Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2006-2007 (2 hours)

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. 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.

(6)

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.

(5)

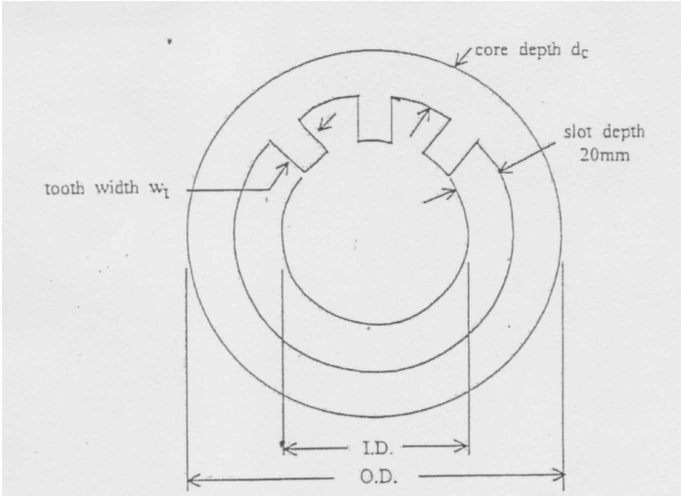
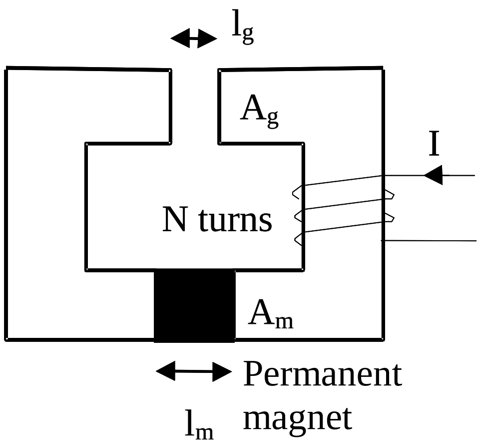
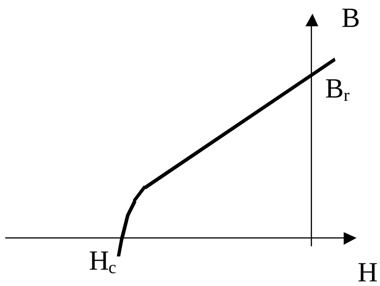


Figure 1.

2. Figure 2(a) shows a simple magnetic circuit which consists of a permanent magnet, an excitation coil having N turns, an airgap and an iron core. It is assumed that the mmf drop in the iron can be neglected and there is no leakage flux. Figure 2(b) shows the demagnetisation characteristic of the permanent magnet.



(a) A_g, l_g, and A_m, l_m are the cross-sectional area and length of the airgap and the permanent magnet, respectively.



(b) B_r is the remanence and H_c is the coercivity of the permanent magnet.

Figure 2

a. Derive expressions for the magnet working point (i) when the coil is on open-circuit, (ii) when the coil carries a current I Amperes, and draw corresponding load-lines on the demagnetisation characteristic of the permanent magnet.

(7)

b. Explain how the partial irreversible demagnetisation of the permanent magnet can be avoided, and derive an expression for the minimum magnet thickness which is required to prevent demagnetisation.

(7)

c. Indicate where the maximum energy product operating point lies on the demagnetisation characteristic, and show that the magnet volume is minimised when the magnetic circuit is dimensioned such that, on open-circuit, the magnet operates at the maximum energy product point. Explain why permanent magnet machines are not designed such that the open-circuit magnet working point coincides maximum energy product point.

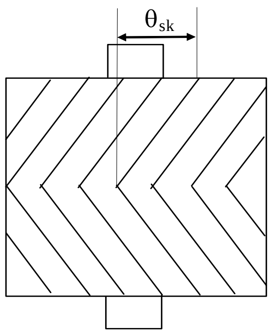
(6)

3. a. Figure 3(a) shows a schematic of a ‘double’ skewed squirrel-cage rotor for a 3-phase induction motor. Derive expressions for its fundamental and harmonic skew factors.

