Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE6204 Permanent Magnet Machines and Actuators

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth 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. For the radial field, 12-slot, 10-pole surface mounted permanent magnet machine shown in Figure 1, the major dimensions and parameters are listed in TABLE 1, (full marks will not be given if the appropriate approximations are not specified).

a. Assuming the permanent magnets are full arc (180^o), calculate the magnetic loading B. List the possible ways to increase the magnetic loading B. **(6)**

b. If the allowable peak no-load lamination flux density is 2 T, choose a reasonable stator tooth width (t_w) and comment on the result. **(4)**

c. If the allowable peak no-load lamination flux density is 2 T, choose a reasonable stator yoke thickness (d_c) and comment on the result. **(4)**

d. Calculate the electric loading Q if the total Ampere-Turns for the 3-phase windings are NI = 1000A. List the major issues of increasing electrical loading Q. **(4)**

e. Calculate the electromagnetic torque using previously obtained electrical loading Q and magnetic loading B. **(2)**

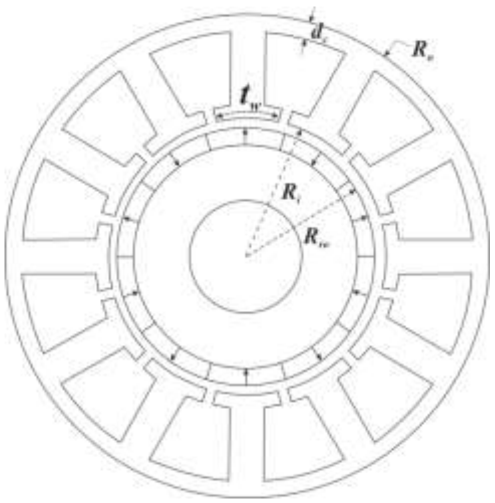

Figure 1

TABLE 1

Slot number (N_s)	12
Pole number ($2p$)	10
Stator outer radius (R_o)	50 mm
Stator inner radius (R_i)	28.5 mm
Active axial length (L_a)	50 mm
Air-gap length (L_g)	1 mm
Rotor outer radius (R_{ro})	27.5 mm
Magnet thickness (L_m)	3 mm
Magnet remanence (Br)	1.2 T

2. **a.** Derive general expressions for the winding pitch factor, K_p, and the distribution factor, K_d, for both the fundamental and the nth harmonic components in the EMF. Based on the coil EMF vectors, in order to obtain a maximum winding factor, determine the coil connections for a 3-phase, 12-slot, 4-pole surface mounted permanent magnet machine with distributed windings. **(6)**

b. Show that the winding skew factor can be derived using a similar method as for the winding distribution factor. Explain the main advantages and disadvantages of using winding skew. **(4)**

c. A concentric winding is distributed in the slots over one pole pitch in a machine having evenly spaced slots, as shown in Figure 2. Calculate the winding factor for the fundamental component of EMF.

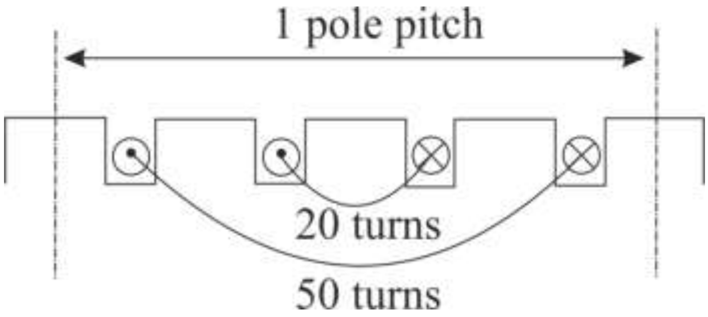

Figure 2 **(4)**

d. Describe the main advantages and disadvantages of the short-pitched concentrated winding, and the fully-pitched distributed winding. **(3)**

e. Describe the main advantages of a single layer, concentrated winding over a double layer, concentrated winding. **(3)**

3. A 2-pole permanent magnet DC motor, having its magnet arcs mounted adjacent to the airgap, has the following main dimensions:

Rotor active length $\boldsymbol{L}$ = 40 mm
Rotor outer diameter $\boldsymbol{D}$ = 60 mm
Effective air-gap length $\boldsymbol{l_g}$ = 0.8 mm
Magnet radial thickness $\boldsymbol{l_m}$ = 5 mm
Magnet pole arc = 110^{o}

The magnet material has recoil permeability (μ_r) of 1.1 and its B-H characteristic is shown in Figure 3.

