Version TJF/5

EGT2
ENGINEERING TRIPOS   PART IIA

Monday 24 April 2017   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
Engineering Data Book
CUED approved calculator allowed
There are no attachments

10 minutes reading time is allowed for this paper.

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

1 (a) Sketch a typical torque-speed characteristic for a universal motor fed from an ac supply. Explain how supplying the machine with dc equivalent to the rms voltage of the ac supply would modify these characteristics. [10%]

(b) A 240 V, 50 Hz universal motor is to be used to drive a stone cutting saw. The machine has a total resistance of 3 Ω and a total inductance of 30 mH. Under load, the current drawn is 9 A. Sketch the phasor diagram for this operating condition. Calculate:

(i) the power factor;

(ii) the efficiency.

Give reasons why the calculated efficiency is unlikely to be achieved in practice. [35%]

(c) The temperature of the motor is found to fluctuate between 100 °C and 113 °C when cutting for two minutes, with one minute between cuts, and an ambient temperature of 20 °C. Calculate the dissipation coefficient, k, and the thermal capacity, c, of the motor. Suggest a suitable means of protecting the motor against overload. [40%]

(d) Because of the brush life problems, an alternative drive based on a permanent magnet synchronous motor (brushless dc motor) is proposed. Give the main advantages and disadvantages of this drive compared to the universal motor drive. [15%]

2 (a) A 4 pole, 50 Hz, 415 V, 2.2 kW delta connected 3-phase induction machine is to be used to drive a vacuum pump. The motor has 36 stator slots and the winding is to be short-pitched by one slot.

(i) Explain why it is usual to distribute and short pitch the windings of medium sized induction motors. [10%]

(ii) Show that the fundamental winding factor is given by

$$K_w = \frac{\sin \frac{mp\beta}{2}}{m \sin \frac{p\beta}{2}} \cos \frac{\alpha p}{2}$$

Describe the meaning of each term and calculate the fundamental winding factor for this induction machine. [20%]

(b) For an ac machine having $2p$ poles the rms air gap flux density, B_{rms}, can be related to the rms phase voltage by

$$B_{rms} = \frac{V_{rms} p}{l \omega d N_{eff}}$$

where N_{eff} is the effective turns per phase, l is the axial length, d is the air gap diameter and ω is the angular supply frequency. Calculate the actual number of turns per phase for the motor of part (a) ensuring that it is possible to manufacture the winding. The following parameters have been specified:

Specific magnetic loading $\overline{B} = 0.5$ T, $d = 112$ mm and $l = 95$ mm.

Evaluate the ratio of the terminal voltages if the machine were wound with a concentrated winding, to that when wound with a distributed winding, to that when wound with a distributed winding short-pitched by one slot. [40%]

(c) The motor is required to have a high starting torque. Sketch a suitable rotor slot shape and explain with reference to deep bar effects why this shape results in a high starting torque. What is the relevance of skin depth to the bar shape? Comment on any effect on normal running. [30%]

3 (a) A manufacturer of all-electric passenger vehicles proposes to use a *sinusoidal brushless DC motor* (BLDCM) as the motor for the electric drive system. Give three reasons why this would be a good choice for this application and explain why these motors are typically operated at a torque angle of 90° up to rated speed. [25%]

(b) A 2 pole, three-phase, delta-connected sinusoidal BLDCM has an emf constant of 0.8 V s rad^{-1} and its rated current (line current) is 450 A. Its rated line-line voltage is 240 V and its phase inductance is 2 mH. The system includes an inverter which is matched to the motor.

(i) Find the rated torque and rated speed of the drive. [15%]

(ii) Determine the maximum speed of the drive at 75% of rated torque assuming that the torque angle is maintained at 90°. [20%]

(iii) Find the maximum torque that the drive can deliver when operating at a speed of 4500 rpm and the resulting output power, power factor and torque angle. Explain how field-weakening has enabled this speed to be achieved, and give a disadvantage of field-weakening. [40%]

4 (a) Give three properties of *hybrid stepper motors* which make them a popular choice for low-cost consumer applications which require precise position control. Explain what is meant by full-stepping, half-stepping and micro-stepping, and give an advantage of each of these modes of operation. [30%]

(b) Consider a standard 2 phase, 2 stack hybrid stepper motor with 50 teeth on each of the two rotor wheels. The peak static torque at the rated current of 2 A is 400 mN m, and the moment of inertia of the rotor is 0.02 kg m^2.

(i) Find the step angle assuming the full-stepping mode of operation. [5%]

(ii) Sketch a graph of static torque vs. rotor angular displacement. [10%]

(iii) Define what is meant by position error for a stepper motor and find the position error if the rotor is subjected to a static torque of 175 mN m when the motor current is 1.5 A. [15%]

(iv) The resonant frequency of the stepper motor is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{N_t \hat{T}}{J}}$$

Evaluate this frequency assuming operation at rated current. Hence find the stepper motor angular speed that should be avoided assuming full-stepping mode with one phase excited at a time. [15%]

(c) The stepper motor has a phase resistance of 1.5 Ω, phase inductance of 2 mH and an emf constant of 2.5 V s rad^{-1}. The motor is driven at a speed of 100 rpm and is controlled so that it operates at an rms current of 2 A such that the phase current lags the excitation emf by 15°.

(i) Draw a phasor diagram of the stepper motor. [10%]

(ii) Find the excitation frequency, phase voltage and load angle of the stepper motor. [15%]

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Short answers

1. (b) (i) $\cos\varphi = 0.94$ lagging (ii) $\eta = 88\%$ (c) $k = 1.87\ WK^{-1}$ $c = 745\ JK^{-1}$

2. (a) (ii) $K_w = 0.945$ (b) $N_{ph} = 480$ Ratio = 1 : 0.96 : 0.95

3. (b) (i) $T_{rated} = 624$ Nm $N_{rated} = 2402$ rpm (ii) $N_{max} = 2575$ rpm

(iii) $T_{max} = 389$ Nm P = 183 kW $\cos\varphi = 0.978$ leading $\beta = 141.4^0$

4. (b) (i) 1.80 (iii) Position error = 0.710 (iv) $f_0 = 5.03$ Hz N = 1.51 rpm

(c) (ii) f = 83.3 Hz V = 29.7 V $\delta = 2.4^0$