ENGINEERING TRIPOS PART IIA

Wednesday 9 May 2007 2.30 to 4.00

Module 3B4

MACHINES AND DRIVES

*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 meaning of the term *distributed winding* and explain its importance in the design of three-phase motors. [15%]

(b) The main pump motor of a dishwasher has 24 slots. Two wire diameters can be seen in four separate bands of the slots, and the slots are filled in each case. The thicker wire occupies 16 slots. Since the dishwasher is single phase, explain the arrangement of the windings and carefully sketch the mmf for the main winding for a nominal dc current.

Explain why the flux can be considered as two counter rotating waves, when the main winding is connected to the ac supply. [35%]

The length of the rotor is 30 mm and the diameter is 50 mm. Stating your assumptions, estimate the approximate power output of the motor. [25%]

(c) The motor of Part (b) is to be replaced with a three phase permanent magnet machine, driven by an inverter. Assuming $SmCo_5$ magnet material is to be chosen, find the ratio between the size of the magnet and the air gap which makes optimal use of the magnetic material, stating your assumptions. Describe briefly the stator windings required and their distribution if the stator of Part (b) is to be used. [25%]

2 (a) An 4 kW induction motor is closely matched in ratings to a *Variable Voltage Variable Frequency* (VVVF) drive. Making reference to the conventional per-phase equivalent circuit for an induction motor, explain carefully why the stator resistance and both leakage reactance terms may be neglected in the analysis of the drive when properly commissioned.

Hence find an expression for torque versus speed of the motor in terms of the the applied voltage V, the synchronous speed of rotation ω_s, the slip s and the referred rotor resistance R_2. Find an expression for the maximum torque in terms of the rated motor conditions. [40%]

Carefully sketch torque speed characteristics for a range of frequencies below base speed and below rated current in all four quadrants of operation. Mark on your curves the maximum steady state torque that can be obtained. How do the characteristics alter when the drive is operated above base speed? [25%]

(b) The equivalent circuit data for a star connected 415 V , 4 kW , 2 pole , 50 Hz , induction motor is given in Table 1.

Table 1. Induction Motor Equivalent Circuit Data

Referred rotor resistance, R2	2.14 Ω
Referred rotor leakage reactance, ωL2	6.0j Ω
Stator resistance, R1	4.7 Ω
Magnetising reactance, ωLm	198j Ω

The motor is closely matched to a VVVF inverter according to Part (a). Estimate the maximum speed at which rated power can be achieved. [35%]

(TURN OVER

3 (a) A large synchronous motor is to be used for ship propulsion. How should the applied voltage be controlled to ensure the motor runs at rated flux at all speeds? Making reference to the phasor diagram, for over excited operation, draw a labelled block diagram of the principle elements and feedback paths for speed control of such a motor.

How should the field excitation be controlled to account for conditions of varying load and speed, to achieve maxium torque per amp in the stator winding? [40%]

(b) The motor chosen for the scheme of Part (a) has manufacturer's data given in Table 2.

Table 2 Manufacturer's Synchronous Motor Data

Frequency	48 Hz
Voltage	1250 V
Current	1400 A
Power factor	0.9
Synchronous inductance	2.7 mH

(i) Find the percentage field excitation required for full load and speed.

(ii) The load torque falls to 50% full load at 80% speed. Find the percentage field excitation required under these conditions. [30%]

(c) A permanent magnet motor is suggested for this application, along with a gearbox. Discuss briefly why this is likely to be a good combination for ship propulsion.

Give two reasons why a *sinusoidal brushless dc* drive system might be preferred compared to a *trapezoidal* scheme. [30%]

4 (a) Describe briefly the design of a 200 step two phase two stack hybrid stepper motor, making clear how a small step size is achieved, and how a detent torque is maintained. [25%]

(b) For the motor of Part (a), carefully sketch the Torque-Displacement curves for one phase excitation and two phase excitation over the range of one rotor tooth pitch. How are these curves related? [25%]

(c) For the motor of Part (a) draw a magnetic equivalent circuit for the main flux path with excitation of one phase only, showing the variation in the reluctance using variable components. Without doing any calculations state how the torque may be calculated. [25%]

(d) When run at speed, the motor may be considered as a synchronous motor. Neglecting the winding resistance, sketch a phasor diagram for motoring under load. Hence or otherwise show that the pullout torque then varies with the inverse of speed. [25%]

END OF PAPER