ENGINEERING TRIPOS PART IIA

Monnday 2 May 2011 9 to 10.30

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.*

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) Explain carefully why the number of poles in an electric motor does not independently affect the overall volume of a motor designed for a particular power. Hence explain briefly why gearboxes are widely used in electric motor drives. [25%]

(b) A brushless dc motor is used to drive the inlet compressor of a car engine, without the use of a gearbox. The maximum speed of operation is 100,000 rpm. The rotor has a diameter of 30 mm and the active length is 125 mm. Give three reasons why the rotor is long compared to its diameter and estimate the continuous output power. [35%]

Shaped permanent magnets for the machine are to be applied to the surface of the rotor. The NeFeB magnets are a uniform 5 mm thick and the airgap is 2 mm. The motor will be wound with a two pole three phase star connected winding with a maximum line voltage of 2470 V rms and current of 15 A. Assuming an average flux density per pole of 0.5 T and a current density of 5 A mm^{-2}, perform a conceptual design making broad approximations to find a value for the final outside diameter of the stator core. State your assumptions. [40%]

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

2 (a) Explain carefully why the operation of an induction motor can be described in terms of vectors of current, voltage and magnetic flux. By consideration of such vectors for a two pole induction motor, or otherwise, show that the torque is proportional to the magnitude of the flux coupling the stator and rotor and the component of rotor current which is in phase with the rotor voltage. [30%]

A particular induction motor drive manufacturer claims that their principle of *direct torque control* as applied to induction motor drives has separate control loops for the flux and the torque. Describe the assumptions necessary to simplify the induction motor equivalent circuit for variable speed control. Hence show that the torque may be controlled separately for short periods if the magnitude of the flux is allowed to drift. Explain why considering the slip s to be a transient quantity, and using this in the consideration of the vectors will result in full continuous control of the flux. [40%]

(b) The induction motor for an electric sports car is rated at 100 kW and is connected to the wheels through a 3:1 gearbox, giving a motor speed of 6000 rpm at 70 mph. The motor is delta connected, with two poles and nameplate values of 100 Hz, 353 V, slip of 0.02 and power factor of 0.96 . The motor is closely matched to the inverter. An engineer proposes a second gear ratio of 2:1 to obtain the maximum design speed of 105 mph. Show that the existing motor and inverter design means that such a gearbox could be considered unnecessary in this case. The magnetising current and stator terms can be neglected. [30%]

(TURN OVER

3 (a) A brushless dc drive found in a computer peripheral has three phases and a trapezoidal relationship between torque and rotor angle for constant current in two of the star connected phases. It has one small Hall effect sensor aligned with an extra magnet mounted on the rotor. The magnet only occupies a small angle of the total rotor periphery. Draw the main feedback paths for such a drive, and carefully explain the brushless dc operation at speed.

Given that there is a single Hall effect sensor, propose a method for starting the motor. [50%]

(b) The ideal voltage profile for one phase of a trapezoidal brushless dc motor is given in Fig. 1. By considering the desired operation associated with Fig. 1, or otherwise, show that the operation of a trapezoidal brushless dc motor is identical to that of the sinusoidal brushless dc motor when considering fundamental components. [30%]

(c) A 3 V, 0.2 W brushless dc motor has a significant winding resistance and is operated in a voltage controlled scheme where the pair of phases conducting is continuously selected by back emf detection. By means of a phasor diagram, show that the speed drops as the load torque increases. [20%]

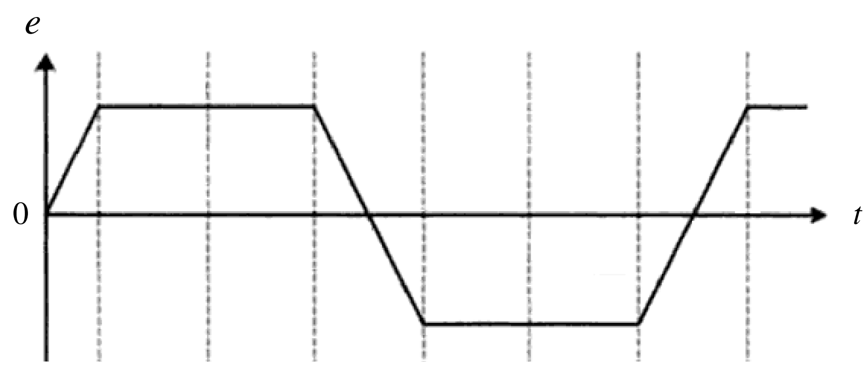

Fig. 1

4 (a) Acceleration rates must be carefully chosen for many stepper motor applications. Explain briefly why a trial and error method may be used with success in applications where the load does not vary. Making reference to a sketch of the poles of a motor, or otherwise, describe carefully the use of *accelerating through* in the choice of acceleration rate. [40%]

(b) A gate in a high speed canning line is driven through 90^{o} using a 1.8^{o} hybrid stepper motor run in half-step mode, via a 10:1 gearbox. The motor has a half-step mode characteristic which is linear from 0.77 Nm at standstill dropping to 0.14 Nm at 6000 half steps per second. No further motor information is available. The existing step rate is low and it is desired that the speed of operation should be increased, while keeping strictly within the known data. The gate has an inertia of 0.002 kg m^2 and the motor-gearbox inertia is 1×10^{-5} kg m^2 at the motor. How fast can the motor achieve full speed (6000 half steps per second) and what should the acceleration profile be set to? Friction may be neglected. [40%]

Hence estimate the total time for the change of position and comment on the choice of gear ratio. [20%]

END OF PAPER

<u>ANSWERS</u>

1.(b) 19.7 kW ~120 mm

2.

3.

4.(a) Exponential rise with time constant of 4.49 ms

(b) 7.65 ms 172.3 ms

P.R Palmer
October 2011