# Reciprocal Motor-Generator Project

CMPE 330
Electromagnetic Waves and Transmissions

Sabbir Ahmed

May 14, 2017

# Contents

# 1 Introduction

This report serves as the writing and documenting portion of the three-part Reciprocal Motor-Generator Project. The components consisted of:

- Construction of the motor-generator set
- Description of the motor-generator set
- Evaluation of others' motor-generator sets

By definition, an electric generator is an electrical machine that converts electrical current into mechanical energy. An electric generator is the inverse of an electric generator, as it converts mechanical energy into electrical current.

# 2 History

The development of both the electric motor and generator follow similar timelines, since their reciprocity was discovered soon after the invention of the first motor.

## 2.1 Electric Motor

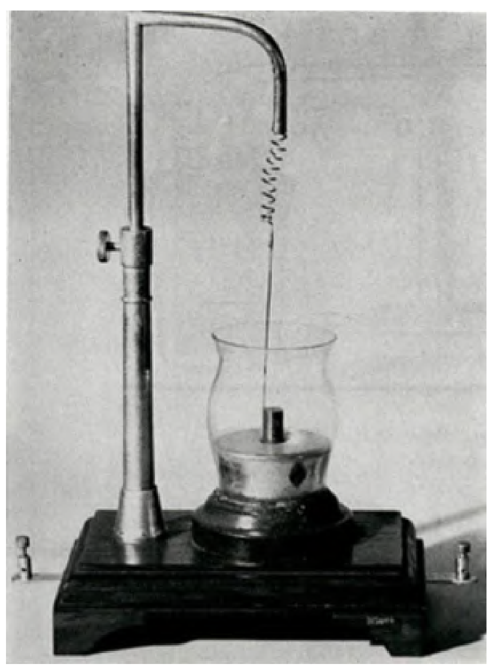


Figure 1: Rotating Wire by Faraday, 1821

Michael Faraday is known for contributing to the earliest development models of the generator. His 1821 prototype consisted of a stiff wire hanging down into a glass vessel half filled with mercury over a bar magnet. When connected to a battery, the wire would rotate clockwise due to its induced field interacting with the magnetic field. [1] The development of his prototype sprung from earlier observations by Hans Christian Oersted on the deflection of a compass needle by electric currents in 1820, and the invention of the solenoid by Andre-Marie Ampere in the same year. [2] The magnetic field generated by the electric current were made stronger with the invention of the electromagnet by William Sturgeon in 1826 by inserting an iron core in the solenoid. [3]

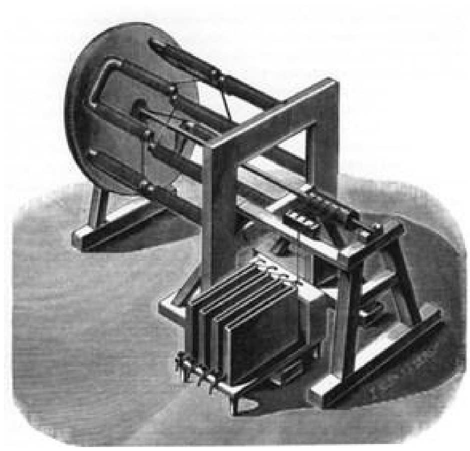


Figure 2: The First Real Electric Motor by Jacobi, 1834

Several models were developed and improved upon since the primitive models, until in 1834 when the electric motor was deemed commercially successful by being able to perform useful tasks. Moritz Hermann Jacobi constructed his motor to lift a weight of of 10 - 12 pounds with a speed of 1 foot per second, which is equivalent to about 15 watts of mechanical power. [4] Jacobi's model is considered the first real and usable electric motor.

## 2.2 Electric Generator

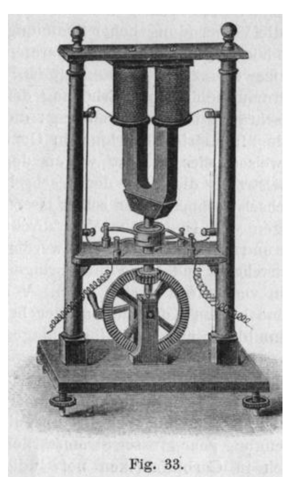



Figure 3: Pixii's First Generator, 1832/1833

Concurrently, the development of electric generators was already under way. Michael Faraday was also responsible for discovering electromagnetic induction in 1831, the inverse of the earlier observation by Oersted. Oersted discovered the generation of magnetic fields from moving currents, while Faraday observed the reciprocal of the process and began documenting the phenomenon. The concept was demonstrated a year later by Hippolyte Pixii, when he noticed how running an electric motor backwards would induce current. He builds the first apparatus for generating pulses of direct current out of a rotation. [5] Commutators and brushes were added in William Ritchie's generator around the same time. Several improvements were attempted after the primitive designs, but mankind had to wait almost 25 years for an electric generator powerful enough for commercial use.

