Declan Stanton
Block A
16 December, 2019

Single-Electromagnet AC Motor

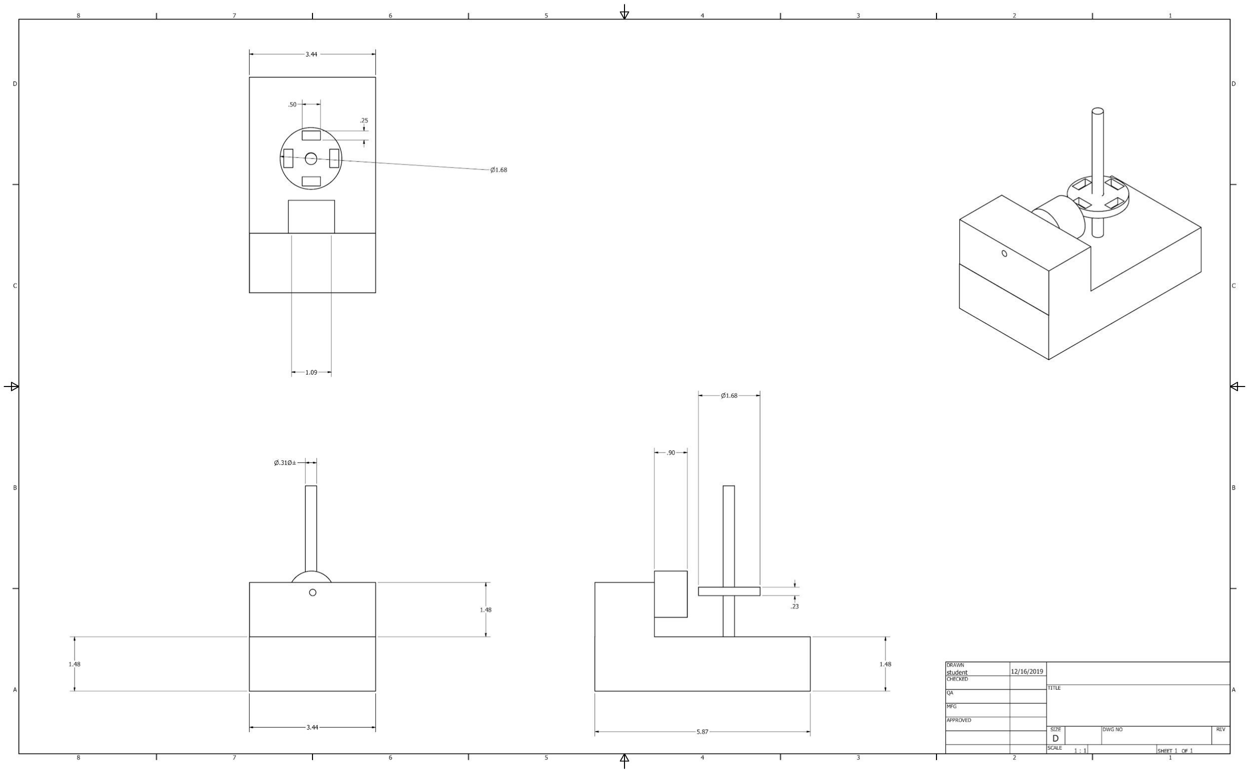
Abstract

I sought to use a single electromagnet with AC power to maximize the efficiency of my motor. I used four permanent magnets with opposite poles relative to the adjacent magnet. The maximum efficiency I achieved was 3.4% and the maximum rpm I reached was 75.

Design

I used a single electromagnet with a nylon core and a circular rotor with 4 permanent magnets. By using a single electromagnet and an AC source, I can maximise the the force exerted on the permanent magnets in the rotor. This is because the magnetic field produced by the electromagnet attracts a permanent magnet and repels the adjacent one. In doing so, I am increasing the amount of force on the rotor without increasing the strength of the electromagnet and thus less energy lost. To decrease the amount of friction in my motor, I allowed the rotor to spin on a bearing which have very little friction compared to simply placing the rotor on the axis of rotation. The front of the electromagnet is as close to the rotor as possible to ensure the permanent magnets are acted on with as much of the magnetic field strength as possible. For my electromagnet, I opted for more turns of wire rather than thicker wire to increase the strength of the magnetic field without using more current. More current means more heat loss which means less energy converted into mechanical energy. The nylon core is used rather than an iron core because the electromagnet has to be drastically stronger than I intended in order to change the polarity of the iron. Flipping the polarity of an iron core would result in hysteresis losses as well chipping away at the total energy going into the rotor.

