Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (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, 4-pole, 12-slot, surface-mounted permanent magnet machine shown schematically 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. Derive the general expression for airgap flux density on load and on open-circuit **(6)**

b. Calculate the magnetic loading **(3)**

c. Calculate the tooth flux density and comment on the result **(3)**

d. Calculate the back-iron flux density and comment on the result **(3)**

e. Calculate the electric loading if the total ampere turns for the 3-phase windings are NI=5000A **(2)**

f. Calculate the electromagnetic torque at the level of electric loading in part (e) **(3)**

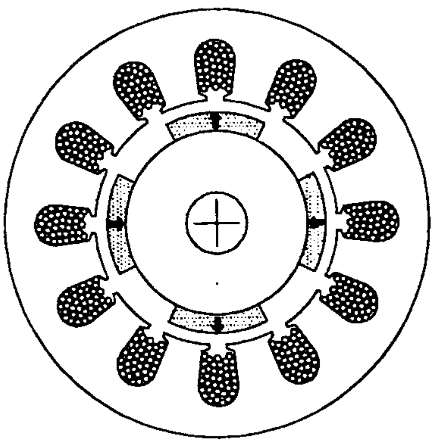

Figure 1

Table 1

Stator outside diameter	D_o	100 mm
Stator inner bore diameter	D_i	60 mm
Airgap length	l_g	1 mm
Magnet thickness	l_m	5 mm
Magnet pole arc	α	120 deg. Elec.
Magnet remanence	B_r	1.2 T
Magnet recoil permeability	μ_r	1
Tooth width	w_t	7 mm
Back-iron thickness	d_c	12 mm
Active axial length	L_a	50 mm

2. **a.** Derive general expressions for the winding pitch-factor, K_p, and the distribution-factor, K_d, for both fundamental and n-th EMF harmonic components. **(6)**

b. Based on the coil vectors, in order to obtain a maximum winding factor, determine the coil connections for a 3-phase, 12-slot, 14-pole permanent magnet machine with double layer, concentrated windings. **(4)**

c. Based on the coil vectors, in order to obtain a maximum winding factor, determine the coil connections for a 3-phase, 12-slot, 14-pole permanent magnet machine with single layer, concentrated windings. **(3)**

d. Explain the main advantages and disadvantages of using single layer winding. **(4)**

e. Explain the main difference between concentrated winding and distributed winding as well as their advantages and disadvantages, respectively. **(3)**

3. A 4-pole permanent magnet DC machine has 15 rotor slots (N_s) and the following dimensions: (the magnets are located adjacent to the airgap)

Rotor outside diameter (D) = 30 mm
Rotor active length (L) = 80 mm
Stator slot area (A_s) = 30 mm^2/slot
Magnet pole arc (α) = 140^o (elec.)
Effective airgap (l_g) = 1.0 mm
Magnet recoil permeability (μ_r) = 1.1

The magnet material has the characteristic shown in the Figure 2.

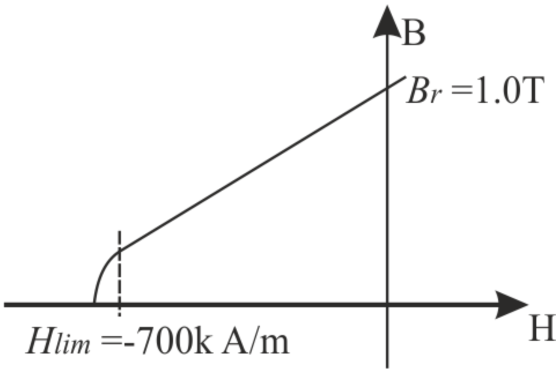

Figure 2

a. If the winding is to be worked at a current density of J = 8 A/mm^2 and the winding has a packing factor of 0.5, calculate the magnet thickness required to get a power output of 600 W at 5000 rpm. **(6)**

b. List the possible ways to improve the open-circuit airgap flux density. **(3)**

c. 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. **(6)**

d. The rotor winding has an effective resistance of 3 Ω, calculate the stall-torque at 100V supply. **(2)**