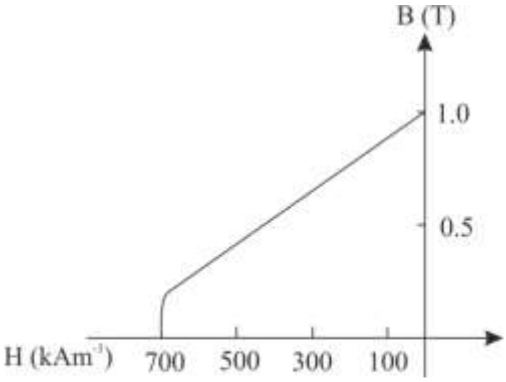

Figure 3 $\boldsymbol{H_{lim}}$ **= 650 kA/m**

a. Use analytical techniques to calculate the flux per pole for the motor. **(5)**

b. If the rotor has a total of 1532 conductors, connected in two parallel paths by the brushes, calculate the speed EMF constant for the motor and the corresponding no-load speed when operating on a 100V dc supply. **(5)**

c. The rotor winding has an effective resistance of 3 Ω, calculate the stall-torque at 100V supply and show whether or not the motor can tolerate starting under these conditions without demagnetizing the magnets. **(5)**

d. What are the major design factors that limit the torque density, and why? **(2)**

e. What are the ideal back-EMF and current waveforms for brushless DC and brushless AC machines? If the waveforms are non-ideal, what are the consequences? **(3)**

4. **a.** Assuming excitation winding carries a peak ac current of $\sqrt{2}I_c$ at a frequency of $\omega = 2\pi f$, derive the general expressions for the airgap field distributions produced in a cylindrical electrical machine by a single-phase winding and a three-phase winding respectively. This machine has p pole pairs, an airgap length L_g and a total number of turns N. **(8)**

b. Describe the main characteristics of the airgap field produced by single-phase winding and three-phase winding. **(4)**

c. List possible ways to minimize the harmonics in airgap field produced by single-phase winding. **(3)**

d. Derive expressions for the corresponding airgap winding inductances for both single-phase and three-phase windings. **(5)**

5. A radial field electrical machine has 12 slots. Figure 4 shows the cross-section of a single stator slot, with relevant dimensions. The equivalent thermal conductivity is λ =0.2 (W/m/K). The lamination active length is L = 50mm in the axial direction. The machine is cooled via convection and radiation to the surrounding air with a temperature T_a = 293 (K). Assuming the resultant radiation and convection coefficient is h = 12 (W/K/m^2).

