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6.061 / 6.690 Introduction to Electric Power Systems
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Massachusetts Institute of Technology

Department of Electrical Engineering and Computer Science

6.061/6.690 Introduction to Power Systems

Problem Set 7

Issued: Ses #13

Due: Ses #16

Problem 1: Figure 1 shows an end view of a special purpose reluctance torquer. This is pictured with the rotor in the maximally aligned position. Assume the following dimensions: Radius $R = 5cm$, Gap $g = 0.5mm$, Angle $\theta_p = \pi/4 = 45°$, Length (the dimension you can't see) $L = 10cm$. The thing is wound with a coil with a total of 200 turns. (Half the turns are on one pole, the other half on the other pole, and they are connected in series so that they push flux in the same direction).

1. Ignore fringing. Calculate the inductance of this thing when the rotor is in the position shown.
2. Sketch the inductance as a function of angle.
3. Compute and sketch torque as a function of angle, for current of 5 Amperes.
4. Now, if the rotor is turned to an angle of 45° and current in the coil is set to $5A$, how much energy can be delivered to a mechanical load as the rotor turns back to the aligned position?

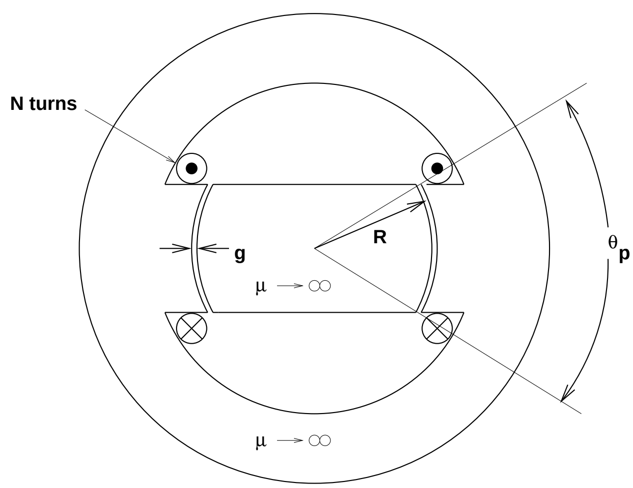

Figure 1: Single Phase Reluctance Torquer

Problem 2: Figure 2 is a cartoon picture of a transformer core. We are going to wind a transformer on this thing. The core is made of a stack of *laminations*, each .014" thick. (that is about 1/2 mm). A top view of the finished transformer is shown in Figure 3 and the dimensions of one of the laminations are shown in Figure 4.