e. What are main differences between BLDC and BLAC drives? **(3)**

4. **a.** Derive an expression to show that when a single phase winding, which produces a non-sinusoidal MMF space distribution, is excited by a sinusoidal time-varying current, it will develop a resultant air-gap field in which each space harmonic can be considered to produce two counter-rotating fields of equal amplitude and rotating at 1/n times the speed of the fundamental, where n is the harmonic order. **(6)**

b. Explain, without further proof, how the above situation changes when a balanced three-phase winding and supply are used. **(4)**

c. Explain why single phase machines cannot self start but three-phase machines do not have self start problems. **(3)**

d. Figure 3 shows the main winding of a 4-pole, 48-slot, single-phase motor uses a set of three concentric coils for each pole, with graded number of turns of 43, 43 and 36 respectively and spans of 11, 9, and 7 slot pitches respectively. Determine the third-harmonic space MMF of the winding as a percentage of the fundamental space MMF.

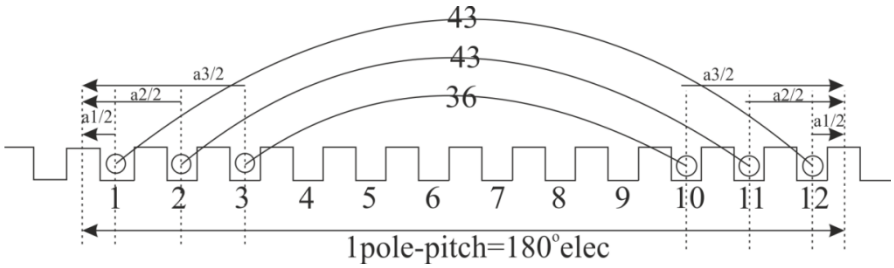

Figure 3 **(5)**

e. List other possible ways to reduce the harmonic contents in the winding MMF. **(2)**

5. Figure 4 shows the cross-section with relevant dimensions of a PM machine with airgap winding. The equivalent thermal conductivities of coils and airgap are λ (W/m/K) and λ_1 (W/m/K). The lamination active length is L in an axial direction. The machine is cooled via convection and radiation to the surrounding air with a temperature T_0 (K). Assume the resultant radiation and convection coefficient is h (W/K/m^2).

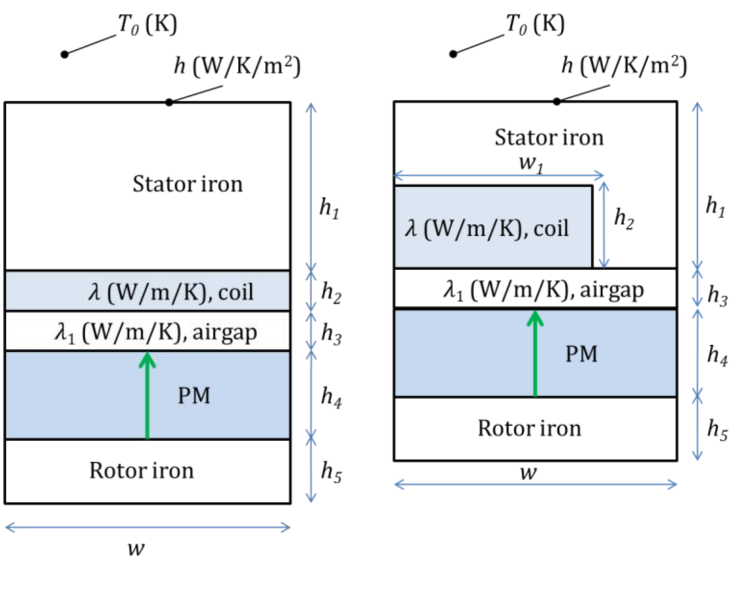

Figure 4 Figure 5

a. List the potential influence of temperature rise within electrical machines on their performance. Explain why accurate thermal models are difficult to achieve. **(4)**

b. With the aid of a sketch, describe the major heat flow path for removal of PM eddy current losses P_e (W) to the outside surface. **(3)**

c. Assume the temperature rises within the lamination and PM (good thermal conductor) are negligible, and there are no iron and copper losses, derive an expression for the maximum temperature within the PM. **(3)**

d. Assume the temperature rises within the lamination and PM (good thermal conductor) are negligible, and there is no iron loss but the copper loss is P_e (W), derive an expression for the maximum temperature within the PM. **(4)**

e. If the machine becomes slotted as shown in Figure 5 with relevant dimensions, redo the question **5.c** and list the main advantages of using a slotted structure over an airgap winding structure. **(4)**

f. List the two possible ways of reducing the temperature rise within coils and PMs of electrical machines. **(2)**

6. Figure 6 shows a cross-section through a slotted, bi-directional, linear permanent magnet actuator. The actuator has an axial length of 40mm (equivalent to the depth into the plane of the paper for the cross-section of Figure 6). The coil is a simple single-phase coil consisting of 100 series turns and has a resistance of 0.1Ω.