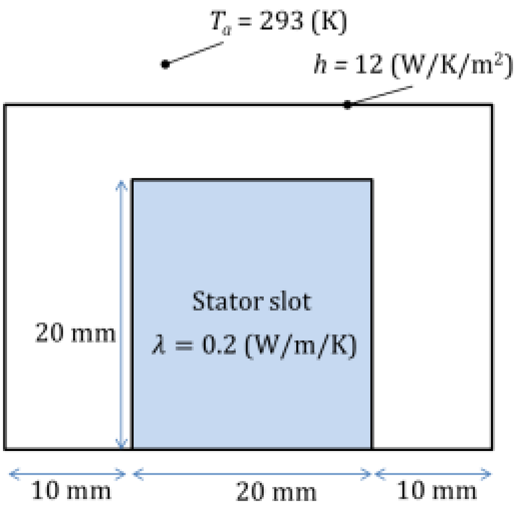

Figure 4

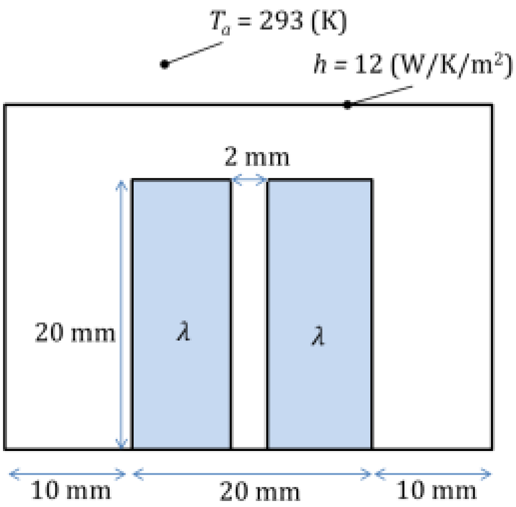

Figure 5

a. Assuming the temperature rise within the lamination is negligible, and there is no iron loss. Estimate the total copper loss which can be dissipated in the 12 slots to give a peak winding temperature rise of 80 K. **(8)**

b. In some electrical machines, 1 auxiliary tooth is added in the middle of each stator slot to separate coils in order to improve fault tolerant capability. Assuming the dimensions and λ are the same as in **5.a**, with the aid of a sketch, describe the main heat flow paths for removal of winding copper loss to the outside surface, and estimate the total copper loss which can be dissipated in the 12 slots to give a peak winding temperature rise of 80 K. **(8)**

c. List possible ways to improve the cooling of electrical machines in order to minimize the peak winding temperature rise. **(4)**

6. Figure 6 shows a top view and a cross-section through a linear actuator which is equipped with NdFeB permanent magnets. The actuator has a single wound coil with the go and return conductors located as shown in Figure 6. The depth of the actuator, as shown, is 40mm. The coil has 430 series turns of circular wire with a diameter of 1mm. The demagnetisation characteristics of the permanent magnet at a series of different magnet temperatures are shown in Figure 7.

a. Calculate the effective coil packing factor **(2)**

b. Estimate from the demagnetisation characteristic a value for the relative recoil permeability of the material at 20°C, taking care to show your calculations. **(2)**

c. Listing any assumptions that you make, calculate the average flux density in the airgap for a permanent magnet temperature of 20°C. **(3)**

d. Listing any assumptions that you make, calculate the force constant of the actuator (i.e. the force per amp).with a permanent magnet temperature of 20°C. **(3)**

e. Calculate the maximum coil current that can flow if irreversible demagnetisation is to be avoided with a permanent magnet temperature 150°C. Calculate the resulting force at this maximum coil current. **(6)**

f. The actuator is driven from a 24V supply and has a coil resistance of 2.5Ω. Neglecting the influence of the electrical time constant (i.e. you may assume that steady state DC current conditions are achieved) calculate the maximum linear velocity at which the actuator can move while producing a force of 50N with a permanent magnet temperature of 150°C. **(4)**

