Data Provided: Linear-linear graph paper for Q4

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2012-13 (2.0 hours)

EEE6120 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 general form of the unconnected Kron primitive machine, labelling all currents and coil voltages according to the accepted conventions. Derive the general form of the voltage matrix equations, leaving all rotational terms in the appropriate G coefficients. **(3)**

b. A 2-pole, uncompensated, series universal motor produces a torque of 0.18Nm at a speed of 12,000 rpm when drawing 1.30A from a 240V DC supply. Calculate the total resistance of the machine, the copper loss in the windings and the efficiency at this operating point. **(4)**

c. The same universal motor is connected to a 240Vrms sinusoidal AC 50Hz supply. For the same output torque of 0.18Nm, the machine operates with a power factor of 0.76 lagging. Calculate the speed in rpm at this operating point and the efficiency. **(5)**

In order to improve the performance of the universal motor on the same 240Vrms AC supply, the manufacturer proposes to include an inductively coupled compensating winding on the q-axis. The armature and field coils in this compensated motor have equal reactance and remain unchanged from the original uncompensated design.

d. ***Sketch*** a phasor diagram for the uncompensated and compensated machines. **(3)**

e. Listing any assumptions that you make, calculate the power factor, rotational speed in rpm and the efficiency of the compensated machine when it is producing 0.18Nm on a 240Vrms AC 50Hz supply. **(5)**

2. **a)** Draw the Kron primitive equivalent of a non-salient, three-phase, induction motor taking care to label each individual coil voltage and current according to normal conventions. **(3)**

b) Starting from the Kron primitive, calculate in a single step the 4×4 matrix that relates the voltage in each coil to the currents in each coil. You may leave time derivative terms in the 'p' notation and there is no need to simplify or group together the various coupling terms in the matrix. **(3)**

c) An industrial air-conditioning compressor is driven by a four-pole, non-salient, star-connected three phase induction motor which is connected to a 400V(rms line to line voltage) 50Hz sinusoidal AC supply. The induction motor has the following per-phase equivalent circuit parameters:

Stator resistance= 0.2Ω

Referred rotor resistance = 0.1Ω

Stator leakage reactance = 0.5Ω

Referred rotor leakage reactance = 0.2Ω

Magnetising reactance = 20Ω

Calculate the following when the motor is running at its rated speed of 1462rpm, noting any assumptions that you make:

i) Magnitude of the input phase current.

ii) Power factor of the motor.

iii) The electromagnetic torque produced by the motor

iv) The total motor copper loss. **(8)**

d) In order to represent the iron loss in the motor, a resistor is added into the equivalent circuit in parallel with the magnetising reactance. The value of this resistor is chosen to dissipate the corresponding real power to the iron loss. During initial commissioning, the machine is tested on no-load at full rated voltage and draws a per phase current of $12.1\angle{-72.6°}$Arms.

Calculate the value of the iron loss resistor in the equivalent circuit and hence the no-load iron loss (you may assume that the no-load current is small in comparison to the on-load current). **(4)**

e) Assuming that the iron loss calculated at no-load is a reasonable representation of the on-load iron loss, calculate the efficiency of the machine when it is operating at 1462 rpm. **(2)**

3. A 3-phase switched reluctance machine has 6 stator teeth and 4 rotor teeth. Each phase consists of two series connected coils.

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 30° on the scale of Figure 3 corresponds to the rotor being fully-aligned with stator teeth of the phase).

a. Calculate the average torques produced by the machine over the 30° angular excursion to the aligned position for currents of 5A and 10A. **(6)**

b. Each coil in the stator has 120 turns. Estimate the length of the airgap between the rotor and stator in the aligned position if the stator and rotor core material begin to saturate at ~1.5T. (Constant required: $\mu_0 = 4\pi\times10^{-7}$ Hm^{-1}) **(4)**

c. Estimate the instantaneous induced emf in one phase of the machine at a rotor angular displacement which is mid-way through the normal stroke when the rotor is rotating at 4000rpm and the phase current is 17.5A (You do **not** need to plot a flux-linkage versus rotor angular displacement characteristic in answering this question) **(4)**

d. In order to enhance the torque capability of the machine, the manufacturer proposes to decrease the airgap to half the value of the original design. Listing any assumptions that you make, estimate the torque that would be achieved at 2A with this new design. **(6)**

