Hand Turned Electric Generator

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Abstract

The purpose of this project was to design and build a hand turned alternator to demonstrate electromagnetic induction on a practical level. An alternator is an electric generator which outputs alternating current. An alternator was designed using a permanent magnet and coils of copper wire encased in a 3D printed frame. The alternator was mathematically modeled, and it was determined that maximum voltage is proportional to frequency. The alternator frame was 3D printed and the rest of the components were acquired. It was then constructed, and experimental data was taken. It was determined that the data is consistent with the model and maximum voltage is proportional to frequency.

Introduction

The goal of this project was to design and build a hand turned alternator using a permanent magnet. An alternator is an electric generator which intakes mechanical power and outputs electrical power in the form of alternating current or A/C. Alternators have a wide variety of industrial applications. A common application is an automotive alternator which charges the battery in a car.

An alternator works by a mechanic known as electromagnetic induction. Electromagnetic induction was first discovered by Michael Faraday in 1831 and described by Lenz's Law three year later. The premise of electromagnetic induction is that nature does not like a change in magnetic flux and will create an electromotive force (EMF) to oppose it. Magnetic flux is simply a measure of how much of a magnetic field is going through a given surface area. Using a permanent magnet and coils of copper wire, a changing magnetic flux can be achieved resulting in an electromotive force. This project aims to design and construct a small alternator to demonstrate electromagnetic induction on a practical level.

Theory

The design for the alternator consists of a cylindrical permanent magnet surrounded by a total of eight coils, see Figure 1.

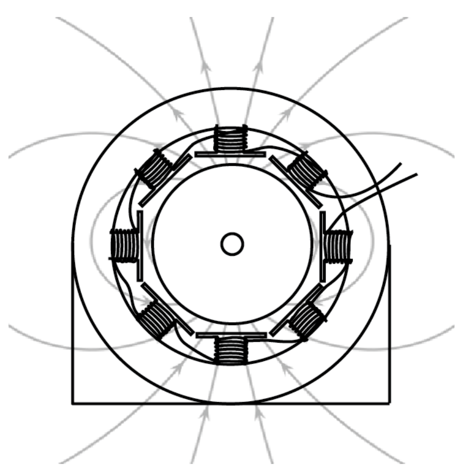

Figure 1: Alternator front view.

By rotating the magnet, the coils will experience a changing magnetic flux which will induce an EMF. The magnet may be modeled as a magnetic dipole. The formula for the magnetic field of a magnetic dipole is as follows:

$$B(r) = \frac{\mu_0 m}{4\pi r^3}(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}) \tag{1}$$

The variable μ_o is the permeability of free space, *m* is the magnetic moment, *r* is the distance from the center of the magnet to the coil, and θ is the angle of rotation. The area vector of a surface area is a vector with a magnitude equal to the area and a direction perpendicular to the area plane. The coils can be oriented so that the area vector of the coils is in the $\hat{r}$ direction which will simplify the resultant flux. To simplify the problem, we can assume the copper coil is a rectangle of wire at a fixed distance *R*. The magnetic field becomes:

$$B(r) = \frac{\mu_0 m}{4\pi R^3}(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}) \tag{2}$$

Flux can now be solved for using Faraday's Law:

$$\Phi = \iint B(r)\,dA$$

$$\Phi = \iint \frac{\mu_0 m}{4\pi R^3}(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta})\,(dA_{coil}\,\hat{r})$$

$$\Phi = 2\frac{\mu_0 m}{4\pi R^3}\cos\theta \iint dA_{coil}$$

$$\Phi = 2lw\frac{\mu_0 m}{4\pi R^3}\cos\theta$$

$$\Phi = lw\frac{\mu_0 m}{2\pi R^3}\cos\theta \tag{3}$$

Where *l w* is the area of the coil. Assuming the magnet is rotated at a constant rate $\dot{\theta}$, the equation for flux becomes:

$$\Phi = lw\frac{\mu_0 m}{2\pi R^3}\cos(\dot{\theta}t) \tag{4}$$

The EMF can now be found using Faraday's Law:

$$\varepsilon = -\frac{d\Phi}{dt}$$

$$\varepsilon = -\frac{d}{dt}(lw\frac{\mu_0 m}{2\pi R^3}\cos(\dot{\theta}t))$$

$$\varepsilon = lw\frac{\mu_0 m}{2\pi R^3}\dot{\theta}\sin(\dot{\theta}t) \tag{5}$$

