Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
6.685 Electric Machinery

Quiz 2   **Two Crib Sheets Allowed**   **December 14, 2005**
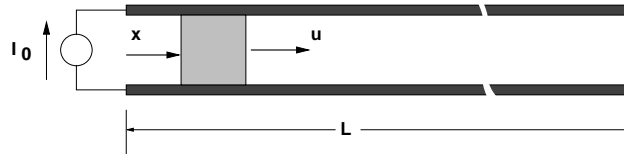
Problem 1: From the Homework:

Figure 1: Problem 1: Cartoon of a Rail Gun

Figure 1 shows a 'cartoon' view of a 'rail gun'. This thing has a depth D in the dimension you can't see (into the paper). The rails are spaced apart by width w and the railgun has barrel length L. The projectile is represented as a conducting block that has mass M and slides between the rails. The projectile is represented in the cartoon as the dark shaded block. The current source establishes a surface current which is uniform in that direction. Magnetic fields produce force which pushes the projectile to the right. Assume that friction, windage and resistive losses are all negligible. Assume that current is a step:

$$I(t) = I_0 u_{-1}(t)$$

1. What is the force on the block, in terms of the dimensions D, w and current I_0?

2. If the block is moving to the right with velocity u, what is the voltage across the current source?

3. Find power converted into mechanical motion and power out of the current source, as a function of projectile velocity $u = \frac{dx}{dt}$.

4. Defining 'efficiency' as the ratio of energy converted into mechanical motion to energy from the current source, what is the efficiency of this thing? Assume that energy input stops when the block leaves the end of the barrel and that energy stored in magnetic field at that time is somehow allowed to dissipate through a mechanism that someone else will design.

5. Find the velocity and position of the block, assuming that it starts at position $x = 0$ and with velocity $u = 0$.

Problem 2: DC Generator A DC generator is tested at a speed of 200 Radians per second and found to have an open-circuit voltage vs. field current characteristic as shown in Figure 2.

The armature circuit (including brushes, etc.) of this machine has a resistance of 1Ω and the field winding has a resistance of 125Ω. If the field winding is connected directly across the brushes but the machine is otherwise open-circuited:
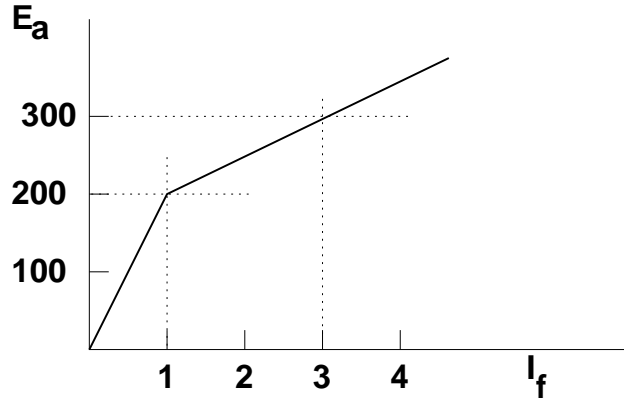
Figure 2: Problem 2: Excitation Curve of a DC generator

1. What is the minimum speed (in Radians/secondfor which this machine will self-excite?
2. If the machine is made to turn at 200 Radians/second, what is the terminal voltage?
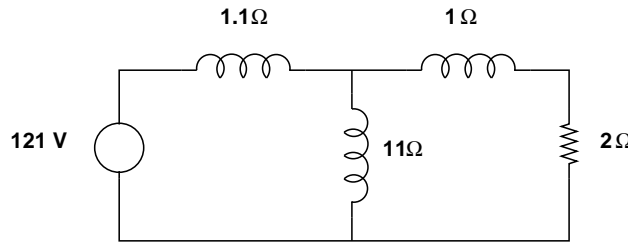3. What mechanical torque is required to turn the machine at this speed?

Figure 3: Problem 3: Induction Motor Equivalent Circuit

Problem 3: Induction Machines Please note that some compromises have been made in the search of 'nice numbers'. The equivalent circuit for an induction machine is shown in Figure 3. Note this is the equivalent of one phase of a three-phase machine. The equivalent circuit is drawn for the machine at locked-rotor conditions and for an electrical frequency of 110 radians/second. Terminal voltage is 121 volts, RMS at the same electrical frequency of 110 /radians/second (about 17.5 Hz). The machine has four poles.

1. What is locked-rotor torque for this machine?
2. If the machine is "run light", that is with no shaft load, what terminal current does it draw?

Problem 4: Permanent Magnets Figure 4 shows, in cartoon form, a structure a little bit like a machine. A ferromagnetic rotor carries a two-pole magnetic structure. The magnets are each $90°$ wide.The rotor is shown in its position at time $t = 0$. The magnet on the right presents a North pole to the air-gap while the other magnet presents a south pole to the air-gap. The stator carries a single, concentrated coil with one turn (essentially a search coil), with the wire directions as shown in the figure. Assume the magnet remanent flux density is 1.0 Tesla.
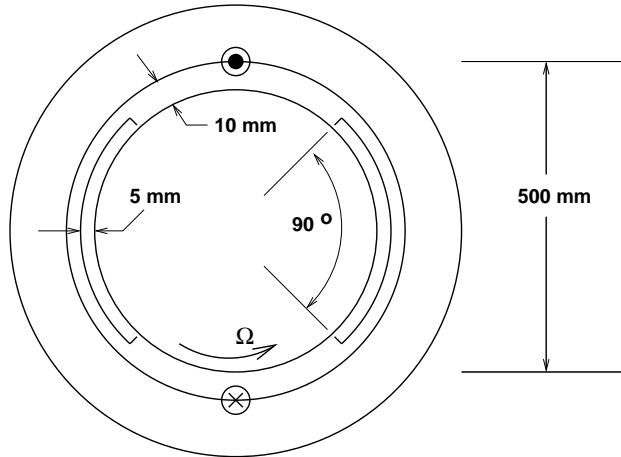
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Figure 4: Problem 2: Excitation Curve of a DC generator

The axial length of this machine-like thing is one meter. Assume the rotor is turning with an angular velocity of 100 Radians/second. Assume that, since the air-gap is quite small with respect to rotor radius, that the simplest model of the permanent magnets can be used (ignoring fringing fields). Finally, assume that the 'positive' terminal of the search coil is connected to the near end of the upper wire.

Draw a carefully dimensioned sketch of the voltage induced in the search coil. Note that factors of π are acceptable in your sketch.