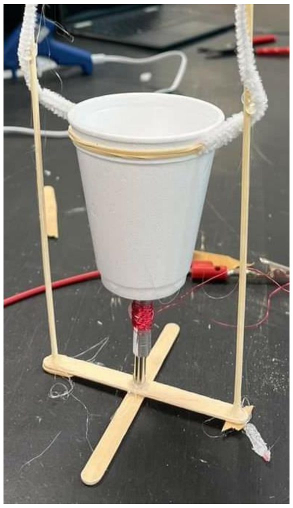
2A04 Lab 5 Writeup – Alexander Bartella (Bartella, 400308868) – Partnered with Jacqueline Leung

Main working principles



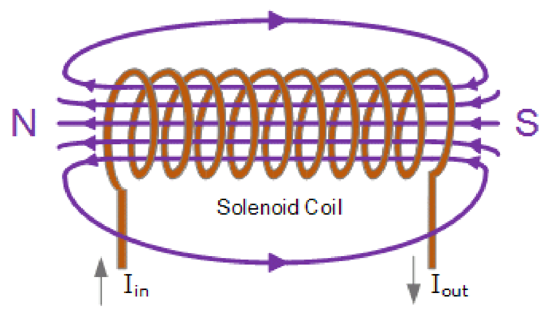
The design of the speaker implements concepts such as Ampere's law applied to a solenoid and electromagnetic properties of a solenoid. Biot-Savart Law and Ampere's Law state that magnetic field lines encircle a current-carrying wire in a plane perpendicular to the wire. In addition, the direction of the current and magnetic field are related (i.e. when current changes direction, so does field). This concept is important in the design of a speaker since it dictates the behaviour of the solenoid in the system. The speaker requires the solenoid to vibrate in order to produce sound. To accomplish this, there is a current applied to the solenoid, and the magnetic field induced by this is approximated to act through the axis in the center of the solenoid. The magnetic field of the solenoid acts colinearly to the magnetic field of the permanent magnet. This magnetic field is quantized by Ampere's law:

$$\oint \boldsymbol{B} \cdot \boldsymbol{ds} = \mu_0 I_{encl}$$

$$\boldsymbol{B} = \frac{\mu_0 N I}{L}$$

Where N is the number of turns of the coil, I is the current, and L is the length of the solenoid.

When a DC voltage is applied, the solenoid acts as an electromagnet. This allows it to act similarly to a bar magnet and causes it to interact with the other permanent magnet just below it. Therefore, it will either be pulled towards the stationary, permanent magnet or, will be repelled by it. This is similar to the typical example used to describe Lenz's law: instead of observing the current induced by the motion of a permanent magnet relative to a solenoid, we are observing the motion of the solenoid due to the current-induced magnetic field's interaction with a stationary permanent magnet.



The next step in the functionality of the speaker is the application of an alternating current to a solenoid, rather than a direct current. As discussed previously, Lenz's law states that magnetic field direction changes with current direction. So, by applying an alternating current to the solenoid, we can repeatedly and rapidly change the direction of the magnetic field, thereby changing the polarity of the solenoid electromagnet.

$$\boldsymbol{B} = \frac{\mu_0 N I}{L} = \frac{\mu_0 N (I_0 sin\,(\omega t))}{L}, where\ \omega = 2\pi f$$

So, the solenoid electromagnet is now changing polarity at a frequency f. Because of this, the electromagnet is continuously switching between being attracted to the permanent magnet, and repelled by it, thereby causing it to oscillate back and forth. This effect causes vibration to occur, which is amplified by the Styrofoam cup (cone) to create sound that is audible to the human ear. As observed in the attached video, the sound pitch varied with change in frequency.

Design

For the design of the speaker, we began with tall, thin magnets with a solenoid surrounding them. The solenoid was suspended overtop of the permanent magnets and is able to move freely. Attached to the top of solenoid is a Styrofoam cup which serves to amplify the vibrations, producing sound that is audible to the human ear. The cup and solenoid system is suspended over the magnets using pipe cleaners and elastics.

As for design decisions, each element was chosen to fulfill a certain functionality. The solenoid was wound approximately 50 times. This value was chosen through trial and error, observing how many coils were needed to produce sound that is easily audible. The cup-solenoid system is suspended by elastics, approximately half a centimeter above the permanent magnets. This distance was chosen also through trial and error: we discovered that there is a “sweet spot” in which the sound intensity reaches a maximum. In addition, the elastics were chosen so to allow for the cup to vibrate freely (rather than being glued to the skewers directly). The tall, permanent magnets were chosen as opposed to the shorter, wider magnets because the increased length made it easier to position the solenoid correctly. The culmination of all of these design decisions allowed the speaker to produce clear sound. However, this was the second iteration of the design. The first design was similar but the solenoid and the base were enclosed in a tin-foil tray and the cone was a paper plate. This design was not successful because the solenoid was not being suspended over the permanent magnets and the cone was not deep enough to amplify the sound.

Reflection

This lab has enlightened me to applications of theory learned in class. This is important because as engineers we are tasked with using advanced concepts in our everyday work to accomplish simple tasks, like making a sound. Through this lab I have learned about the applications of Lenz’s law and Ampere’s law upon solenoids, and their many uses in everyday life. For example, solenoid electromagnets are used in electric motors, and induction of a current upon a coil is used commonly in wireless communication and wireless charging. Overall, I feel that this lab is highly applicable and offered good hands-on experience making simple electronic devices using simple components.

References:

F. T. Ulaby and U. Ravaioli, *Fundamentals of Applied Electromagnetics*. Pearson, 2020.