Assuming there are *N* turns per coil, the equation becomes:

$$\varepsilon = Nlw\frac{\mu_0 m}{2\pi R^3}\dot{\theta}\sin(\dot{\theta}t) \tag{6}$$

This will be the resultant EMF for the alternator for one coil, an alternating sine wave EMF. The alternator contains a total of eight coils all $\pi/4$ away from each other. The resultant EMF will become:

$$\varepsilon = N\,l\,w\frac{\dot{\theta}\mu_0 m}{2\pi R^3}\Big[\sin\dot{\theta}t + \sin(\dot{\theta}t + \frac{1}{4}\pi) + \sin(\dot{\theta}t + \frac{1}{2}\pi) + \sin(\dot{\theta}t + \frac{3}{4}\pi) - \sin(\dot{\theta}t + \pi) - \sin(\dot{\theta}t + \frac{5}{4}\pi) - \sin(\dot{\theta}t + \frac{3}{2}\pi) - \sin(\dot{\theta}t + \frac{7}{4}\pi)\Big]$$

Using rules for the addition of sine waves, the resultant EMF for the alternator becomes:

$$\varepsilon = N\,l\,w\frac{\dot{\theta}\mu_0 m}{2\pi R^3}\,2\big(\sqrt{2}+1\big)\cos(\dot{\theta}t) \tag{7}$$

This may be rewritten in terms of frequency instead of period.

$$\varepsilon = 2\big(\sqrt{2}+1\big)\,N\,l\,w\,\mu_0\,m\,R^{-3}f\cos(\dot{\theta}t) \tag{8}$$

Methods

The alternator was first designed in illustrator, isometric shown below. For full blueprints, see Appendix A.

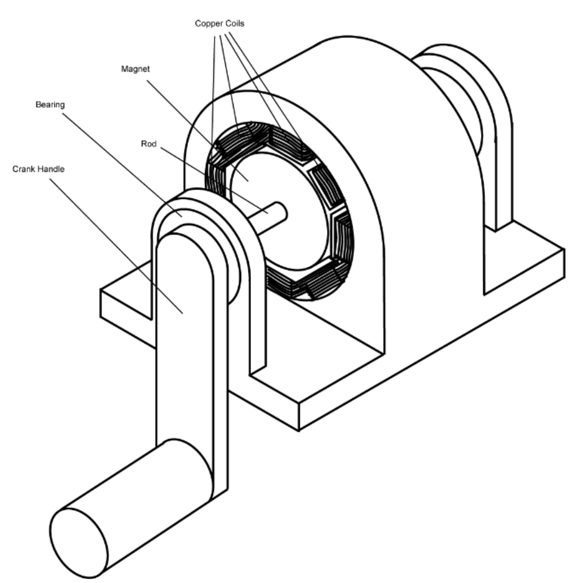

Figure 2: Isometric view of alternator.

For this design, I decided to 3D print the frame due to its intricate shape. The frame for the alternator was designed in Blender according to the blueprint specifications. The frame was then 3D printed using ABS plastic. 28 AWG solid wire was coiled around each wire holder a total of 45 times. The magnet, rod, bearings, and handle were all assembled in their specified locations according to the blueprints. Now that the alternator was assembled, testing may begin.

A ruler was used to measure the length and width of each rectangular coil with uncertainties. Uncertainties in measurement were half of the smallest unit of measurement given by the ruler. Likewise, a ruler was used to measure the distance from the center of the magnet to each coil of wire with uncertainties. The alternator was attached to an oscilloscope. While turning the handle at a constant rate, frequency and peak voltage were recorded. Because the alternator was turned by hand, extra care was taken to ensure a constant frequency. Data was only recorded if the frequency remained constant after a few turns to ensure constant frequency.

Data

First, measurements in coil area and coil distance were taken as shown below. Measurements were taken initially in inches and converted to meters.

	Measurement	Uncertainty
Length (*l*)	0.0381 m	±0.00159 m
Width (*w*)	0.00794 m	±0.00159 m
Magnet to Coil (*R*)	0.0254 m	±0.00318 m
Number of Turns per Coil (*N*)	45	N/A

Table 1: Alternator measurements.

Using these measurements, the formula for maximum EMF becomes:

$$Max\ \varepsilon = (0.230 \pm 0.098)\ f \tag{9}$$

Experimental data for frequency and maximum EMF are given in Appendix B. The data was plotted in Excel and a trendline was drawn shown below.

