Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2009-2010 (2 hours)

Modelling of Electrical Machines 4

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. A hand-held electric drill consists of a 2-pole series connected universal motor. Draw the Kron primitive equivalent of this series universal motor and derive voltage equations for its steady-state operation when connected to (i) DC voltage supply and (ii) a sinusoidal AC voltage supply. **(4)**

b. This 2-pole series universal motor has a total self inductance measured at the terminals of 0.14H and a total resistance measured at the terminals of 12Ω. When connected to a 200V DC voltage supply, the motor rotates at 15,650rpm, drawing an input power of 600W. The same machine is then connected to a 230V (rms), 50Hz sinusoidal AC supply and provides the same torque during drilling as that produced on the 200V DC supply.

Listing any assumptions that you make, calculate the following:

The mechanical output torque produced by the machine when connected to the DC supply and rotating at 15,650rpm.

The rotational speed achieved when connected to the AC supply

The power factor of the motor when connected to the AC supply

The ratio of the starting torques produced on the DC and the AC supplies **(9)**

c. The company that manufacturers the drill is considering adding an additional inductively coupled compensation coil into the stator in order to improve performance. This inductively compensated machine is connected to the same 230V (rms), 50Hz sinusoidal AC supply and provides the same torque to the mechanical load as that produced on the 200V DC supply at 15,650rpm.

Assuming that the q-axis rotor coil and the d-axis stator coil have the same self inductance of 0.07H and that ideal compensation is achieved, calculate the speed at which the inductively compensated motor rotates and its power factor at this operating point. **(5)**

2. **a.** Draw the Kron primitive equivalent of a single-phase induction motor, labelling all currents and voltages according to the accepted conventions. **(2)**

b. Starting from this Kron primitive equivalent of a single-phase induction motor, derive the steady-state terminal voltage equations and hence an equivalent circuit for operation with a sinusoidal AC supply. **(10)**

c. Describe briefly, including a sketch of typical torque-speed curves, the reasons why a basic single-phase induction motor does not produce any useful starting torque. **(2)**

d Describe 3 methods which are employed to start practical single-phase induction motors. For each of the 3 methods, draw a schematic of the physical arrangement, briefly describe the purpose of additional components and sketch a representative torque speed curve showing taking care to highlight key features. **(6)**

3. Figure 3.1 shows a schematic cross-section of normal force linear reluctance actuator from an electromagnetically actuated lock which has a total stroke of 4mm. The stator consists of C-shaped iron core which is equipped with a single coil. The moving armature is a simple rectangular iron core which is mechanically constrained such that it only moves in the direction indicated in Figure 3.1. When there is zero current in the stator coil an external mechanical spring (not shown) forces the actuator to the 'open' position shown in Figure 3.1(a). At this open position, the separation between the armature and stator poles in the direction of motion is 4mm. When current is passed through the coil, the armature is attracted towards the stator until it reaches the 'closed' position. In this closed position it can reasonably assumed that the separation between the armature and the stator in the direction of motion is zero.

Figure 3.1(b) shows a series of measured flux-linkage versus current characteristics between the fully open and fully closed position, including intermediate curves for stator to armature separations of 3mm,2mm and 1mm.

