Data Provided: Linear-linear graph paper

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2008-2009 (2 hours)

Modelling of Electrical Machines 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.** Draw the Kron primitive equivalent of a series universal motor, and derive voltage equations for steady-state operation on (i) a DC supply and (ii) a sinusoidal AC supply. **(3)**

b. Draw a typical phasor diagram for operation on an AC supply, taking care to define any symbols used. **(1)**

c. A domestic washing machine is equipped with a series universal machine. The machine is connected to a 230V rms 50Hz AC sinusoidal mains supply. When operating at its maximum speed of 17,000rpm, the series universal machine draws an rms current of 7.2A at a power factor of 0.78 lagging. If the mechanical output torque of the machine is 0.65 Nm at this 17,000rpm operating point, calculate the total resistance and reactance of the machine and the copper loss at this operating point. **(6)**

d. Calculate the starting torque of this series universal machine when connected to a 230V rms 50Hz AC sinusoidal mains supply. **(2)**

e. In order to improve the performance of the machine, the machine manufacturer is proposing to add a series connected conductive compensating coil to the universal machine. Draw the Kron primitive equivalent of this conductively compensated Kron primitive machine and its phasor diagram for the case in which the criteria for full compensation are satisfied. **(3)**

f. If the self inductance of the field coil is 44×10^{-3}H and the resistance of the compensating coil is 0.8Ω, calculate the power factor of this fully compensated machine at 17,000rpm and the mechanical output torque at this operating point. **(5)**

2. **a.** Starting from the Kron primitive equivalent of a non-salient three-phase, squirrel cage induction motor, derive the voltage equations and a corresponding exact equivalent circuit for steady-state operation with a sinusoidal AC supply. **(9)**

b. A large industrial paint-mixer is driven from a two-pole, star-connected, three phase induction motor. The motor exhibits no saliency and is connected to a

415V(rms line to line voltage) 50Hz three-phase mains supply. The motor has the following per-phase equivalent circuit parameters:

Stator resistance= 0.16Ω

Stator leakage reactance = 0.26 Ω

Referred rotor leakage reactance = 0.24Ω

The motor draws a magnetising current of 15.0∠-90° A on no-load. This magnetising current is small in comparison with the total input current drawn at rated load.

At the start of the mixing process, the paint mix is very thick and a torque of 101.5 Nm is required to mix the paint. Under this condition, the speed of the motor is 2850rpm and the magnitude of the input current is 46.1A. Calculate the magnetising reactance of the motor and the referred rotor resistance. **(3)**

c. At the end of the mixing process the paint has become easier to mix and the speed of the motor increases to 2910 rpm. Using the per phase equivalent circuit for the induction motor, calculate the following for the end of mix conditions:

i) Phase current drawn

ii) Power factor of the motor at this operating condition

iii) The torque produced by the motor at this operating point

iv) The efficiency at this operating point (list any assumptions) **(8)**

3. A 3-phase switched reluctance (SR) machine has 18 stator teeth and 12 rotor teeth. Each phase consists of 6 series connected coils. Each individual coil is equipped with 52 series turns. Figure 3 shows the measured variation in the flux-linkage of one phase with current at a series of discrete rotor angular displacements which correspond to the normal stroke during which the phase is normally excited to produce torque (Note: An angular displacement of 10° on the scale used in Figure 3 corresponds to the rotor being fully-aligned with stator teeth of the phase).

a. Calculate the average torque produced by the machine over the 10° angular excursion to the aligned position for currents of 30A and 50A. **(6)**

b. Using the measured flux-linkage versus current characteristic in the aligned position, estimate the length of the radial airgap between the rotor and stator if the stator and rotor core material begin to saturate at ~1.5T. **(3)**

c. The SR machine forms part of a system which has sufficient moment of inertia to ensure that the rotational speed of the SR machine can be assumed to be constant despite the pulsed nature of the torque it produces. The SR machine is running at a constant rotational speed of 300rpm. Calculate the induced emf in one phase of winding at a rotor angular displacement of 5° and a phase current of 60A. **(4)**

d. Calculate the maximum value of absolute phase self-inductance, taking care to define the rotor angle and current at which you calculate this maximum value. **(3)**

e. ***Sketch*** two dynamic flux-linkage versus current trajectories for this SR machine operating from a constant voltage source in motoring mode (one for the interval up to the point of commutation and another for interval following commutation). Label the various energy changes which occur and list the factors which influence the shape of the trajectories. **(4)**

