application note describing programming an inverter driven induction motor drive suggests that the rotor time constant is a sufficient model for the induction motor and can be used to obtain the required torque for use in a closed-loop speed control system. The time constant τ is determined by the magnetising inductance L_m divided by the referred rotor resistance R_2 (per-phase quantities). By considering the magnetising current i_m and the rotor current i_2 show that

$$s\omega = \frac{i_2}{i_m}\frac{1}{\tau} ,$$

where s is the fractional slip and ω is the applied frequency. State the approximations necessary. [30%]

(c) The 415V, 3.7 kW, 2 pole, 50 Hz delta-connected induction motor to be operated in the drive scheme of part (b) has a referred rotor resistance of 2.62 Ω and a magnetising inductance of 185 mH. When running at a speed of 1500 rpm driving a fan load with a high inertia the motor runs at 25% maximum torque. Find the maximum immediate change in applied frequency if the speed is to be increased at the greatest rate of acceleration without the motor torque exceeding the rating and damaging the fan. [35%]

3 (a) The *Kinetic Energy Recovery System* (KERS) for a high performance racing vehicle racing relies on recovering energy during braking and then powering the car for a period of 6.5 s per lap. Sketch a brushless dc drive system showing the main feedback paths suitable for this application, commenting on the type of power storage and electronic converter you consider necessary. Also mark on a torque speed diagram the quadrants in which the system operates and the direction of the power flow. [30%]

(b) One manufacturer has opted for a motor-generator with a sinusoidal field pattern and a conventional distributed three phase winding. The manufacturer warns that the motor-generator must be used with the correct controller. Give two reasons why this warning is necessary.

Sketch a phasor diagram for operation at speed as a brushless dc drive. Using your phasor diagram or otherwise explain how the torque is controlled. [30%]

The star connected three phase brushless dc motor has the following data.

Rated speed	15000 rpm
Number of poles	4
Maximum Voltage (Line-Line)	270 V
Maximum Continuous Current	183 A
Resistance per phase	20 mΩ
Inductance per phase	0.2 mH
Rated Frequency	500 Hz

Iron losses and the winding resistance in the stator may be neglected when operating at speed. The power is limited electronically by the controller to 60 kW.

(i) Find the line voltage and current under full electric braking at 12000 rpm, with conventional brushless dc operation.

(ii) Estimate the current when accelerating at 18000 rpm.

Comment on the efficiency of the system noting that the inverter employs IGBTs. [40%]

4 (a) A 4-pole single-phase *brushless dc motor* is shown in Fig. 2. The single phase winding is placed around the main poles. Explain briefly why such a motor is unable to produce any starting torque unless the airgap or magnets are shaped in some way. Suggest a shape which would provide a non-zero starting torque. [20%]

Carefully sketch the waveform of the emf produced when rotating and using your sketch explain why this is described as a brushless dc motor. [30%]

(b) By considering the response of a stepper motor to a small displacement around a step position show that there exists a natural angular frequency of oscillation given by

$$\omega = \sqrt{\frac{N_S \hat{T}}{J}} ,$$

where N_S is the number of steps per revolution, J is the combined moment of inertia for the motor and load and $\hat{T}$ is the peak torque at a given level of excitation. [20%]

Hence explain the use of *microstepping* to reduce the development of unstable oscillations. By means of a phasor diagram for operation at speed, or otherwise, explain why careful commissioning of a stepper motor drive without microstepping can avoid the occurrence of instabilities. [30%]

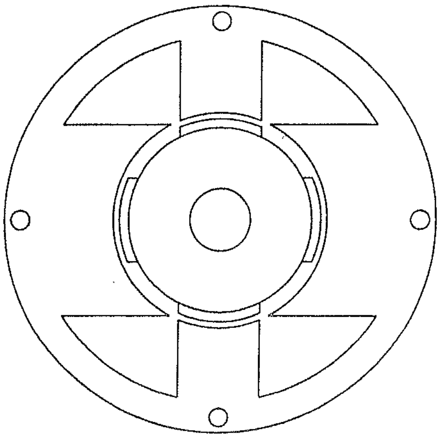

Fig. 2

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