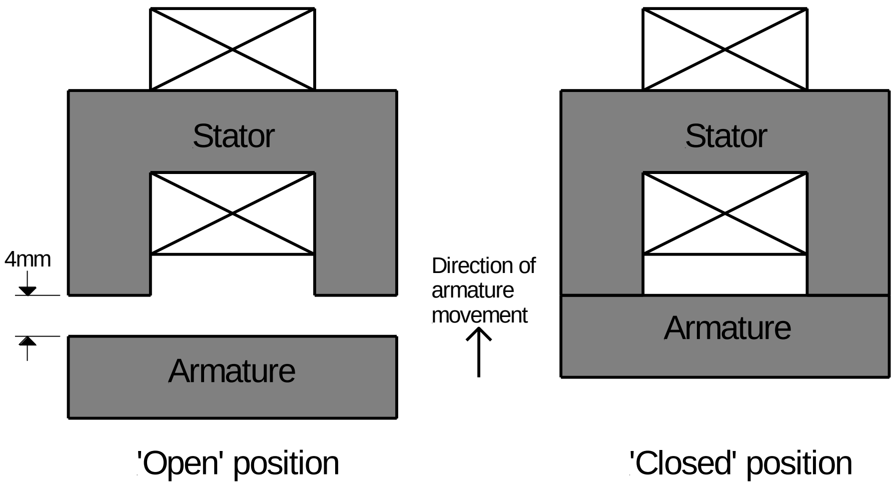

Figure 3.1 – Schematic of linear actuator

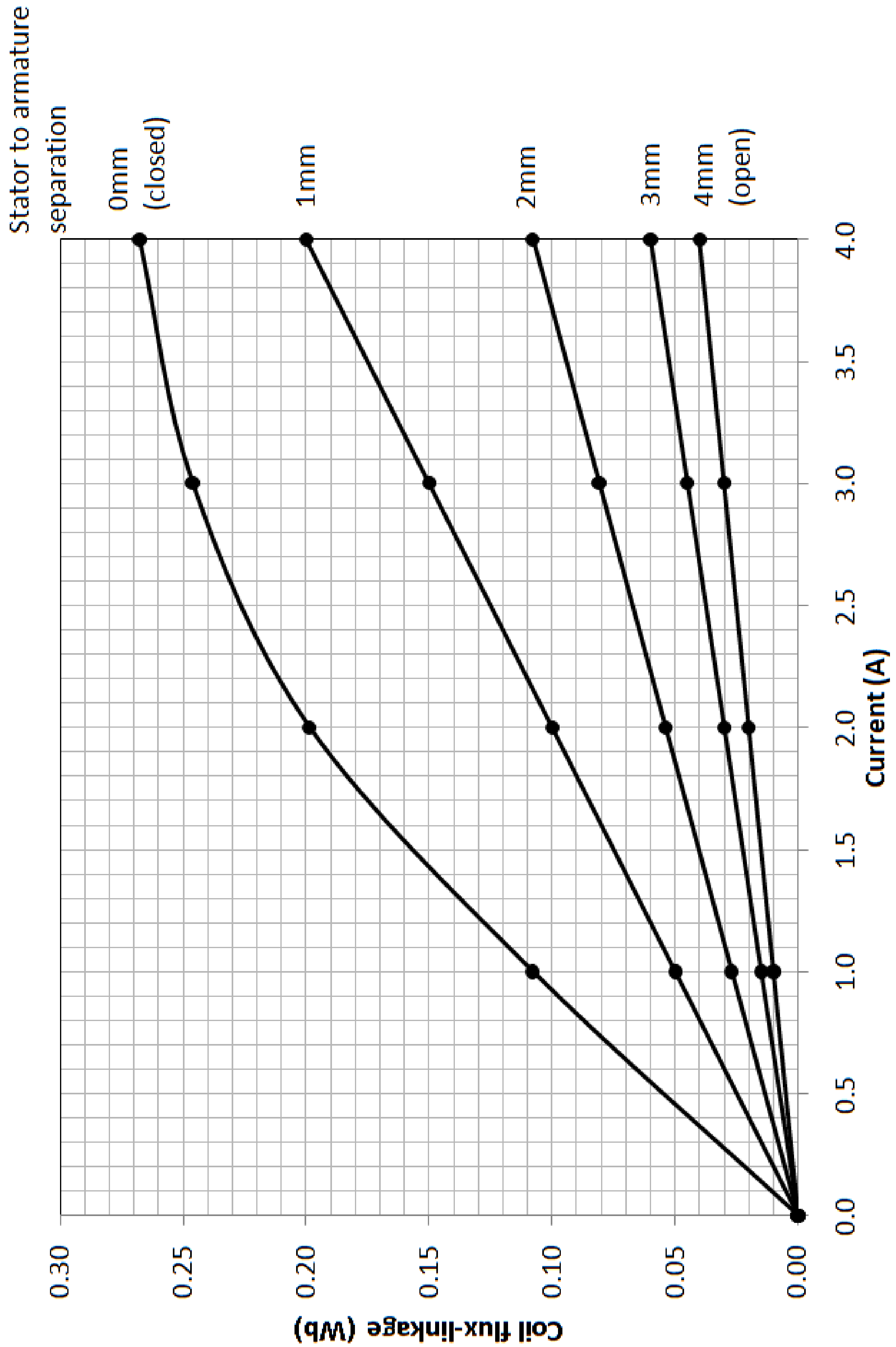

Figure 3.2. Measured flux-linkage versus current characteristic for a range of armature to stator separations

a. Using the flux-linkage characteristics of Figure 3.2 plot (on the graph paper supplied) the variation in actuator force as a function of the seperation between armature and stator for the particular case of a coil current of 3A. **(10)**

b. Comment on the shape of the force versus seperation characteristic plotted in part 3a, with particular emphasis on whether it is what you would expect from idealised magnetic ricuit analysis and the role of magnetic saturation. **(4)**

c. Plot (on a separate piece of graph paper from that used in part 3a) the variation in flux-linkage with airgap for a current of 4A and hence estimate the maximum induced voltage in the coil if the armature is moving at a constant linear velocity of 0.6m/s over the full stroke. **(6)**

4. Figure 4 shows the measured variation of flux-linkage of one phase of a non-salient, three-phase permanent magnet brushless machine for various levels of current between 0A and 100A. This machine has 6 stator teeth and 4 rotor poles.