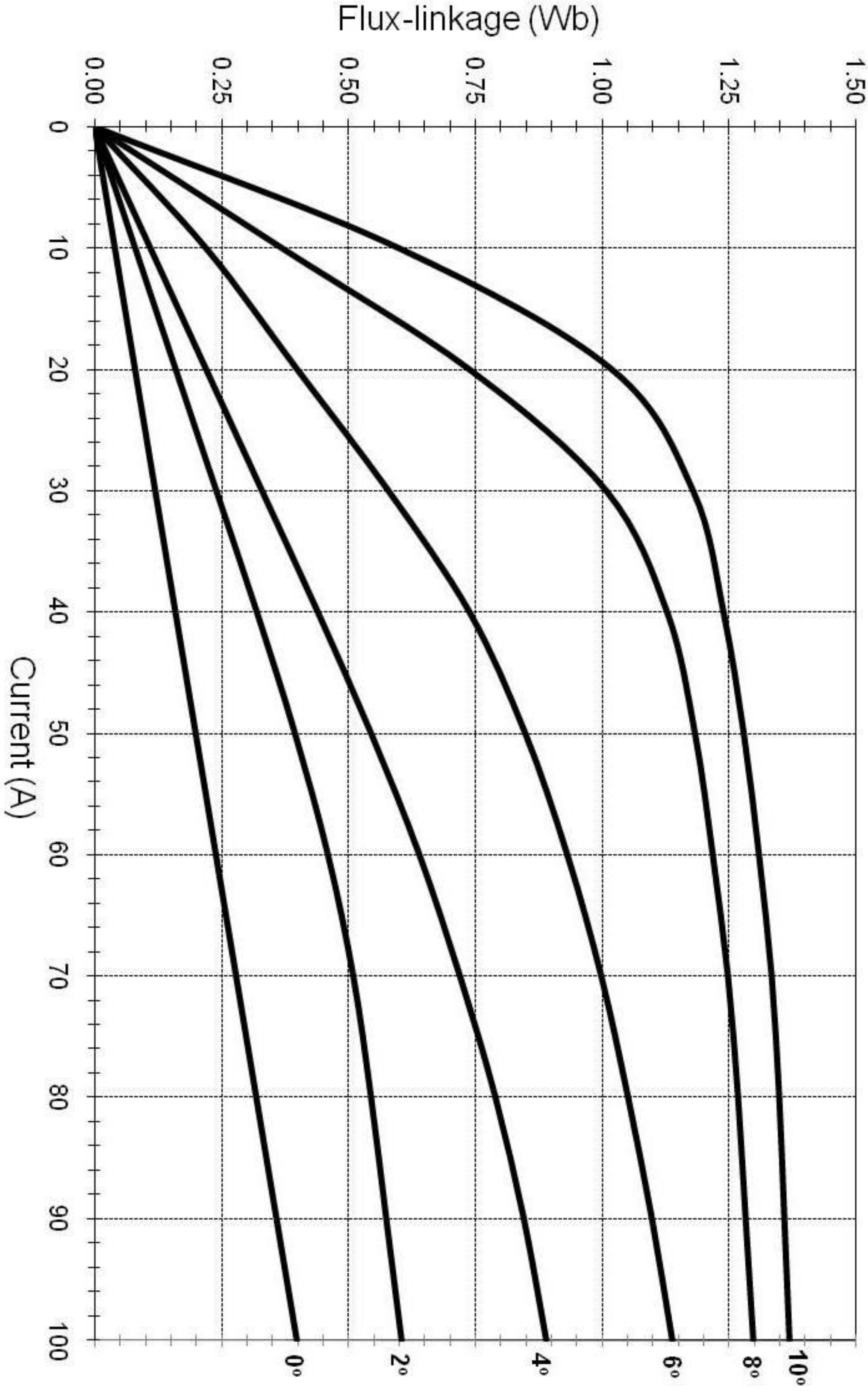

Figure 3 Measured flux-linkage versus current characteristic for one phase of a 3-phase machine with 18 stator teeth and 12 rotor teeth (Note the fully-unaligned to aligned excursion would be 15° mechanical for this machine)

4. Figure 4(a) shows a schematic of a low-cost, single-phase, two-pole brushless permanent magnet motor. The machine is driven from a battery supply via a power electronic converter. The rotor consists of a two-pole magnet ring with a wall thickness of 2mm which is mounted on a cylindrical Silicon Iron core. The stator consists of a single 4000 turn coil which is wound on a Silicon Iron laminated core.

Under normal operating conditions, the motor is driven by a power electronic converter that produces a 180° (elec) wide square-wave currents 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(b).

a. Calculate the peak value of the open-circuit back-emf at 3200rpm. **(4)**

b. Given that the Silicon Iron cores begins to magnetically saturate at a flux density of 1.6T, estimate the length of the airgap between the rotor and stator (You may assume that the permanent magnet has a relative permeability of 1.0). **(5)**

c. By plotting the appropriate flux-linkage versus current characteristics, calculate the average torque produced by the motor for currents of 0.25A and 1.0A. **(7)**

d. The motor manufacturer is considering modifying the power electronic converter such that the width of each pulse is reduced from 180° (elec) to a 120° (elec) wide pulse which is symmetrical about 0° (as defined in Figure 4b). Calculate the torque that would be produced by this new converter at 0.25A. **(4)**