CAD Drawing



Theory of Operation

When current travels through a wire, a magnetic field is created curling around the wire. The direction of the current dictates the direction of the magnetic field based on the RH rule. When a wire is coiled up, the direction of the magnetic field at each point in the wire points in a uniform direction creating North and South magnetic poles. Since alternating current is used to power the electromagnet, the direction of the current flips at a certain frequency thus changing the polarity of the electromagnet. When electrons wiggle back and forth at a certain frequency, this is called alternating current because the current direction alternates from positive to negative. In magnetism, like poles repel and unlike poles attract; so, south facing permanent magnet will attract to the north pole of the electromagnet and north facing permanent magnets will be repelled by the north pole of the electromagnet.

My plan is to gradually increase the frequency of the AC generator in order to make the rotor spin faster. The push-pull action on the rotor will gradually increase as the frequency increases because the polarity of the electromagnet will switch faster.

Results

RPM Calculation

To calculate the RPM of my motor, I used a hall chip and an oscilloscope to detect the presence of a magnet in my rotor. Since I have four equally spaced magnets in my rotor, I know that in the time two positive spikes on the oscilloscope appear, my rotor has completed ½ a revolution.

$$rpm = \frac{revolutions}{minute} = \frac{revolutions * 60s}{seconds}$$

Efficiency Calculation

To calculate the efficiency of my motor, I calculated the power output of the AC generator and, simultaneously, the power output of the motor. To calculate the power output of the AC generator, I looked at the voltage difference across a .1 Ω resistor and the voltage across the resistor and electromagnet.

Since the voltage amplitude and current are sinusoidal and have different phase because of the inductor in the circuit, the instantaneous power is:

$$P = V_m \times I_m[sin(\omega t + \theta_v)sin(wt + \theta_I)]$$

This using trigonometry this simplifies down to:

$$\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} = P$$

Since I = V/R, I found the max current by determining the voltage across the circuit divided by the resistance, so:

$$\frac{V_m}{\sqrt{2}} \times \frac{V_m}{R} = P_{in}$$

To calculate the power output of the motor, I recorded the distance and time it took for the motor to lift a certain mass. To do so, I placed two pins on the edge of the rotor and attached a mass to a string with a noose at the other end. As the motor came up to speed, I hovered the noose over the pins until the string caught on the rotor. I placed a meter stick and stopwatch next to the string, hung over a pulley, and slow-mo filmed the entire scene. This allowed me to record when the string caught on the rotor, and how far the mass traveled over a certain amount of time.

$$P_{out} = \frac{Work}{\Delta t} = \frac{F \cdot d}{\Delta t} = \frac{mg \cdot d}{\Delta t}$$

Efficiency is the power output of the rotor divided by the power input from the AC generator, so $\frac{P_{in}}{P_{out}}$.

Data

Table 1: Calculations for the mechanical power of the motor

Mass	Distance (m)	Time (s)	Power (W)
1.1g	.1	.19	.0057
4g	.08	.21	.015
7g	.04	.21	.013

Table 2: Calculations for electrical power input into the motor

Mass	V_{total}	Voltage across .1Ω resistor	Power (W)
1.1g	5.6V	.0112V	.443
4g	5.6V	.0112V	.443
7g	5.6V	.0112V	.443