a. Calculate the phase inductance of the machine at rotor angles of 0^o and 45^o and currents of 25A and 100A (i.e. four values of inductance in total) and comment on any differences between the calculated inductances. **(3)**

b. Calculate the peak magnitude of the open-circuit emf when the machine is rotating at 5500 rpm. **(4)**

c. By plotting appropriate flux-linkage versus current characteristics (using the graph paper provided) estimate the average torque produced by the machine over the full angular excursion of -30^o to $+30^o$ for currents of 25A and 100A. Comment on any differences in the torque per unit current for these two values of current. **(6)**

d. The mechanical airgap in this machine is 1.0mm and the rotor magnets have a thickness in the direction of magnetisation of 6.0mm. Listing assumptions that you make, estimate the number of turns in each phase given that the stator core starts to saturate at a flux density of 1.6T (You may assume that the relative permeability of the magnet is 1.0) **(7)**

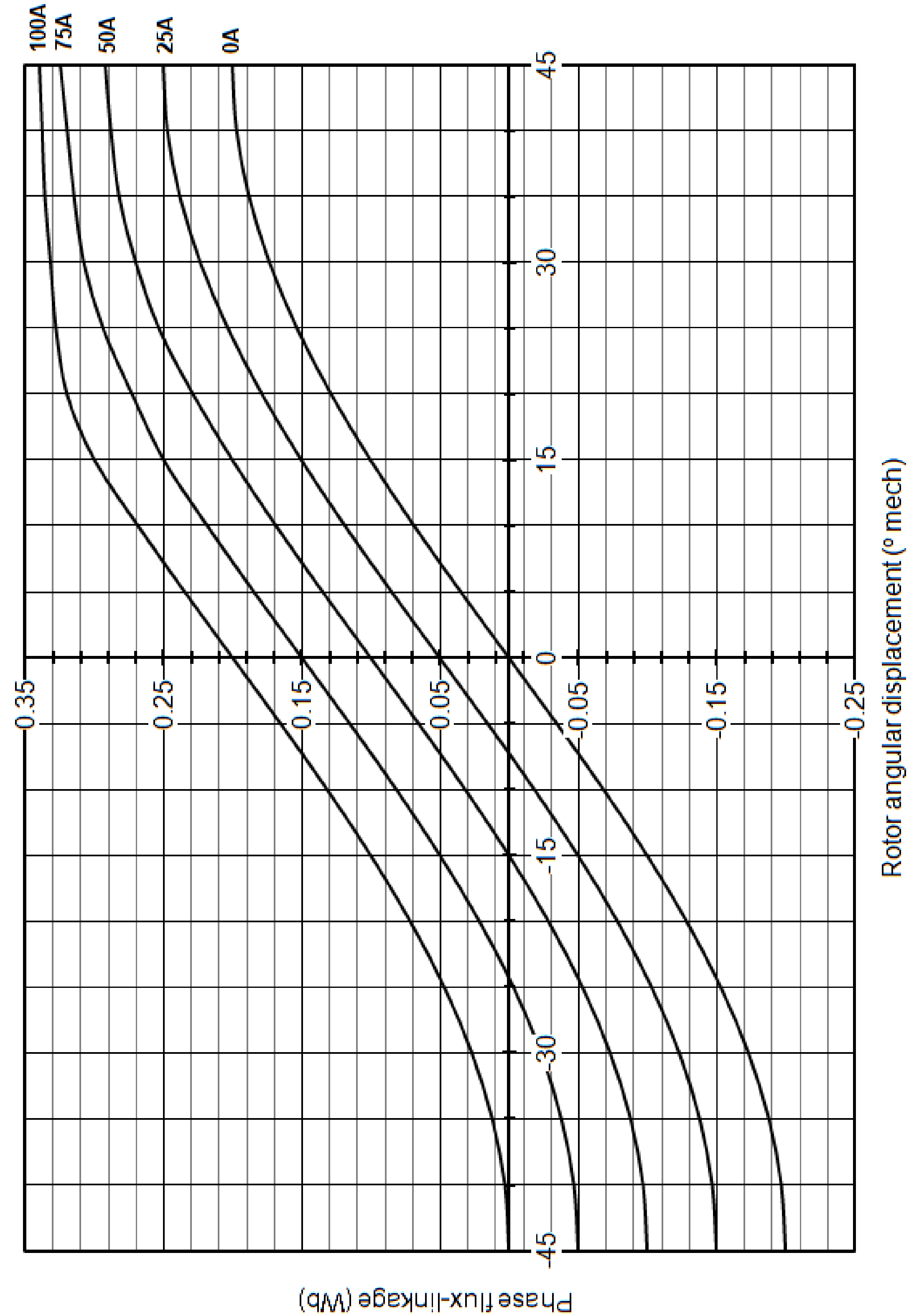

Figure 4 Measured variation of flux-linkage of one phase of a non-salient, three-phase permanent magnet brushless machine with rotor angular displacement for levels of stator current between 0A and 100A.

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