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ECEN 3400
Project: Problem Set
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Electromagnetic Crane Details

A construction company looking to save some money buys an electromagnetic crane from the "Qo'noS Construction Company". However, when the electromagnet arrives, the instruction manual is in a language no one can read! However, with a bit of cleverness on the part of the construction crew, the following information is ascertained about the electromagnet:

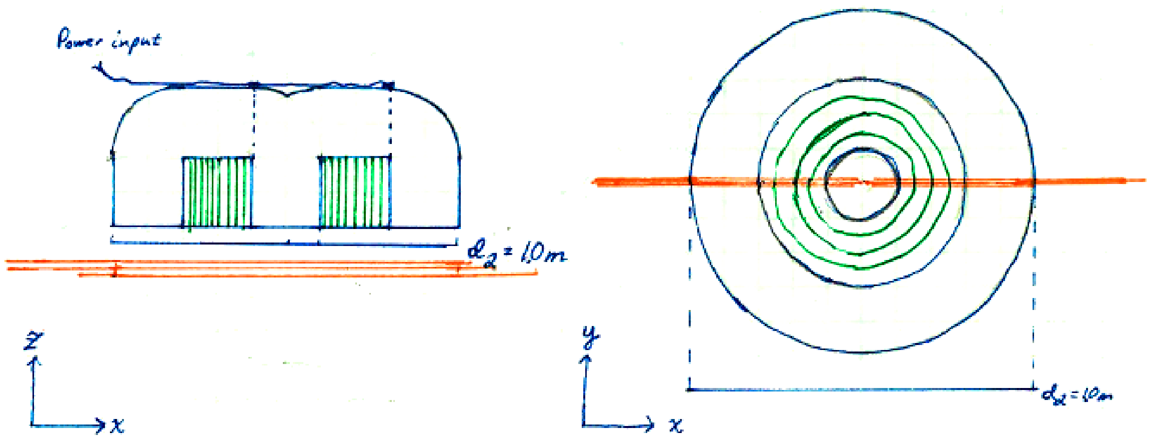

Figure 1: Sketch of the head of the electromagnet from a side-on view (left) and a top-down view (right)

Electromagnet Properties:

- The voltage supplied is always a steady 220V DC
- The current can be adjusted from 0-2A by the operator
- The $B(H)$ dependence in the crane is:

$$B(H) = \frac{B_0 H}{H_0 + H}$$

- Where the coefficients are approximated as:

$$B_0 = 2.2T$$

$$H_0 = 50A/m$$

- The permeability of the core is assumed to be very high
- The mass of the magnet itself is 800kg.
- The total diameter of the electromagnet is 1m
- The coils inside are layers of copper insulated by mica and asbestos, the total coil assembly is a toroid with a thickness of 0.2m.
- The mean radius of the square toroid core is $R = 0.2m$.
- The surrounding ferromagnetic material is always *at least* a thickness of 0.2m around the core, except at the base, which is covered with a thin steel plate to protect the coils.

Rebar Properties:

- Each rod of rebar is 8kg/m
- Each rod of rebar is 10m long
- Each rod of rebar has a diameter of 36mm
- Rebar comes in bundles of 10

1 Magnetic Field Intensity $\vec{H}$

2 Magnetic Flux Φ

Find the magnetic flux through the electromagnet to the rebar. Assume that a "bundle" of rebar is a sheet of 10 rebar rods tied together. *(Hint: start by finding S)*

Solution: To simplify the problem, neglect the area of the electromagnet that isn't above the rebar rods. Namely, let S be the surface area common between rebar and any one of the segments of electromagnet. Because the width of the rebar raft is small, this segment can be approximated as a rectangle:

$$S \approx 0.2m \cdot (10 \cdot 36mm) = 72mm^2$$

3 Magnetic Flux Density $\vec{B}$

Let $N = 4000$. The current has been set to $I = 1A$

Solution:

4 Magnetic Forces

Solution:

5 B(H) Dependence

Solution:

6 Magnetic Energy

Solution:

(a) What is the force required to lift the rebar?

Solution: First, calculate the force on the rebar due to gravity:

$$F_g = mg$$

Mass of a bundle of rebar:

$$m = 10m \cdot 8kg/m \cdot 10 = 800kg$$

$$F_g = 800kg \cdot 9.81m/s = 7.848kN \approx \boxed{7.9kN}$$

7 Faraday's Law and Inductance

Once the rebar hauling is completed, the workers decide to use it to move other items on the construction site. One such item is a ring-shaped piece of copper pipe with a diameter that is 1m. Unfortunately, the construction workers forgot that copper is diamagnetic, and assume that the metal ring is simply stuck. The confused operator of the crane moves the magnet only inches away from the ring, such that the $\vec{B}$ field through it is effectively uniform. When this has no effect, he fiddles with various knobs that have an unknown purporse, and asks his friend to "free" the pipe while he tries to get the crane to work "better". One such button the frustrated operator presses initializes a sinusoidal oscillation in the supplied voltage of 60Hz, with the RMS value being equal to the DC value of the crane in DC mode (220V). The operator's friend is not wearing any gloves, and has exceptionally sweaty hands.

When the operator's coworker grabs the metal ring, he grabs it such that there is 1/3 of the circumference of the ring between his two hands

(a) How much current passes through the coworker?

(b) Will the coworker live?

8 Magnetic Fields and the Trajectory of Electrons (Ampère's Law)

During break, many of the workers are watching TV on an old CRT set. However, the workers have since continued watching TV instead of returning to work, and the impatient foreman decides to get their attention by using the electromagnetic crane.

With the magnetic unit positioned a very short height over the set, the foreman fires up the electromagnet as seen in the figure below. Assuming that the TV is smaller than the magnet (and that the $\vec{B}$ field is approximately uniform)

(a) Describe and/or sketch what the workers see on the screen once the magnet has stabilized.

(b) The foreman is determined to try and destroy the television. Even with the magnet on top of the set and the current at maximum, can he do it? If so, what current value will destroy the set?

Solution:

(a) The screen will be distorted and will move to the left because the electrons moving in a magnetic field can be thought of as currents. As a result, their trajectory will change in response.

(b) At maximum current (2A), the electron will only be deflected into the wall of the tube.