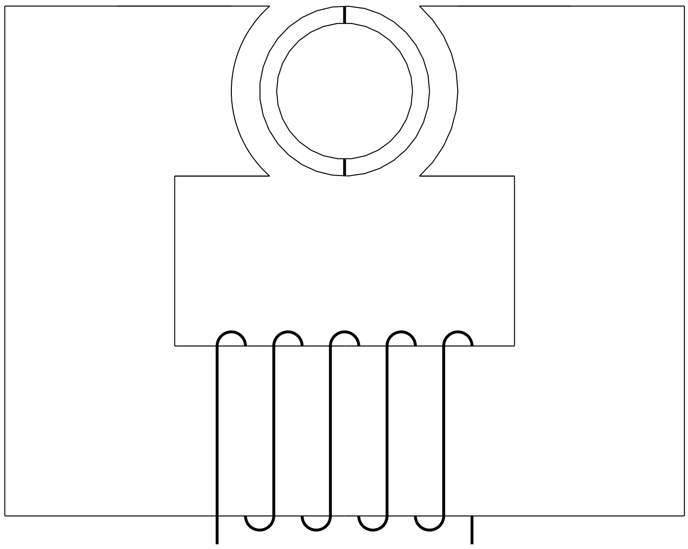

Figure 4a – Schematic of a single-phase permanent magnet brushless machine

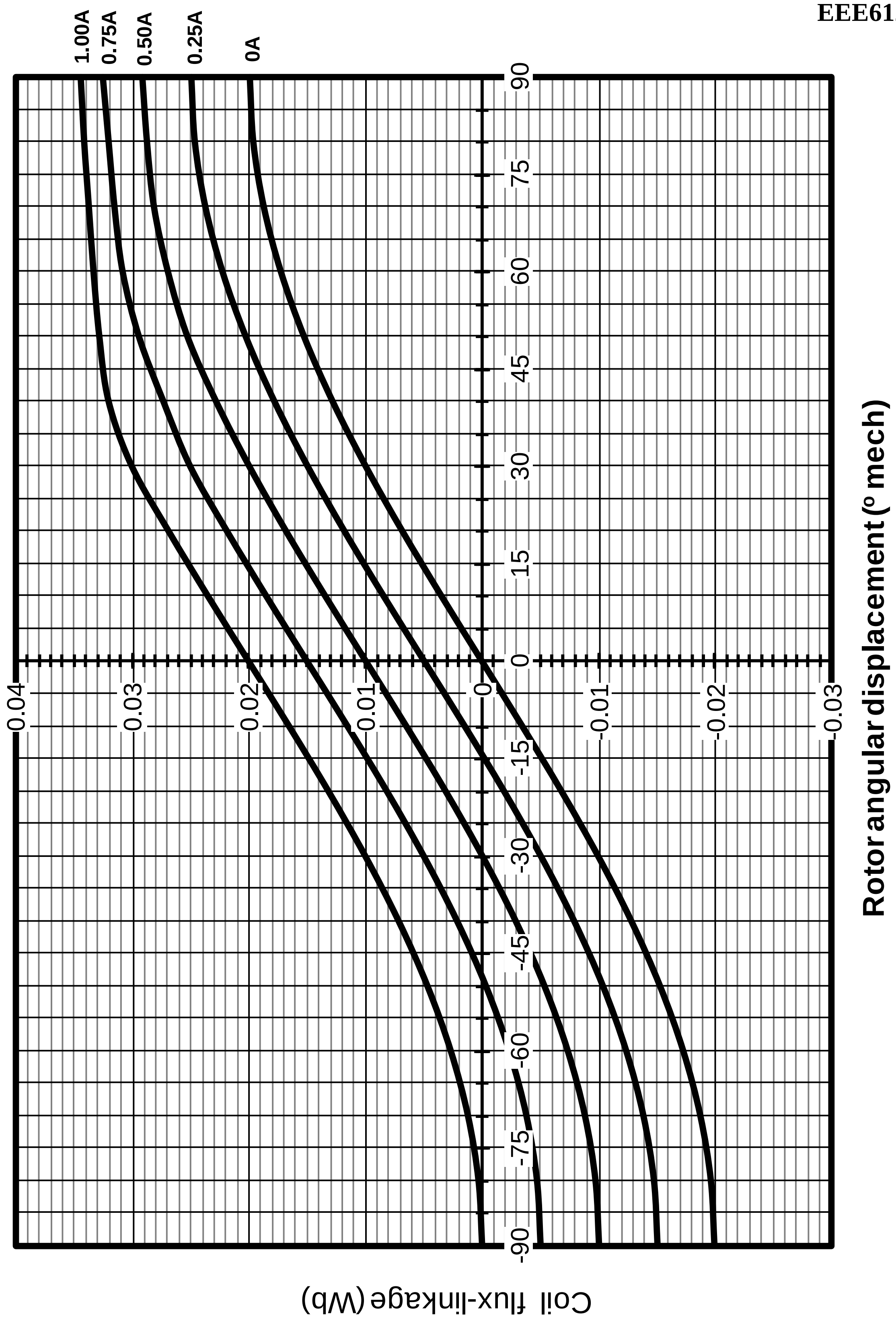

Figure 4b – Measured variation in coil flux-linkage with rotor angular dispalcement for the motor of Figure 4a

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