The University Of Sheffield.

Data Provided: 1 sheet of linear-linear graph paper for Q4.

Figure 3, Figure 4.1 and Figure 4.2 (all included in the body of the examination paper)

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2013-14 (2.0 hours)

EEE6120 Modelling of Machines

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.** Draw the Kron primitive equivalent of a series universal motor and derive voltage equations for steady-state operation on:

(i) DC supply

(ii) Sinusoidal AC supply. **(4)**

b. Draw a typical phasor diagram for operation on an AC supply, taking care to define any symbols used. **(2)**

c. A power tool is equipped with a series universal machine which is connected to a 230Vrms 50Hz AC sinusoidal mains supply. When operating at 20,000rpm, it draws a current of 9.52Arms at a power factor of 0.70 lagging and produces a mechanical output power of 840W. By appropriate use of the phasor diagram in part (b) calculate the following:

i) The impedance of the machine

ii) The copper loss at this operating point.

iii) The efficiency at this operating point, listing any assumptions that you make.

iv) The starting torque produced by the machine at standstill. **(8)**

d. The universal machine in part(c) is now connected to a DC voltage supply. Calculate the following:

i) The magnitude of the DC voltage which must be applied to produce the same mechanical output power of 840W at 20,000rpm.

ii) The starting torque if this DC voltage was applied. **(4)**

e. Comment on why the starting torque on the DC voltage calculated in part (d) is unlikely to be realised in practice. **(2)**

2. **a.** A four-pole single-phase induction motor is connected to a 230Vrms, 50Hz sinusoidal AC supply and is running at a constant speed of 1305rpm. It has the following equivalent circuit parameters (all rotor values are already referred to the stator):

Magnetising reactance X_m: j300Ω

Stator resistance: 11Ω

Rotor resistance: 45Ω

Stator leakage reactance: j10Ω

Rotor leakage reactance: j10Ω

Draw an equivalent circuit for this machine, taking care to include numerical values for all circuit elements. **(3)**

b. For this operating condition, calculate the following:

i) The input current.

ii) The mechanical torque produced by the motor.

iii) The copper loss produced by the motor.

iv) The efficiency of the motor. **(10)**

c. Briefly describe with the aid of appropriate diagrams, why single phase induction motors do not produce any starting torque in their most basic configuration. **(3)**

d Describe **<u>one</u>** method which can be employed to produce starting torque in a single-phase induction motor. Include in your answer an explanation of the function of any additional components and a ***sketch*** of a representative torque speed curve, taking care to label any key features. **(4)**

3. A low-speed, three-phase switched reluctance machine has 12 stator teeth and 8 rotor teeth. The 4 coils which make up a phase are series connected. Figure 3 shows the measured variation in the flux-linkage of one phase with coil current at a series of discrete rotor angular displacements which correspond to the stroke during which the phase is normally excited to produce torque. The curves are equally spaced in terms of angular displacement intervals.