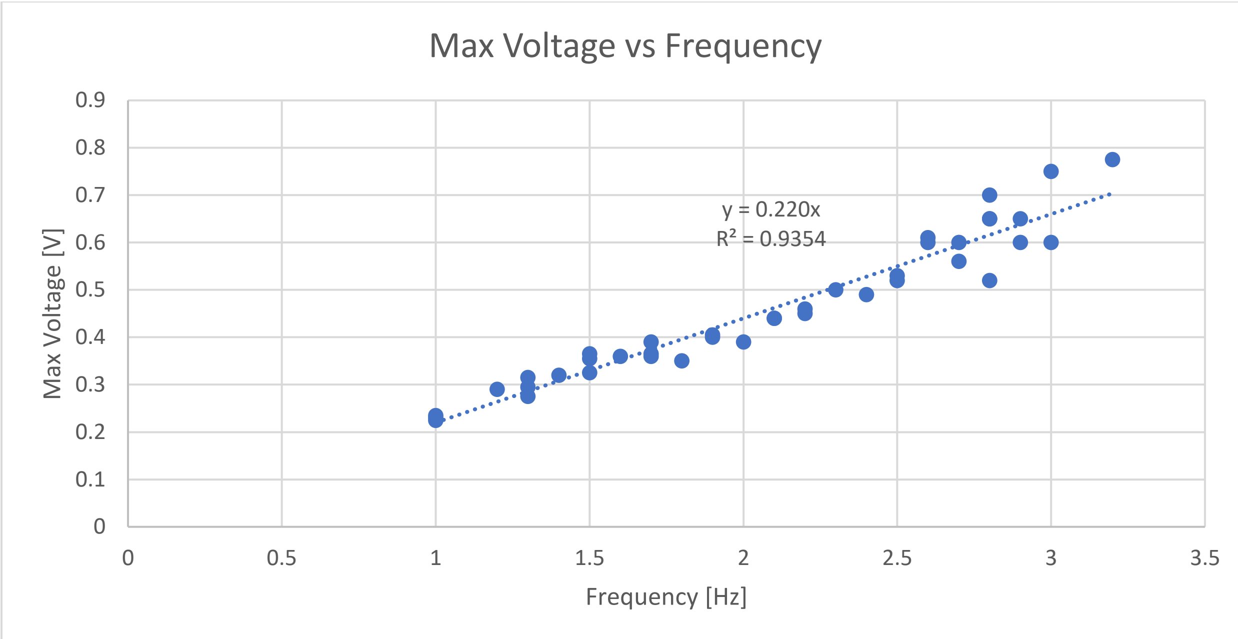

Figure 3: Experimental data

The linear trendline is a good fit as show by the R^2 value close to 1. The figure suggests there is a linear relation between max voltage and frequency with a coefficient of 0.220. The accuracy of this result can be determined using the percent error formula.

$$\%\ Error\ = \frac{0.230 - 0.220}{0.230} x100\%$$

$$\%\ Error = 4.3\%$$

This low error says that our theory gives an accurate model of the system.

Discussion and Conclusions

The theory stated that for the alternator, the resultant EMF was proportional to frequency. After taking experimental data, the low error of 4.3% is confirmation that the theory is accurate. The resultant EMF is rather low and practically can only power an LED. If this model was to be applied for a more practical use, some changes could be made to increase the output voltage.

By observing the theoretical model, several changes could be made. Adding more loops to each coil would increase the resultant EMF. However, for larger output voltages, a larger gauge wire would be used and therefore less loops may be achieved. The power of the magnetic field may be increased by replacing the permanent magnet with a DC powered solenoid. If enough input voltage is applied, a stronger magnetic field may be achieved. The down side to this approach is that brushes would be needed increasing energy loss to friction. The final change that could be made which would have the largest effect would be to fill the could with a magnetic material such as iron. The alternator designed in this project had empty space inside the coils which is why the permeability of free space was used. The permeability of free space is 1.26e-6 while for 99.8% pure iron it is 6.3e-3, a whole 3 degrees of magnitude larger. If the coils were filled with iron instead, the resultant EMF would increase dramatically depending on the purity of iron. The drawback to this solution would be that the handle would be very difficult to turn for a person. This would be comparable to an automotive alternator.

Although this alternator design may be made more powerful with a few changes, for this project the output voltage is acceptable. The purpose of this project was to demonstrate electromagnetic induction on a practical level. That may be achieved simply by powering an LED with the alternator. The alternator was successfully constructed, and experimental data matches the underlying theory. Overall, this project has been a success.

