ENGINEERING TRIPOS PART IIA

Friday 9 May 2003 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.*

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

(TURN OVER

1 (a) A Variable Voltage, Variable Frequency (VVVF) induction motor drive is controlled by a controller with a constant stator voltage to frequency ratio. Sketch the variation of the drive torque versus speed at various stator frequencies in all of the four quadrants (each quadrant should be clearly identified).

Identify the operating points for forward motoring with a typical fan load. [30%]

(b) An induction motor is supplied by a current source inverter. Given that the series stator impedances, together with the iron losses, may be ignored, draw the equivalent circuit for the motor including the magnetising branch and the rotor circuit. Hence show that for operation at rated magnetising current I_{mr} the stator current I_1 must be controlled according to the relationship

$$I_1 = I_{mr}\sqrt{\frac{R_2^2 + \omega_2^2 (L_m + L_2)^2}{R_2^2 + \omega_2^2 L_2^2}}$$

where ω_2 is the slip frequency in rad s^{-1}, L_m is the three-phase magnetising inductance, L_2 is the referred rotor leakage inductance and R_2 is the referred rotor resistance. [35%]

(c) A 5 MW, 2 pole, 6.6 kV star-connected induction motor supplied by a current source inverter has the following equivalent circuit parameters at 50 Hz.

Three-phase magnetising reactance	j60	Ω
Referred rotor resistance	0.1	Ω
Referred rotor leakage reactance	j2.4	Ω

Calculate the stator frequency required for motoring operation at rated magnetising current at a speed of 1000 rpm, when the fundamental of the stator current is 400 A rms. [35%]

2 (a) Assuming that the stator phase resistance can be neglected, draw and carefully label the phasor diagram of an over-excited salient-pole synchronous motor.

From your diagram show that the load angle δ is given by:

$$\delta = \tan^{-1}\left[\frac{IX_{qs}\cos\phi}{V + IX_{qs}\sin\phi}\right]$$

Where:

- ϕ is the input power factor
- X_{qs} is the quadrature-axis synchronous reactance
- V is the phase voltage
- I is the phase current

[45%]

(b) A three-phase, 50 Hz, 6.6 kV, 10 MW, 4-pole star-connected salient-pole motor delivers rated power to its load at unity power factor. It has a direct-axis synchronous reactance, X_{ds}, of 1.8 Ω per phase and a quadrature synchronous reactance, X_{qs}, of 1.3 Ω per phase. You may assume that the stator windings have negligible resistance.

(i) Determine the excitation, E, (phase) required at this operating point.

(ii) Show that the torque may be expressed in terms of the load angle as:

$$T = \frac{3V}{\omega_s}\left(\frac{E\sin\delta}{X_d} + \frac{V}{2X_q X_d}\left(X_d - X_q\right)\sin 2\delta\right).$$

(iii) Plot the torque vs. load angle characteristic accurately. Graphically estimate the maximum torque and the load angle at which it occurs.

[55%]

3 A 240 V_{rms}, 50 Hz Universal Motor is used to drive the spindle of a machine tool. It has a total resistance of 8 Ω and total inductance of 0.1 H.

(a) The motor is connected to a 240 V dc supply and takes 2.8 A when running at 4500 rpm. Calculate the torque developed by the motor. [25%]

(b) The dc supply is replaced by a 240 V_{rms} , 50 Hz supply. Sketch the phasor diagram for when the motor is loaded to 2.8 A_{rms}.

Under these conditions calculate:

(i) the speed of the motor in rpm;
(ii) the torque;
(iii) the power factor;
(iv) the efficiency.

Compare the torque developed when the motor is run as a dc machine with that when it is run as an ac machine. . [45%]

(c) The motor is run as an ac machine with the excitation as given in part (b) and using the following duty cycle:

Run for 90 seconds
Rest for 45 seconds (while the workpiece is changed over).

If the ambient temperature is 18°C and the temperature of the motor varies between 40°C and 70°C , calculate the dissipation coefficient k and the thermal capacity C of the motor. [30%]

4 The fundamental airgap mmf produced by a single-phase induction motor having a stator winding that comprises a concentrated winding with $2\text{-}p$ poles and N turns per coil is approximately:

$$F(\theta, I) = \frac{2NI}{\pi}\cos(p\theta)$$

where I is the winding current and θ is the angle in the stator coordinate reference frame.

(a) If the winding current varies sinusoidally with time show that two counter-rotating mmf waves are produced. Write down the angular velocity of each wave. [20%]

(b) Assuming that the motor can be analysed by superposing the effects of the two waves on an otherwise ordinary induction motor draw an appropriate equivalent circuit, labelling each component carefully. You should use the standard notation:

R_1 is the stator resistance
X_1 is the stator leakage reactance
R_2' is the referred rotor resistance
X_2' is the referred rotor leakage
X_m is the magnetising reactance

Compare the slips in the forward and backward rotating branches and the referred resistances when the motor is stationary. [35%]

(c) The torque is calculated by finding the power lost in the rotor resistances. Given that the torque is zero when the motor is stationary calculate an expression for the running speed at no load and explain why this is less than the synchronous speed. [35%]

(d) Using the expression derived in (c) sketch various torque speed curves for different ratios of R_2' to $(X_2' + X_m)$, and explain what happens if

$$R_2' > (X_2' + X_m).$$ [10%]

END OF PAPER

Solutions for 3B4

1

c) 17.2 Hz

2.

3.

a) 1.3Nm

b) i) 4151 rpm

ii) 1.3 Nm

iii) 0.931 lagging

c) k = 1.075 W/ degree C

C = 55.9 J / degree C