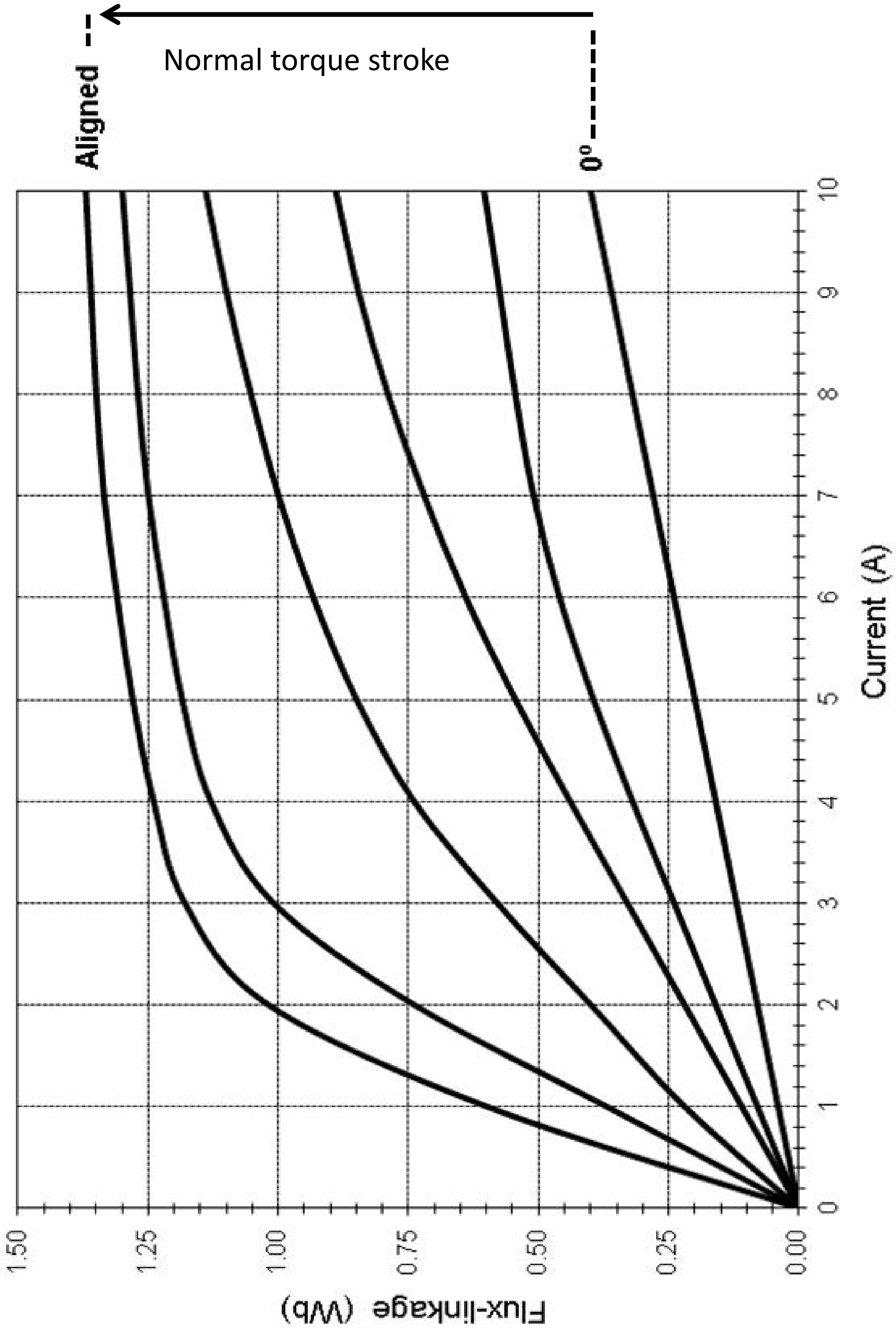

Figure 3 Measured flux-linkage versus current characteristic for a 3-phase, 12-8 switched reluctance machine

a. Calculate the following:

i) The number of torque strokes per mechanical revolution.

ii) The angular displacement which corresponds to a normal torque stroke.

iii) The average total torque produced by the machine at a current of 5A. **(8)**

b. The stator and rotor cores are manufactured from Silicon Iron. The radial airgap between the stator and rotor in the fully aligned position is 0.5mm. Listing any assumptions that you make, estimate the number of turns on each coil. ($\mu_0=4\pi\times10^{-7}$ Hm^{-1}). **(3)**

c. The machine is rotating at a fixed speed of 200rpm. Calculate the maximum value of induced emf in the stator coil if the current is a constant 5A during the entire stroke (you **do not** need to plot the variation in flux-linkage versus rotor angular displacement unless you wish to do so to calculate the emf). **(3)**

d. The machine is driven from a 200V DC supply. At the start of the stroke, the full 200V is applied to the 4 series connected coils which make up a phase. Calculate the time taken for the current to rise to 5A when the machine is at standstill. **(3)**

e. Assuming that coil resistance is negligible, sketch typical dynamic flux-linkage versus current characteristics for:

i) The period up to commutation.

ii) The period following commutation.

In each case, identify and label the main components of energy. **(3)**

4. a. Figure 4.1 shows a schematic of a single-phase, 2-pole brushless permanent magnet motor. The machine is driven from a power electronic converter. The rotor consists of a 2-pole magnet ring which is mounted on a cylindrical Silicon Iron core. The airgap between the outer surface of the magnet ring and the stator core is 0.5mm.

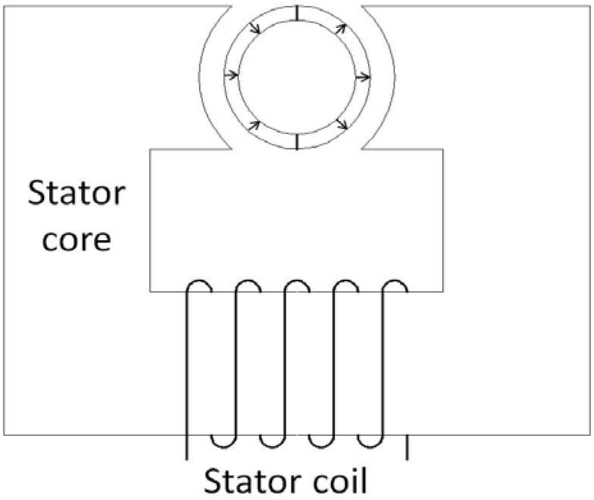

Figure 4.1 – Schematic of a single-phase permanent magnet brushless machine (shown at an angular displacement of 90°)

Under normal operating conditions, the motor is driven by a simple power electronic converter that produces a 180° (elec) wide square-wave current waveform of alternating polarity. The measured variation in the coil flux-linkage with rotor angular displacement for a series of different DC currents is shown in Figure 4.2. In each case, a constant DC current was applied for all rotor angular displacements from -90° to +90°.