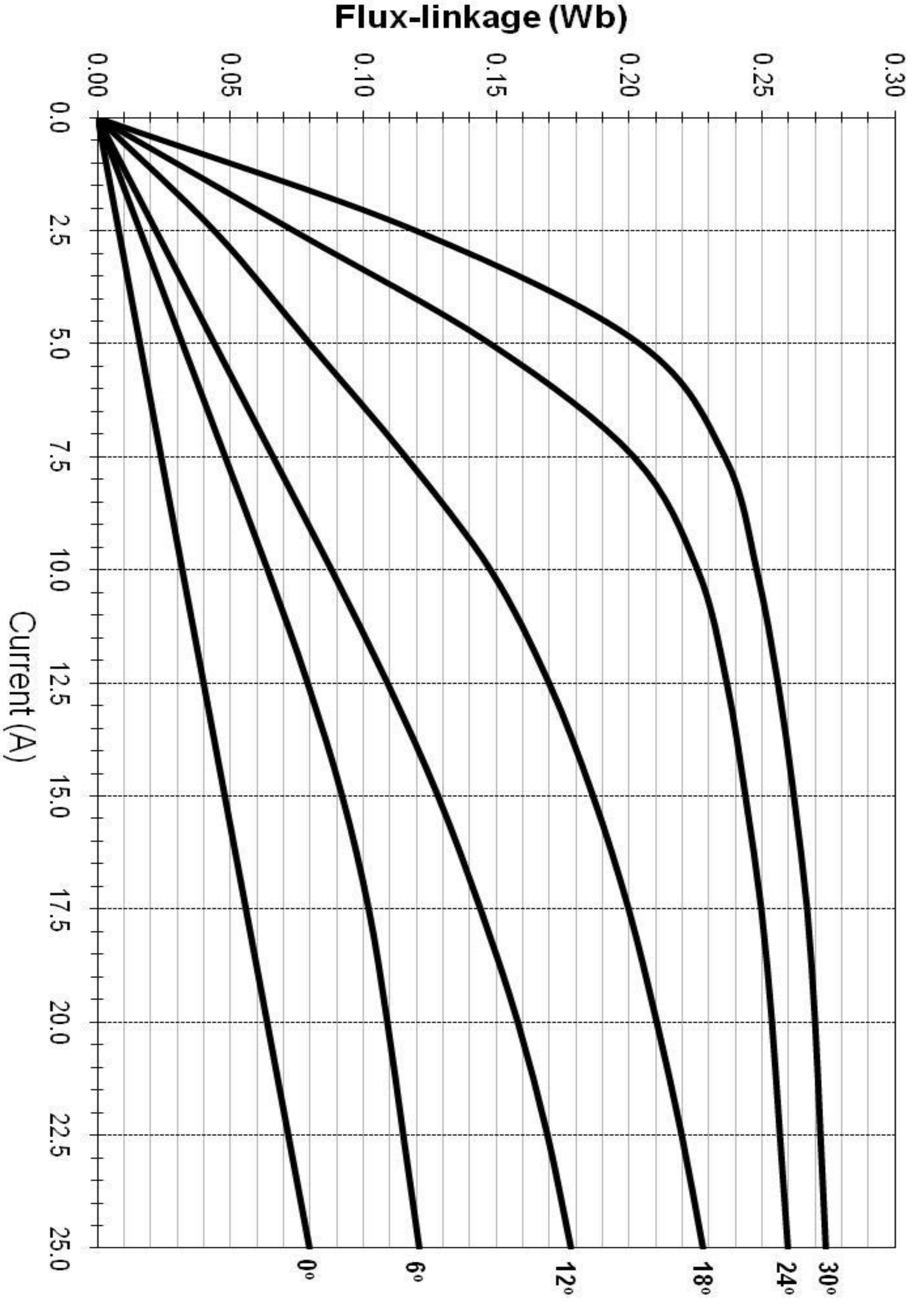

Figure 3 Measured flux-linkage versus current characteristics for one phase of a three-phase switched reluctance machine with 6 stator teeth and 4 rotor teeth

4. Figure 4 shows the measured variation of flux-linkage with rotor angular displacement of one phase of a non-salient, three-phase permanent magnet brushless machine for various levels of DC current between 0A and 150A (in each case the DC current was present over the full excursion of angular displacement). This machine has 12 stator teeth and 8 rotor poles. The machine is normally operated in brushless DC mode.

a. Calculate the magnitude of the 'flat top' region of the nominally trapezoidal open-circuit induced emf in one phase of the machine at 6000rpm. **(3)**

b. The machine is operated in brushless DC mode with 120° (electrical angle) six-step square wave currents. By plotting appropriate Ψ-i curves on the graph paper provided, estimate the average torque produced by the entire machine for phase currents having flat-top values of 50A and 150A, noting any interesting behaviour in terms of their relative magnitudes. **(8)**

c. Calculate the absolute phase inductance of the machine at rotor angular displacements of 0^o and 22.5^o and currents of 50A and 150A (i.e. four values of absolute inductance in total) and comment on any differences between the calculated inductances **(3)**

d. The airgap in this machine is 1.0mm and each magnet pole has a radial thickness of 5mm (i.e. the magnet length in the direction of magnetisation). You may assume that the relative permeability of the magnet is 1.0. The core is manufactured from Silicon Iron.