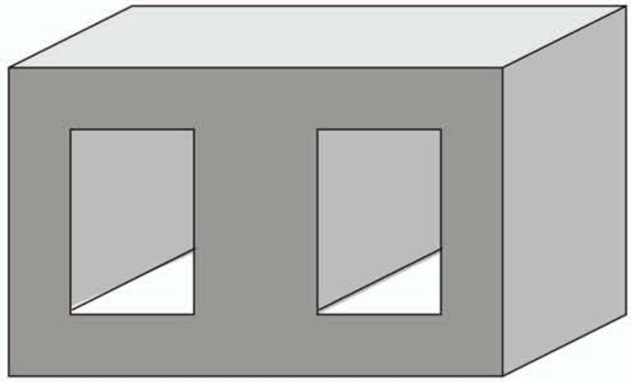

Figure 2: Transformer Core

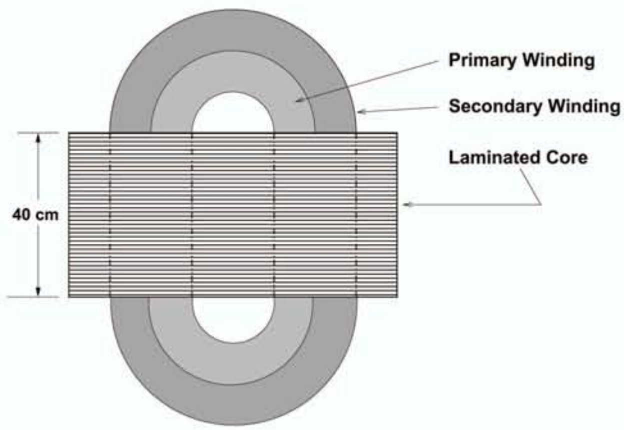

Figure 3: Transformer Core and Windings: Top View

1. First, assume that this is to be a 60 Hz transformer. We are to operate the core at a *peak* flux density of 1.5 T. The transformer is to have a primary:secondary voltage of 4.2 kV:277 V, RMS, suitable for use as one phase of a delta-wye connected, 4.2 kV to 480 V three phase transformer. What are the numbers of turns in the primary and secondary windings?
2. The rating of this transformer is to be 300 kVA. Assuming for the moment that equal area is reserved for the primary and secondary windings, what is the superficial current density in each winding?
3. **for 6.690** The core of this transformer is made of 29 Gage M-15. You should be able to estimate the core loss in this transformer. Assume that the core material has a density of $7650 kg/m^3$. What is the value of the equivalent core loss element (resistance) referred to the high side of the transformer? A document that describes many different types of core steel is located nearby as a 'supporting document'.
4. **for 6.690** Assume that the windings are made of copper (conductivity is about $5.8 \times 10^7 S/m$). Also, assume that the windings have a space factor of 40%. Allowing for circular end turns, what are the resistances of the primary and secondary windings?

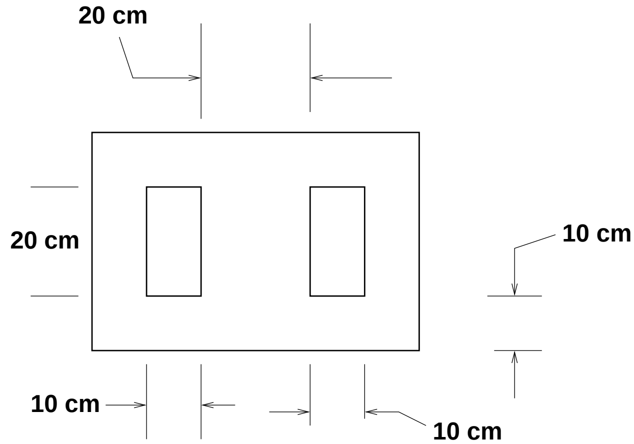

Figure 4: Transformer Core Lamination

What is the power dissipated in those windings when the transformer is running at its rating?

Problem 3: Figure 5 shows a rather fanciful and cartoonish picture of a magnetically levitated vehicle similar to the "Trans-Rapid" train developed in Germany. The purpose of this problem is to look into two aspects of the magnetic levitation support.The car is supported by two levitation rails, each of width w and length L (not shown in the illustration, but L approximates the length of the car). The stationary rail is fastened to the underside of a structural system that holds everything up. The car carries a magnetic circuit which consists of a series of poles with coils wrapped around them. Assume the number of poles is even so there is an equal number of north and south poles.The rails are of width w and you can assume that the stationary and moving structures are of the same width. Assume that the rails and poles are of highly permeable material ($\mu \rightarrow \infty$).

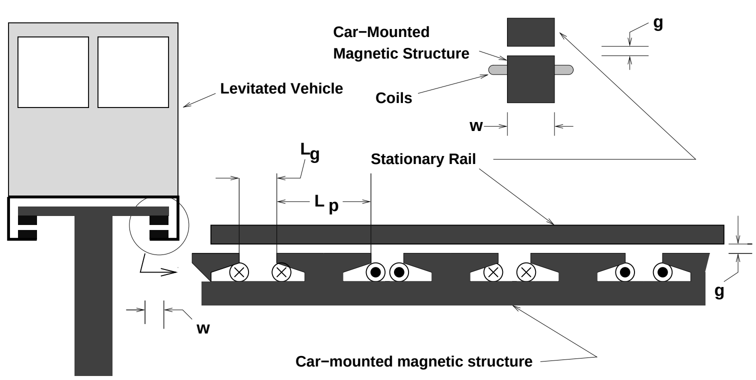

Figure 5: Maglev Rail Car

1. Assume the car weighs about 20 metric tons (20,000 kg) and that the active length of each of the two rails is $L = 8m$ and the active width is $w = 10cm$. If the car is to be suspended with a gap of about one centimeter ($g = .01m$), what is the required current

(NI) in each pole? Note, NI is total ampere-turns per pole, and you don't need to worry about how that is divided into turns. Assume the pole gap L_g is small compared with the pole length L_p.

2. Assume the current in the lifting coils is set to the value you calculated in the previous part. Estimate and sketch the lift force as a function of gap over the range $0.5cm < g < 1.5cm$.
3. Note that this suspension force is *unstable* (why?) so that an active control system will be required.
4. There will also be a *lateral* force if the car becomes misaligned to the side. What is this force? Estimate its magnitude and sketch it as a function of lateral displacement. Is the cars lateral position stable or unstable?