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

Problem Set 7 Issued October 16, 2005
Due November 2, 2005

Note: This problem set is due in two weeks.
Reminder: Quiz on October 24, in class. Venue is Problem Sets 1-6. One handwritten 'Crib Sheet' allowed.

Problem 1: Rail Gun

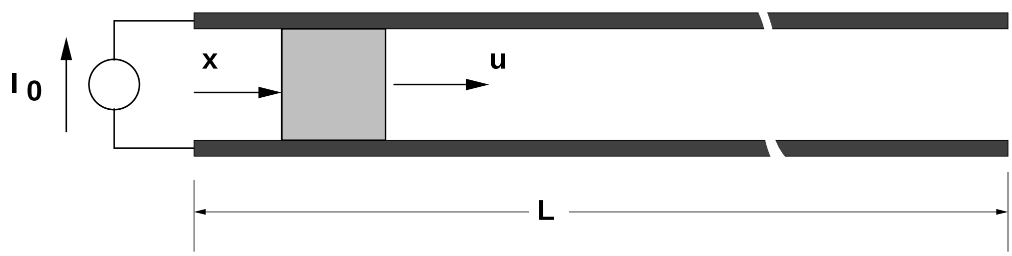

Figure 1: Cartoon view of idealized rail gun

Figurereffig: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 current source establishes a surface current which is uniform in that direction. Current flows through the dark shaded block of material which is the projectile. 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 the velocity and position of the block, assuming that it starts at position $x = 0$ and with velocity $u = 0$.
4. Find power converted into mechanical motion and power out of the current source.
5. 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 is somehow allowed to dissipate through a mechanism that someone else will design.

6. Note we are about to compute some ridiculous numbers. Assume that the mass of the projectile is 1 kg, the length of the barrel is 10 m, the depth and separation of the rails are both 5 cm. Also, assume the muzzle velocity is to be 200 m/s.
   (a) What current is required?
   (b) Compute and plot or sketch voltage between the start of the transient and when the projectile leaves the barrel. (How long does this take?
   (c) Compute and plot or sketch power input to the system.

Problem 2: Machine Loss

This concerns the large machine you encountered first in Problem Set 4, Problem 2. In that set you calculated and plotted magnetic field. In Problem set 5 you calculated the voltage that would be induced by fifth and seventh harmonics in a search coil. In this problem you are to estimate losses induced in the rotor by those fifth and seventh harmonics. To do this, assume the rotor is smooth and made of steel with conductivity that is 10% of copper, or 5.5×10^6 S/m. Use the loss model described in Chapter 3 of the notes (Pages 9-11). This loss model assumes abrupt saturation of the steel and you can make the same assumption. Assume the full-pitched winding with two slots per pole per phase and a balanced excitation of 10,000 A, peak, per phase.

Problem 3: DC Traction Motor

In this problem you will consider a DC, series connected traction motor driving a trolley car. In dynamometer tests this motor was found to develop 400 kW at 1000 RPM with terminal voltage of 600 V. At that condition the motor drew 800 A. The motor has a combined field and armature inductance of 8 Hy.

The trolley car weighs 25,000 kg and is geared so that it is going 25 m/s when the drive motor is turning 1000 RPM. Traveling on level track, the car requires 200 kW to overcome drag at 25 m/s, and that drag may be considered to be proportional to the square of velocity.

1. When the trolley car is going 25 m/s on level track, how much current is the motor drawing?
2. If current into the motor is limited to 2,000 A, how steep a grade can the trolley climb? If terminal voltage is limited to 600 V, how fast can it go up that grade? (For the purpose of this part of the problem, ignore drag).
3. *Jerk* is the rate of change of acceleration, or third derivative of position. The motor is operated in the following fashion from rest:
   - The motor is connected to a stiff voltage source of 600 V,
   - Current is limited to 2,000 A

   What is the maximum jerk during the ensuing acceleration? Make reasonable approximating assumptions to simplify the problem.
4. Simulate acceleration from rest to a speed of 25 m/s under conditions as stated in the previous part of this problem.Assume level track.