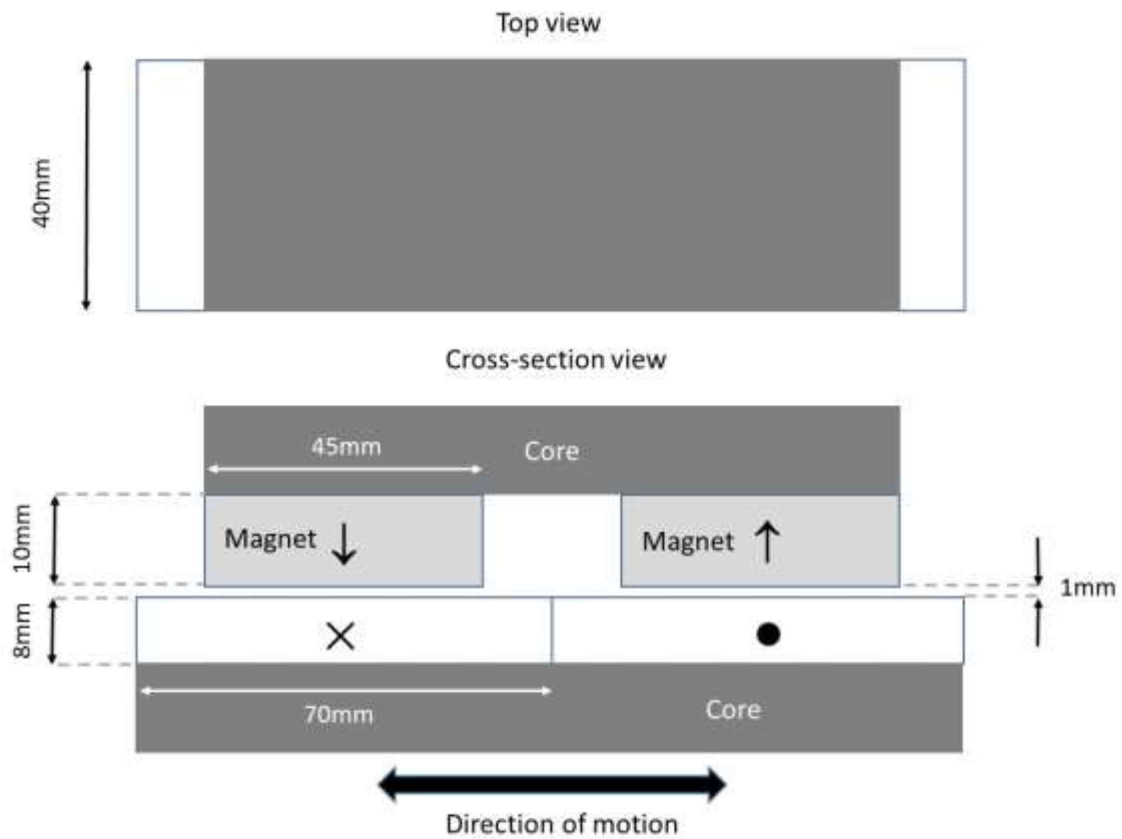

Figure 6 Schematic of linear permanent magnet actuator

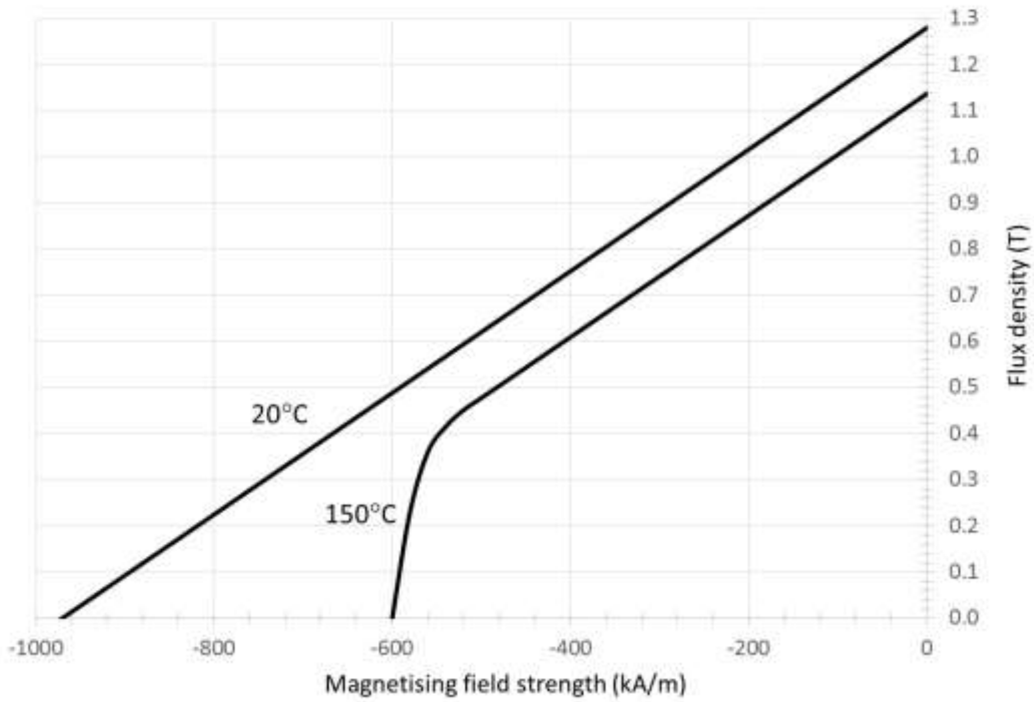

Figure 7 Demagnetisation characteristics of NdFeB permanent magnets

GJL/ZQZ/GWJ/AG