By adopting an appropriate value of flux density at which the Silicon Iron core begins to saturate, calculate the number of effective number of turns per phase. (Constant required: $\mu_0 = 4\pi\times10^{-7}$ Hm^{-1}) **(6)**

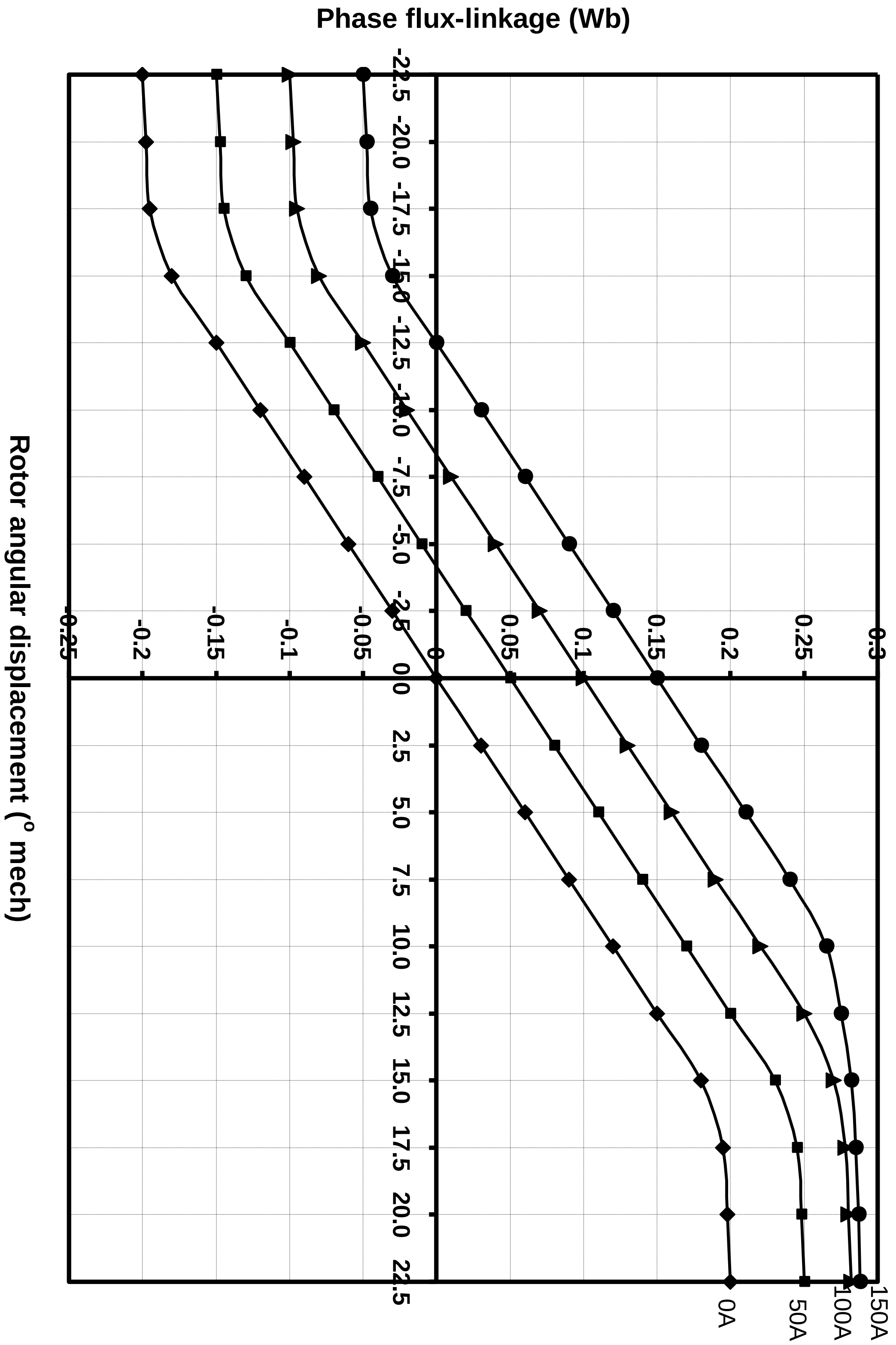

Figure 4 Measured variation of flux-linkage with rotor angular displacement of one phase of a non-salient, three-phase permanent magnet brushless machine

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