Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2010-2011 (2 hours)

EEE6140 Machine Design 6

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. a. Show that, on no-load, the acceleration of a cylindrical electrical machine is proportional to the magnetic and electric loadings, B and Q, respectively, and is inversely proportional to the square of the rotor diameter, D, i.e.

$$acceleration = \frac{16BQ}{\rho D^2}$$

Note: The moment of inertia of a solid cylinder of length L and diameter D is:

$$J = \frac{\pi D^4 L \rho}{32}$$

where ρ is the mass density. **(4)**

b. A 4-pole brushless dc servo motor is to be designed to produce a continuously rated torque of 10Nm and to be capable of accelerating at a constant rate from 0 to 300 rads^{-1} in 100ms. Determine a suitable rotor length and diameter, assuming that electric and magnetic loadings of 20kAm^{-1} and 0.6T, respectively, can be achieved and that the rotor has a mass density of 7.5x10^{3}kgm^{-3}. **(5)**

c. The 24-slot stator for the above motor has slots of radial depth 20mm and parallel-sided teeth, as shown in Figure 1 (given on next page). Assuming an airgap length of 0.5mm and that no part of the lamination should have a flux density greater than 1.4 T, use reasonable approximations to calculate the tooth width, the core depth, and the inside and outside diameters of the stator. **(7)**

d. If a greater acceleration rate is required without compromising the torque, suggest three possible design changes, in each case stating the implications of the change.

(4)

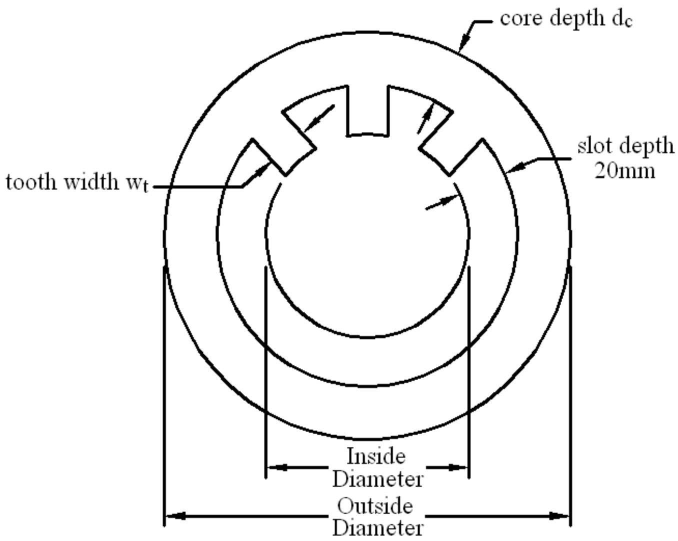

Figure 1.

2. **a.** Derive an expression for the slot leakage inductance per-unit length, for a slot shown in Figure 2(a), specifying any assumptions which need to be made (Full marks will not be given if the assumptions are not specified)

