Version TL/4

EGT2
ENGINEERING TRIPOS PART IIA

Monday 04 May 2026 14.00 to 15.40

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
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

You may not remove any stationery from the Examination Room.

1 (a) Give three advantages and three disadvantages of the sinusoidal Brushless DC Motor (BLDCM) compared to the trapezoidal brushless DC motor in the context of electric drive systems. Assuming that the stator winding resistance may be ignored, draw and label a phasor diagram for a sinusoidal brushless DC motor operating at a general torque angle β, and show that the torque may be expressed as $T = 3kIsin\beta$, where k is the torque constant and I is the armature current. Hence, explain why this type of motor is typically operated in a drive application with a torque angle of 90° where possible. Outline the principles of operation of the drive system which ensures this, assuming that the application requires speed control only. [25%]

(b) A 4-pole trapezoidal Brushless DC Motor (BLDCM) is driven round at a speed of 1000 rpm and the measured open-circuit line voltage is 20 V. The phase resistance is 1 Ω and the rated motor current is 5 A. The motor is supplied from an inverter of maximum output frequency 200 Hz, which in turn is supplied from a 40 V DC power supply. Find:

(i) the rated torque and rated speed of the drive; [10%]

(ii) the maximum speed that the drive can attain whilst delivering 25% of its rated torque. [15%]

(c) The drive of part (b) is used to accelerate a mechanical load consisting of a total moment of inertia of 10×10^{-3} kgm^2 and a viscous load. The torque required to drive the viscous load is proportional to its speed, and at a speed of 800 rpm is 0.4 Nm. The drive is operated so that the motor is always drawing 4 A from the inverter. Find:

(i) the motor torque and the final speed of the drive; [10%]

(ii) an expression for the drive speed as a function of time; [25%]

(iii) the time taken for the drive to accelerate to 50% of its final speed. [15%]

2 (a) Comment on the relative advantages and disadvantages of hybrid stepper motors and brushless dc motors for small automation applications. [25%]

(b) Why do some small hybrid stepper motors have bifilar windings? Sketch circuits for exciting one phase of a standard hybrid stepper motor and a bifilar wound hybrid stepper motor. [25%]

(c) By considering a small displacement about a step position show that a stepper motor exhibits a natural resonant frequency $f_c = \frac{1}{2\pi}\sqrt{\frac{N_s\hat{T}}{J}}$, where N_s is the number of steps per revolution, J is the combined moment of inertia of the rotor and $\hat{T}$ is the peak torque at a given level of excitation. How can microstepping be used to reduce the onset of oscillations? [35%]

(d) 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 Nm, and the moment of inertia of the rotor is 0.02 kgm^2. The stepper motor has a phase resistance of 1.5 Ω, phase inductance of 2 mH and an emf constant of 2.5 V/rad/s. 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°. Draw a phasor diagram of the stepper motor. [15%]

3 (a) Give the definition of the electrical loading and the magnetic loading used in describing the power rating of an electrical machine. Derive the power of a three-phase electrical machine as:

$$S = \frac{\pi}{\sqrt{2}}\pi\left(\frac{d}{2}\right)^2 l\frac{\omega}{p}\bar{B}\bar{J}$$

and define all the terms in the expression. [20%]

(b) A 100 kW, 6.6 kV, 50 Hz, star-connected, three-phase, 10 pole induction motor is to be designed with a specific magnetic loading of 0.5 T and a specific electric loading of 20 kAm^{-1}. When operating at the rated output power, the power factor is 0.8 lagging and the efficiency is 92%. The air gap diameter of the motor is four times its axial length. The stator is to be wound with a single-layer balanced three-phase winding in 60 slots. The peak stator tooth and stator core flux densities are to be 1.57 T and 1.4 T, respectively. The RMS stator winding current density is to be 6 Amm^{-2} and the stator slot-fill factor is to be 70%.

(i) Find the airgap diameter and axial length of the motor. [10%]

(ii) Find the winding factor and the number of turns per phase of the stator winding. [20%]

(iii) Find the width and depth of the stator tooth and the core thickness. [30%]

(iv) Estimate the total volume of the machine. [20%]

The following may be quoted without proof

$$\bar{J} = \frac{6N_{ph}k_w}{\pi d}I_{ph}$$

$$\bar{B} = \frac{2\sqrt{2}}{\pi}B_{rms}$$

$$k_w = \frac{sin(\frac{mp\beta}{2})}{msin(\frac{p\beta}{2})}cos(\frac{p\alpha}{2})$$

$$E_{rms} = \frac{l\omega}{p}dN_{ph}k_wB_{rms}$$

4 (a) Sketch a set of torque-speed curves for a three-phase induction motor for the following two cases:

(i) variable voltage, fixed frequency speed control; [10%]

(ii) variable voltage, variable frequency (VVVF) speed control. [10%]

Use your sketches to explain the advantages of VVVF speed control for three-phase induction motor drives. [10%]

(b) Derive the expression of the torque-speed characteristic of a three-phase induction motor as:

$$T = \frac{2{V_1}^2 s}{\omega_s R_2}$$

State the assumptions made. State the definition of each variable of this expression. For VVVF speed control, explain how the expression $V_1 = k\omega$ can be achieved. [20%]

(c) A three-phase VVVF induction motor drive uses a star-connected, 415 V, 50 Hz, 8 pole induction motor with the following parameters (at 50 Hz):

$$R_1 = 1.5\ \Omega;\ X_1 = 1.0\ \Omega;\ R_2 = 1.2\ \Omega;\ X_2 = 0.8\ \Omega;\ X_m = 100\ \Omega.$$

The rated stator current is 15 A. The motor is connected to an inverter with a maximum output voltage of 415 V and maximum output frequency of 150 Hz.

(i) Determine the maximum unloaded speed of the drive, the rated torque of the drive, and the maximum speed at which the rated torque can be delivered. [25%]

(ii) Determine the voltage boost required when operating at the rated magnetising current and delivering 50% of the rated torque at a stator frequency of 1 Hz. [25%]

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