The permanent magnet material used in the actuator has a remanence of 1.23T at 20°C, a relative recoil permeability of 1.04 and a negative temperature coefficient of remanence of -0.3% per °C). The stator and armature core material starts to saturate significantly at a flux density of 1.8T.

[$\mu_0=4\pi\times10^{-7}$ Hm^{-1}]

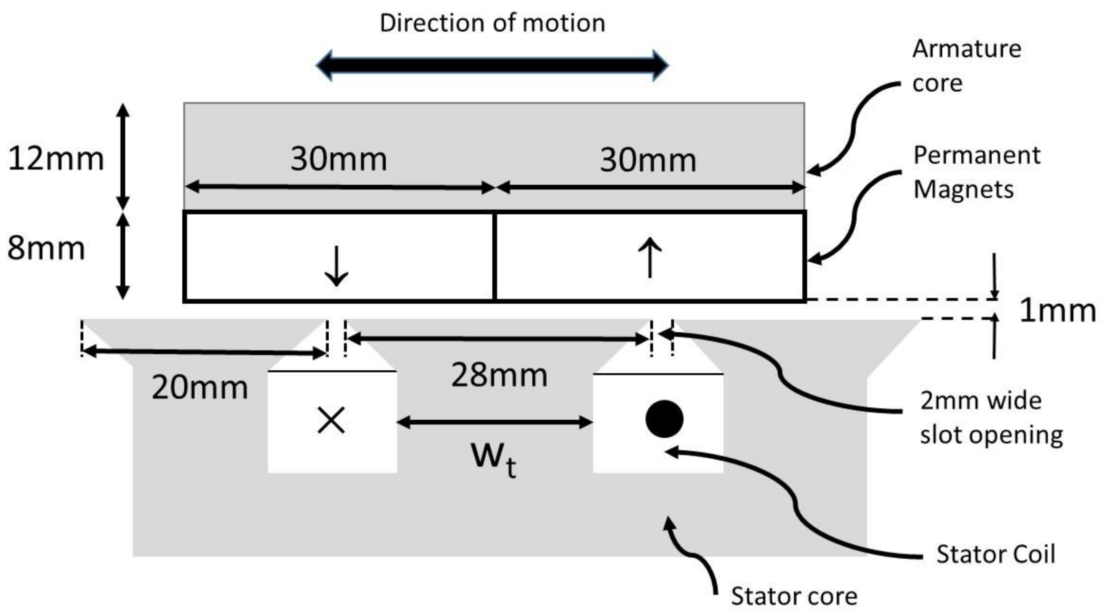

Figure 6. Cross-section through a linear actuator

a. Listing any assumptions that you make, calculate the airgap flux density at 20°C in the region of the airgap above the stator teeth. **(2)**

b. If the stroke of the actuator is ±6mm from the central position shown, select an appropriate values for w_t, taking care to explain your reasoning (Figure 6. is a schematic and not drawn to scale). **(3)**

c. Calculate the magnitude of the force produced by the actuator at 20°C when the armature is in the central position shown and the coil carries a current of 5A. **(4)**

d. Calculate the magnitude of the back-emf when the armature is moving at 3m/s **(3)**

e. During continuous operation, the temperature of the magnet rises to 80°C. Calculate the increase in the coil copper loss which occurs when the actuator is producing the same force at calculated in part (c). **(3)**

f. If the density of the magnet and armature core are both 8000 kg/m^3, calculate the acceleration of the armature from the central position with a current of 25A **(3)**

g. What check would need to be performed during the design to ensure that the operating condition in part (f) is safe for the actuator, even if this current is only present for a few milliseconds, and explain briefly the procedure followed. **(2)**

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