ENGINEERING TRIPOS PART IIA

Wednesday 10 May 2006 2.30 to 4

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

Single-sided script paper

SPECIAL REQUIREMENTS

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

1 (a) State the definitions of the terms *Specific Magnetic Loading* and *Specific Electrical Loading*, when used in motor design.

Explain briefly the significance of each. [20%]

(b) A drain pump for a washing machine is driven by an induction motor. The motor has a single concentrated winding set to the side of the motor, Fig. 1. The length of the rotor is 35 mm and the diameter is 30 mm. Stating your assumptions, estimate the approximate power output of the motor. [30%]

(c) The motor of part (b) has single-turn coils of copper set into slots in the stator pole faces. Making use of a magnetic equivalent circuit of the motor, explain carefully the purpose and operation of the copper coils in the stator poles. [30%]

(d) It is proposed that the induction motor of part (b) should be replaced by a permanent magnet motor, with a simple drive circuit. Make conceptual design choices regarding the magnetic material type and the stator winding.

Explain briefly your reasoning. [20%]

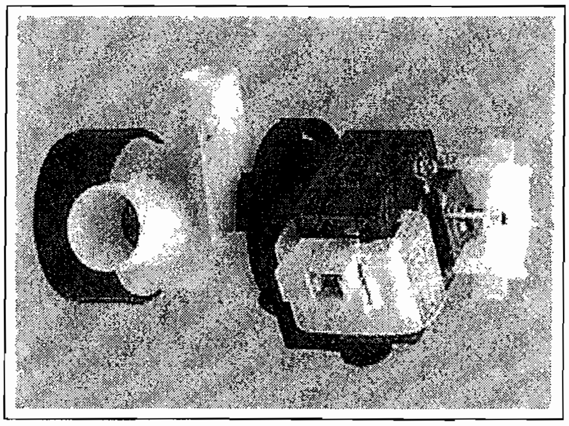

Fig. 1

2 (a) Show that the torque-speed curve for an induction motor may be approximated by the formula

$$T = \frac{3V^2}{\omega_s^2}\frac{(\omega_s - \omega_r)}{R_2} \ ,$$

where T is the torque, V is the applied voltage, ω_s is the synchronous speed of rotation, ω_r the actual speed and R_2 the referred rotor resistance. State the approximations necessary and the extent of the validity. [40%]

(b) List the conditions necessary for obtaining rated torque at various frequencies in a variable voltage variable frequency induction motor drive. Hence or otherwise, carefully sketch a number of torque-speed curves for this drive in all four quadrants. [30%]

(c) The manufacturer provides the following data for the per-phase equivalent circuit of a 415 V, 4 kW, 2 pole, 50 Hz, three-phase induction motor.

Referred rotor resistance, R_2	2.14 Ω
Referred rotor leakage reactance, ωL_2	3.0j Ω
Stator resistance, R_1	4.7 Ω
Magnetising reactance, ωL_m	198j Ω

The motor is closely matched to a VVVF inverter and runs open loop. Assuming operation with the motor conditions of part (b), estimate the actual speeds for the following conditions:

(i) Input frequency 33 Hz, 1.5 times rated torque;

(ii) Input frequency 67 Hz, rated torque. [30%]

(TURN OVER

3 (a) A machine tool drive based on a permanent magnet synchronous motor with sinusoidal flux is shown in Fig. 2. The drive is used in a position control loop. Describe briefly one method for generating the stator current reference signals.

Noting that the motor has a very low value of stator winding resistance, sketch the phasor diagram for the motor and hence describe the control strategy required to give the drive the characteristics of a brushless dc drive. [40%]

Making reference to the dynamics of an inertial load, explain carefully why the speed ω is a feedback variable as well as position θ.

State two reasons why this is a practical way of obtaining the desired effect. [30%]

(b) An alternative drive scheme is described as a trapezoidal brushless dc drive. The torque-angle characteristic is shown in Fig. 3, for a current flowing in two of the three star connected stator windings. Describe carefully the operation of the drive and compare it to that of part (a) for machine tool use. [30%]

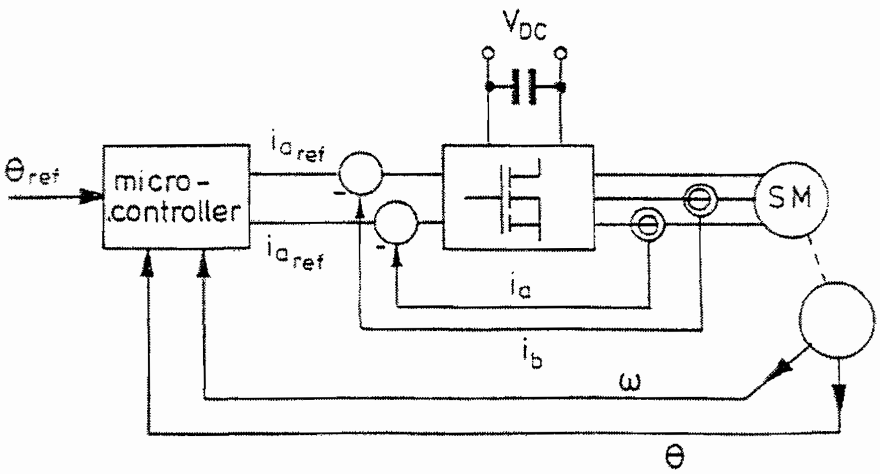

Fig. 2

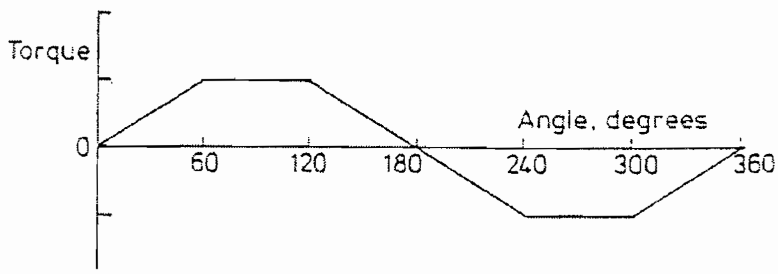

Fig. 3

4 (a) Describe briefly the design of a three stack variable reluctance stepper motor. [20%]

(b) It can be assumed that the inductance of Phase A of a 3 stack variable reluctance stepper motor varies as

$$L_A = L_o + L\cos m\theta \ ,$$

where m is the number of stator teeth.

Show that the torque produced by Phase A when excited by a dc current i_A may be expressed as

$$T_A = \tfrac{m}{2} i_A^2 L \sin m\theta \quad .$$

A 3 stack variable reluctance stepper motor has 8 stator teeth. From measurements the maximum inductance is 70 mH and the minimum is 50 mH . Calculate the peak torque produced by the motor when one phase is excited by a dc current of 5 A . [30%]

(c) For the motor of part (b), with a freely moving rotor, show that simultaneous excitation of two phases with the same magnitude of dc current causes the rotor to move to a half step position.

Determine the ratio of the peak torque available when two phases are excited to that available when only one phase is excited (for the same dc current). [20%]

(d) A new washing machine employs a three phase 6/4 (stator teeth to rotor teeth) variable reluctance motor for the main drum drive. Sketch a drive circuit for one phase of the motor and suggest how it may be applied to minimise acoustic noise, without significant loss of torque.

State two advantages of this type of motor compared to a small induction motor. [30%]

END OF PAPER