Appendix A: Full blueprints

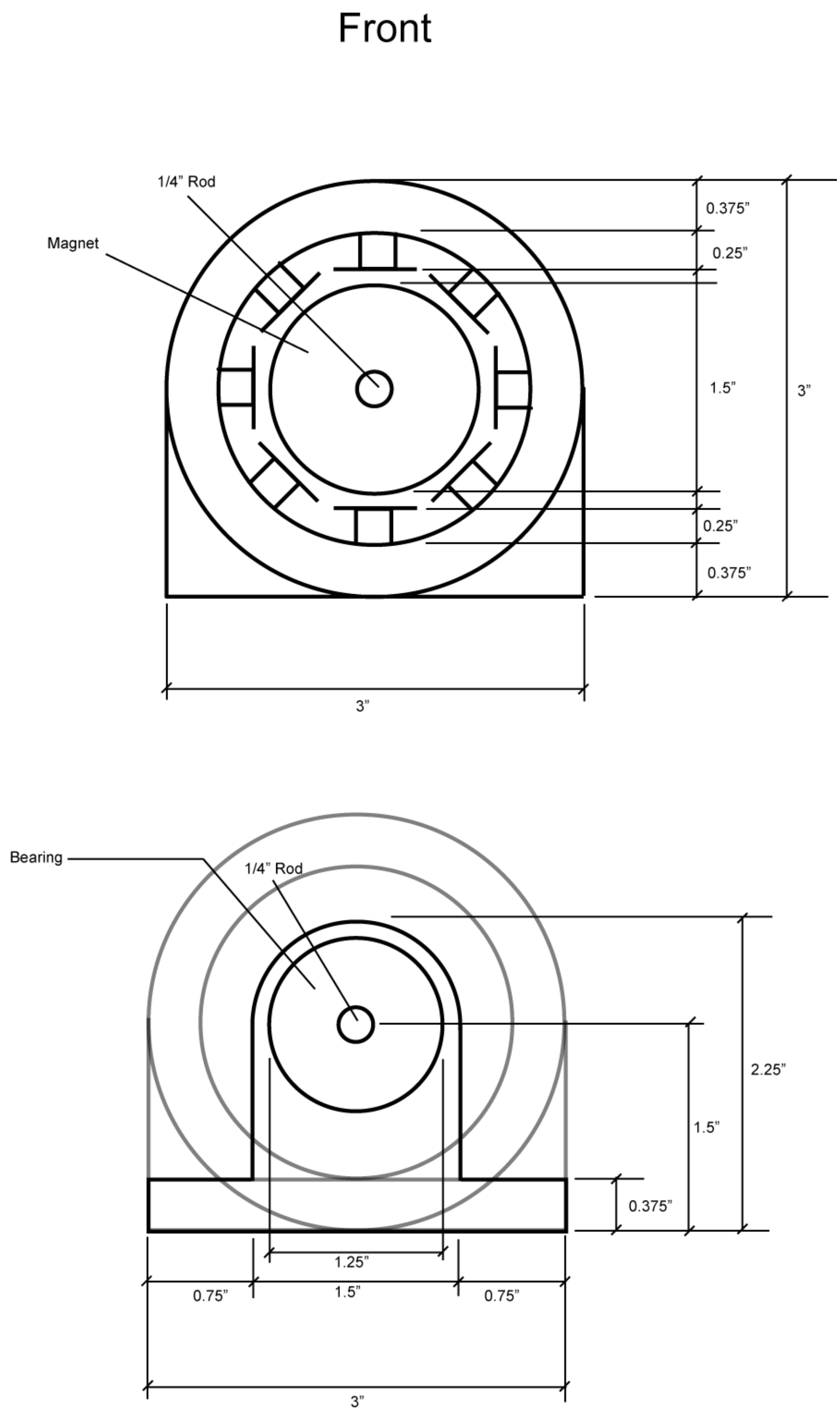

Figure 4: Front view blueprint.