Table 3: RPM of the motor

Time elapsed (s)	Total Spins	Total RPM
.4 s	.5	75

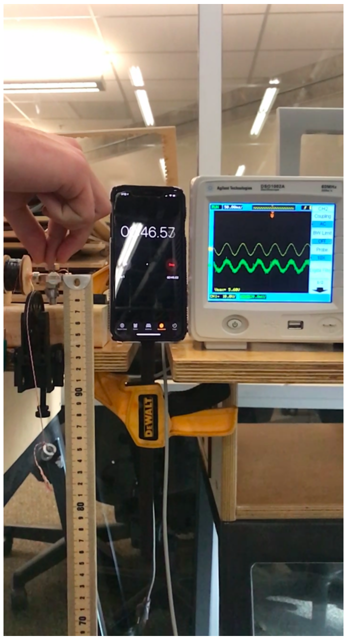
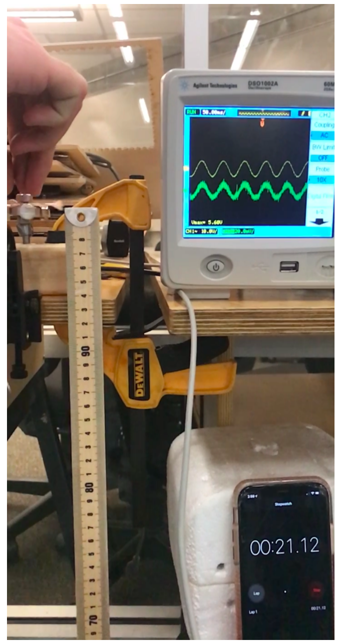
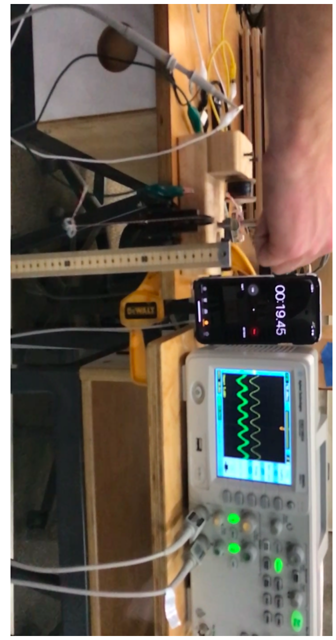
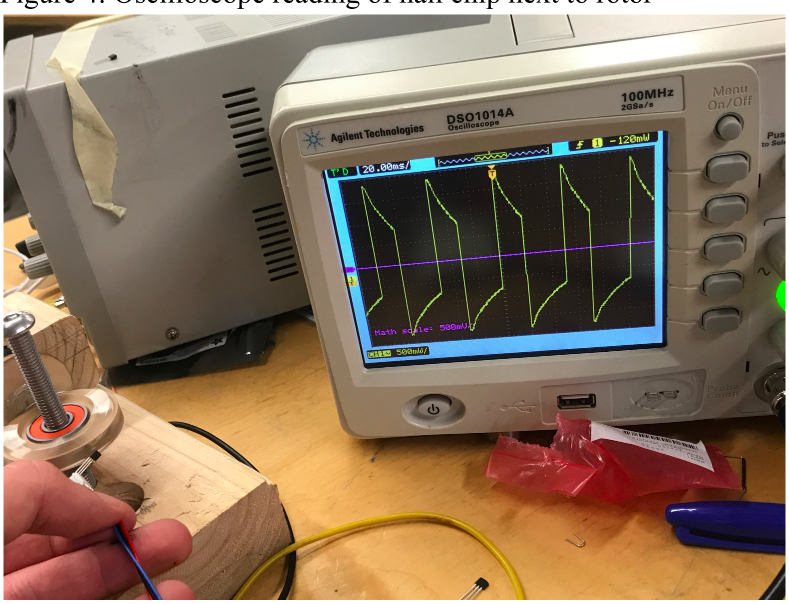
Figure 1: Single gram mass oscilloscope reading	Figure 2: Four gram mass oscilloscope reading	Figure 3: Seven gram mass oscilloscope reading
		

Figure 4: Oscilloscope reading of hall chip next to rotor



Results

The maximum efficiency I obtained is 3.4% (Table 1, Table 2). What is interesting is the efficiency reached a maximum around 4 grams and decreased as the weight increased to 7 grams. The maximum rpm I achieved was around 75rpm (Table 3).

Next Steps

The next step will be to create an RC-circuit to gradually increase the frequency of the AC generator, so I can have a consistent rpm each time the motor is turned on. I also want to see if using a stronger electromagnet (more turns) with a silicon steel core because metal cores amplify the strength of the magnetic field, but the silicon will increase the resistivity of the core enough to prevent core losses. The rpm only reached 75rpm so I would like to calculate the efficiency of the motor at a higher rpm to see if that has any impact.

Bibliography

https://www.electronics-tutorials.ws/accircuits/power-in-ac-circuits.html, *Website accessed on 12/14/2019*