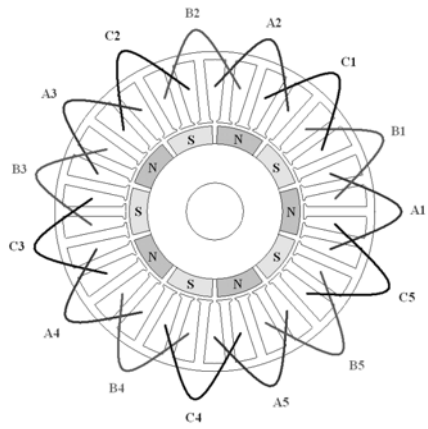
(5)

b. Figure 3(b) shows cross-sections of four 10-pole permanent magnet brushless ac motors. Explain why the coils in the two 12-slot/10-pole motors should be connected as shown in the figures (iii) and (iv). Derive winding factors for all four motors, and compare the advantages and disadvantages of the alternate winding configurations. In general, which winding configuration will result in the most sinusoidal back-emf waveform? Explain why?

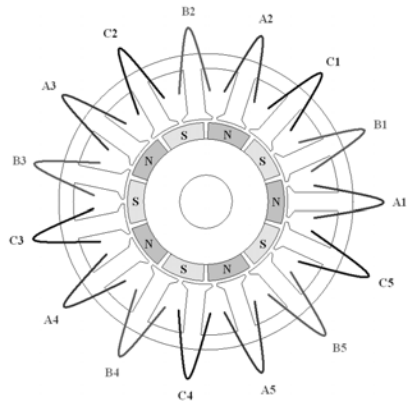
(15)



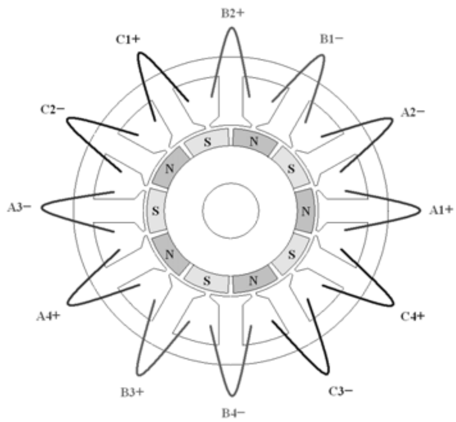
(a)



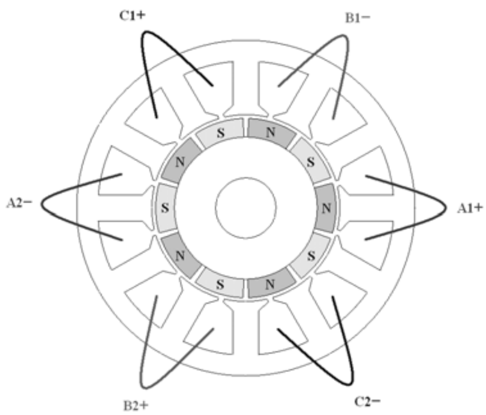
(i) 30-slot/10-pole



(ii) 15-slot/10-pole



(iii) 12-slot/10-pole



(iv) 12-slot/10-pole

(b)

Figure 3

4. **a.** Figure 4 shows a cross-section of a rotor slot and conductor for a 3-phase squirrel-cage induction motor. Assuming that the current density is uniformly distributed throughout the conductor, derive an expression for the specific permeance for the slot. Full marks will only be given if all assumptions underlying the analysis are clearly stated.

(10)

b. Calculate the slot-leakage reactance of a rotor conductor of axial length 100mm when it forms part of the squirrel cage of a 6-pole, 50Hz, 3-phase induction motor when it is operated at a speed of 970rpm.

(5)

c. How will the assumptions made earlier change if a more accurate calculation of the performance is required when the motor is operating at standstill? Explain how this relates to the operation of induction motors, and how it might affect the choice of rotor slot shape. Explain also why this type of rotor slot shape is not essential in inverter-fed, variable-frequency induction motor drives.

(5)

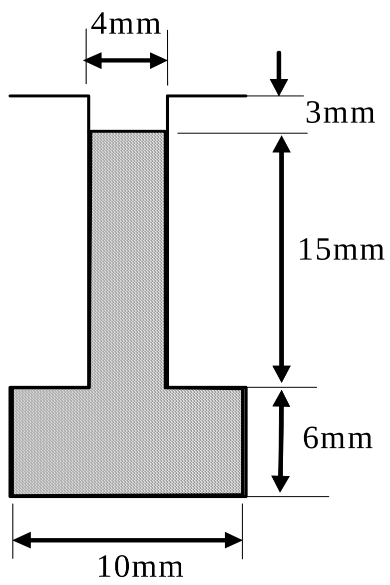


Figure 4

ZQZ- / KA-