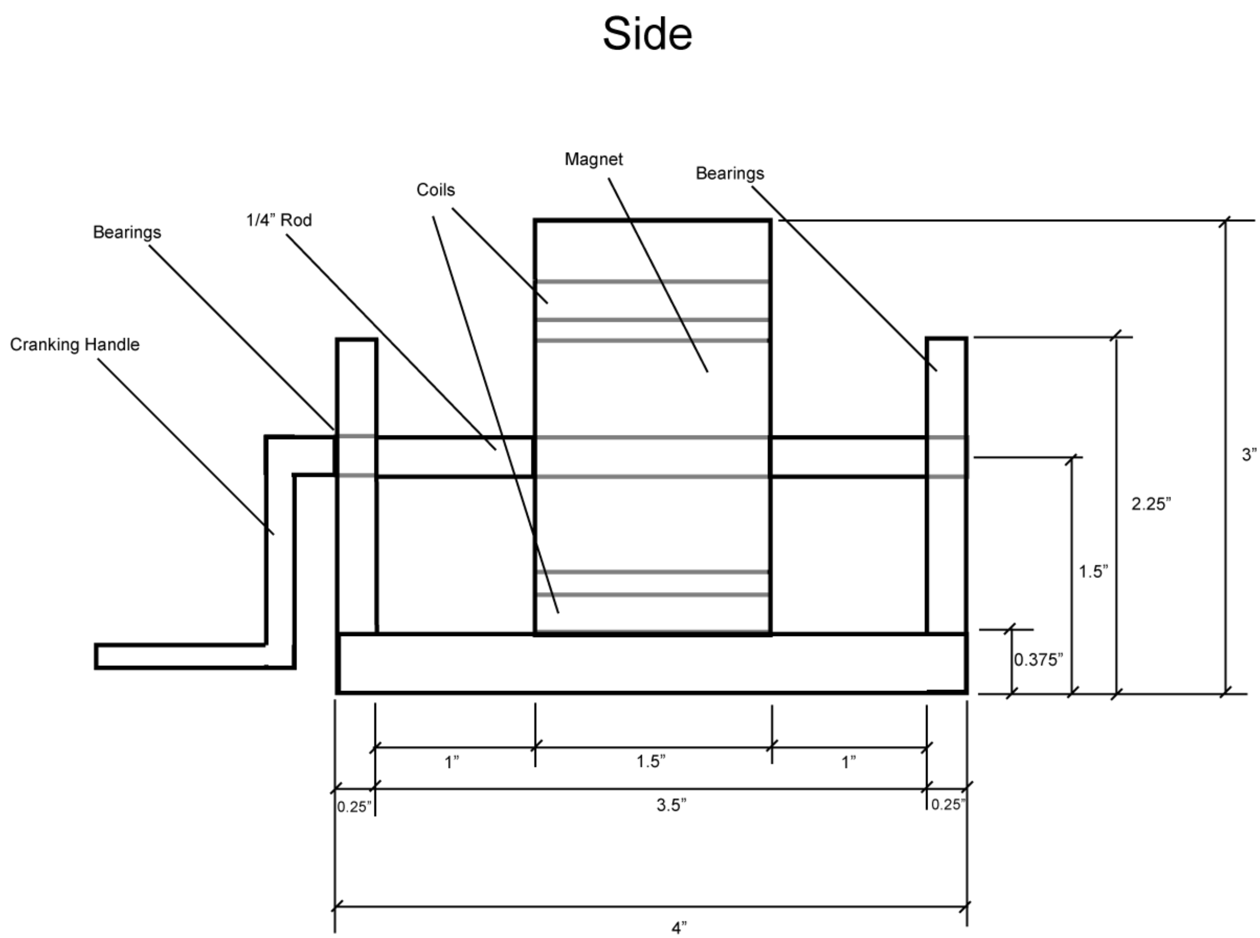

Figure 5: Side view blueprint.

Appendix B: Experimental data

Frequency (Hz)	Max Voltage (V)
1	0.225
1	0.23
1	0.235
1.2	0.29
1.3	0.315
1.3	0.275
1.3	0.295
1.4	0.32
1.5	0.355
1.5	0.365
1.5	0.325
1.6	0.36
1.7	0.39
1.7	0.365
1.7	0.36
1.8	0.35
1.9	0.4
1.9	0.405
2	0.39
2.1	0.44
2.1	0.44
2.2	0.46
2.2	0.45
2.3	0.5
2.4	0.49
2.5	0.53
2.5	0.52
2.6	0.6
2.6	0.61
2.7	0.56
2.7	0.6
2.8	0.52
2.8	0.65
2.8	0.7
2.8	0.65
2.9	0.65
2.9	0.6
3	0.6
3	0.75
3.2	0.775

Table 2: Frequency and max voltage.

Bibliography

Griffiths, D. J. (2013). *Introduction to Electrodynamics (Fourth ed.)*. Pearson Education Limited.