ENGINEERING TRIPOS PART IIA

Monday 27 April 2009 9 to 10.30

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 terms *Specific Electrical Loading* and *Specific Magnetic Loading* when applied to motor design. Explain briefly how the current density is applied. [20%]

(b) A three phase motor is required for an electric sports car. The desired continuous peak output of the motor is 50 kW and the motor is to be connected to the wheel through a simple 3:1 gearbox, giving a motor speed of approximately 6000 rpm at 70 mph. Using typical industrial motor design factors, such as a *Specific Electrical Loading* of 30,000 $\mathrm{Am^{-1}}$ and a *Specific Magnetic Loading* of 0.5 T, estimate the volume of the rotor required. [30%]

State one advantage and one disadvantage of the use of a geared motor.

Suggest two factors which influence the choice of number of poles. [20%]

For reasons of integration in the structure of the vehicle, the motor is designed to have a large diameter compared with its length. The rotor diameter chosen is 240 mm. If the drive inverter is able to provide a maximum ac voltage of 200 V, design a distributed winding for this motor, assuming it is to be an 8 pole motor, and smooth torque is required, stating any assumptions. [30%]

[Hint: The *Distribution Factor,* $k_{\mathrm{d}} = \dfrac{\sin(m\beta p/2)}{m \sin(\beta p/2)}$]

2 (a) Show that an industrial induction motor driven by a *Variable Voltage Variable Frequency* inverter may produce the full load torque at standstill, stating any assumptions you make. Hence or otherwise sketch a set of torque speed characteristics for an induction motor drive, such that the drive can produce rated torque over a wide range of speeds. [40%]

(b) A motor constant K_M for the induction motor can be defined as

$$\frac{k}{\sqrt{R_2}} ,$$

where k is the ratio of voltage to frequency for the machine and R_2 is the referred rotor resistance per phase. What is the significance of the ratio k ?

The value of K_M required for an application can be described by the expression

$$\frac{T/p}{\sqrt{3(P_{in}-P_{out})}} ,$$

where T is the motor torque, p is the number of pole pairs, P_{in} and P_{out} are the input and output power respectively for the motor, neglecting stator losses.

By considering the torque required in an application show how this factor is derived and explain briefly the assumptions required. [30%]

(c) A 2 pole motor is required to produce full load torque at standstill and has the following nameplate rating.

Power	3.7 kW
Speed	2940 rpm
Voltage	415 V
Frequency	50 Hz
Connection	Delta
Power Factor	0.8

Choose the voltage and frequency that must be applied at standstill. [30%]

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3 (a) The brushless dc motor for a machine tool has a sinusoidal field pattern and a distributed three phase winding. The manufacturer explains that for these reasons the motor is listed in the catalogue as an ac motor. Draw a block diagram for the motor drive showing the main feedback paths and the controller required for stability. [40%]

Sketch a phasor diagram for operation at speed as a brushless dc drive. Using your phasor diagram or otherwise explain the manufacturer's reasoning for considering such a motor as an ac motor.

The manufacturer of the motor states that it has a skewed stator winding to avoid a *cogging torque*. Explain the term cogging torque and its drawback in a machine tool motor drive. [30%]

(b) The machine tool manufacturer requires the brushless dc motor chosen for the main drive to be able to run at speeds significantly higher than the base speed of the drive imposed by the maximum applied drive voltage. Using a phasor diagram, show that the requirement may only be met by adding a *phase advance* to the stator current.

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

EMF Constant Per Phase	65 V/1000 rpm
Number of poles	6
Maximum Voltage (Line-Line)	520 V
Maximum Continuous Current	21 A
Inductance per phase	2.5 mH

Find:

(i) the maximum operating speed with full current and voltage under brushless dc conditions

(ii) the maximum operating speed with full current and 30^{O} phase advance in the stator current. [30%]

4 (a) A new stepper motor driver chip offers quad, eight and 16 step *microstepping* modes. Explain the term *microstepping* and why these modes may be of use. By considering the alignment torque between teeth or otherwise, discuss briefly why microstepping is unlikely to be an accurate positioning step mode in contrast to the half and full step modes. [40%]

(b) A brushless dc motor for a model aircraft has 14 magnetic poles arranged around the inside surface of the external rotor. Concentrated windings can be seen positioned around 12 teeth on the internal stator. There are three wires attached to the windings, and the drive circuit has three phases. Carefully sketch a linear arrangement of the magnetic poles and the three phase windings and show that the motor can be considered to operate as a permanent magnet stepper motor and find the step angle. [30%]

(c) Table 1 shows a partially completed weighted design selection table of motor technologies. A three phase motor is required for an electric bus. The desired continuous peak output of the motor is 100 kW and the motor is to be connected to the wheels through a simple 3:1 gearbox, giving a maximum motor speed of approximately 3000 rpm. Making estimates for the values missing from Table 1, copy out and complete the table and comment on the choice of motor which arises. [30%]

Table 1

Weighted design factors for motor type selection

	Conventional DC Motor	Induction Motor	Brushless DC Motor	Switched Reluctance Motor
Efficiency			6	
Maturity		6		
Low Cost	4			6
Low Audible Noise				0
Total				

END OF PAPER