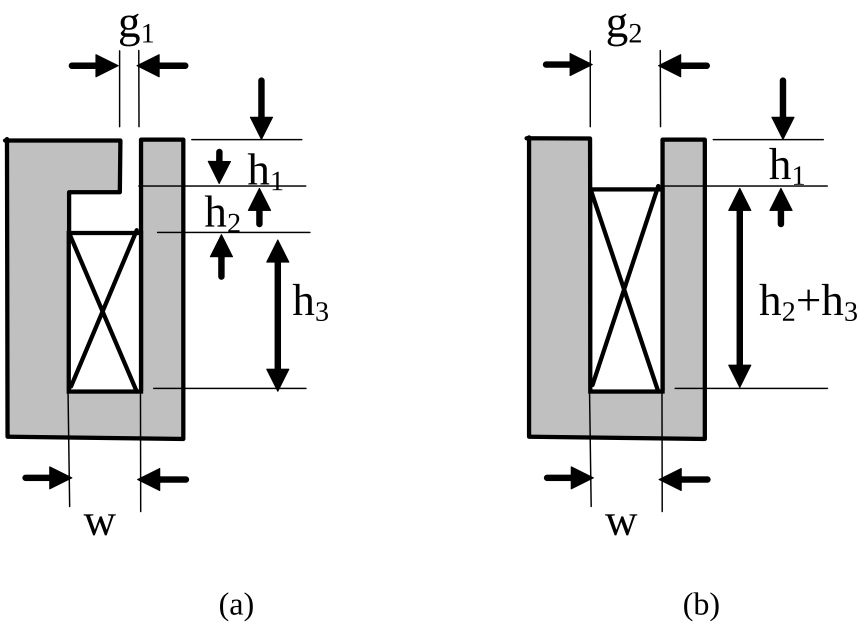

Figure 2 (Number of turns in the slot is N)

(8)

b. For the design of large wind power generators and hydroelectric generators, it is often preferred to employ open slots, as illustrated in Figure 2(b). Show the difference in winding inductances between Figure 2(a) and 2(b). (Full marks will not be given if the evidence is not provided). **(6)**

c. State the advantages and disadvantages of slot configurations shown in Figures 2(a) and 2(b). **(2)**

d. Show how winding pitch and distribution affect the winding inductance. **(4)**

3. The following two equations are often used in the design of surface-mounted permanent magnet machines:

Open-circuit airgap flux density produced by the magnets:

$$B_g = \frac{B_r}{1 + \mu_r \dfrac{L_g}{L_m}}$$

Minimum magnet length to avoid irreversible demagnetization of magnets:

$$L_{\min} = -\frac{NI}{H_{\lim}} - \frac{B_r L_g}{\mu_0 H_{\lim}} - \mu_r L_g$$

where B_r, L_m, $H_{\lim}$ and μ_r are the remanence, magnet thickness, critical coercivity and recoil permeability of the magnets, respectively, and NI and L_g are the external demagnetising mmf and effective airgap into which the magnets operate, respectively.

The above equations are to be used to select some critical design details for a 2-pole, surface-mounted permanent magnet brushed dc motor whose rotor diameter and length are both 30mm and whose airgap is 0.5mm. The magnets have a 120^o arc and the following parameters: B_r=0.6T, $H_{\lim}$= - 400kAm^{-1}, μ_r=1.1.

a. Select a suitable magnet length to achieve reasonable utilization of the magnet material on open-circuit. Explain the reason for your choice. **(5)**

b. Derive an expression for the open-circuit emf and determine the number of series conductors which are required to give a no-load speed of 5000rpm when the motor is supplied from a 24 volt DC supply. **(7)**

c. Using a sketch of the cross-section of the motor showing the armature current pattern, draw a developed mmf pattern for the magnets and armature winding and, hence, show how the minimum length of magnet to avoid irreversible demagnetization can be related to the electric loading Q of the armature. If the motor draws a full load current of 10A from the supply check that the magnet length selected in (a) is adequate. Why might a greater radial magnet length be required? **(8)**

4. **a.** Derive the following torque equation for a single-airgap, slotless, axial-field permanent magnet brushless motor, assuming the airgap field distribution is uniform under the full pole-arc magnet.

$$T = \frac{\pi}{8} D_i (D_o^2 - D_i^2) BQ$$

where D_o and D_i are the outer and inner diameters of the magnets, B is the magnetic loading, and Q is the electric loading which is defined at the inner diameter. **(9)**

b. Show how the torque equation would be modified if the airgap field distribution is uniform under the magnet but its pole-arc to pole-pitch ratio is equal to 0.8. **(2)**

c. What is the torque equation if the airgap field distribution is sinusoidal. **(2)**

d. If the outer diameter is fixed and the electric loading is maintained constant at the inner diameter, derive the optimal ratio of the inner diameter to the outer diameter for maximum torque density. **(4)**

e In a recently developed Toyota hybrid electric vehicle (HEV), the speed of the permanent magnet brushless drive motor has been doubled compared to that which was used in the previous version of the HEV. What are the possible implications of this motor design change? What is the potential implication in an aerospace application? **(3)**

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