a) By plotting appropriate flux-linkage versus current characteristics on the graph paper provided, calculate the average mechanical output torque over an angular excursion from -90° to +90° at a constant current of 1.0A. **(7)**

b) Calculate the peak value of open-circuit induced emf when the machine is rotating at 6000rpm. **(3)**

c) Assuming that the Silicon Iron stator core begins to magnetically saturate at a flux density of 1.5T. Estimate the thickness of the magnet in the direction of its magnetisation (i.e. the radial wall thickness of the ring) if the magnet has a remanence (B_r) of 1.25T and a relative recoil permeability (μ_r) of 1.05. You may neglect any curvature effects in the magnet. **(6)**

d) Estimate the number of turns on the coil. ($\mu_0=4\pi\times10^{-7}$ Hm^{-1}). **(4)**

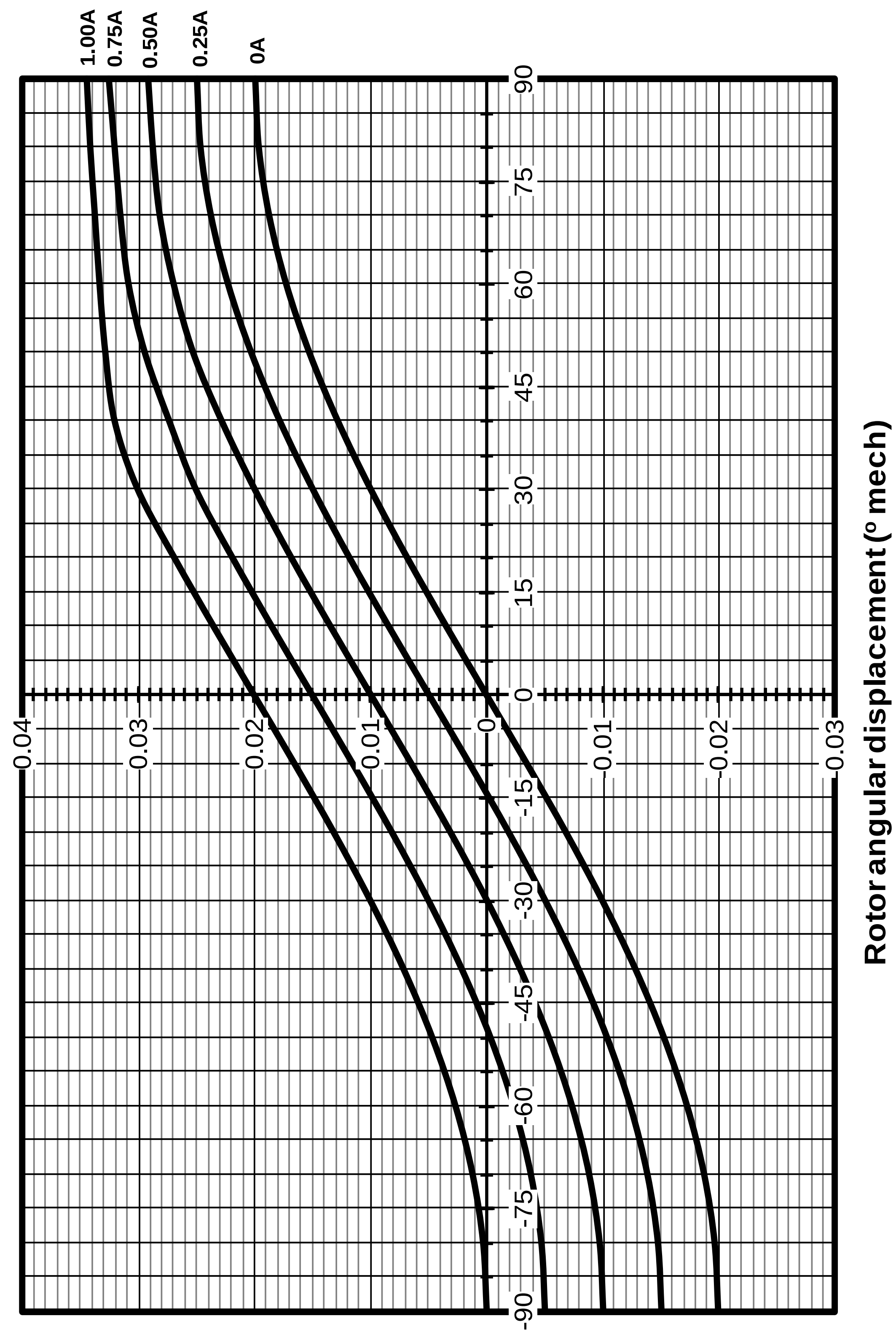

Figure 2 – Measured variation of coil flux-linkage with rotor angular displacement for

the motor of Figure 4.1

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