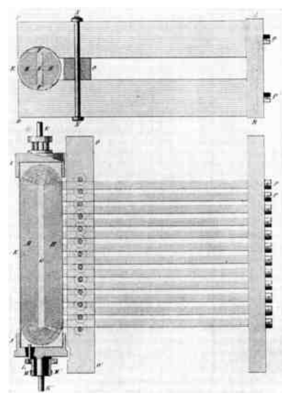


Figure 4: Double-T Armature Winding by Siemens, 1857

In 1856, Werner Siemens builds an electric generator with a double-T armature winding. He became the first inventor to place the windings in slots, a design that almost all electric motors to date are built with. [6] Around a year later, he develops the dynamo-electric machine based on his double-T armature capable of generating sufficient power. The current generated was however in pulsating direct current. Friedrich von Hefner-Alteneck improves Siemens' design by wrapping wire around a cylinder-shaped anchor to produce a smooth DC current. [7]

## 2.3 Contributions to Society

The introduction of the electric motor and electric generator laid down the foundations for most of the technological advancements in society to date. The electricity that is provided in our homes, workplaces, commercial and public areas is generated through electric generators in power plants. Almost all home appliances, such as refrigerators, air conditioners, fans, vacuum cleaners, blenders, and computer hard drives operate with at least one electric motor inside them. Society today would not be able to function properly without the benefits of motors and generators.

# 3 Physics

One of the main requirements of the motor-generator set was its reciprocity. The model was to be robust and able to function as both a motor and generator with the same parts when operated backwards. Therefore, only a few laws unifying magnetic fluxes with electric fields are required to explain the functionality of the motor-generator kit.

## 3.1 Maxwell's Equations

Maxwell's Equations together form the foundation of classical electromagnetics. [8]

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Figure 5: Maxwell's Equations

Only one of these laws are required to explain the reciprocal functionality of the motor-generator kit - the third law - Faraday's Law of Induction.

## 3.2 Faraday's Law of Induction

Electromagnetic induction is the bidirectional process where a changing magnetic field around a conductor, or a conductor moving through a stationary magnetic field, generates (or induces) current.

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

Figure 6: Faraday's Law of Induction

## 3.3 Relating to Coils

Faraday's law of induction can be related to coils to demonstrate the relationship between the electromotive force (induced voltage) and the induced magnetic flux with Figure 7.

$$\varepsilon = -N\frac{\Delta(BA)}{\Delta t}$$

Figure 7: Faraday's Law of Induction Relating to Coils

According to the law, a conductive coil rotating in a uniform magnetic field would induce current. Inversely, if current is supplied to the coil, a magnetic field is generated from it, demonstrated on Figure 8. Once the induced magnetic field properly aligns with the field lines of the already existing magnetic fields, the coil would begin repelling on same poles and attracting on the opposites, causing consistent rotations. The alignment of the fields that the models constructed were based on Figure 3.3.

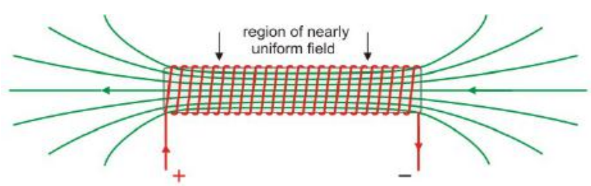
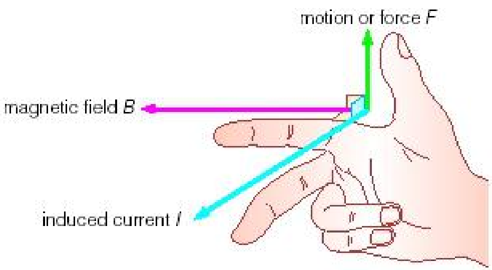
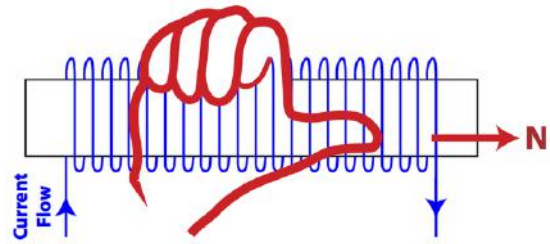


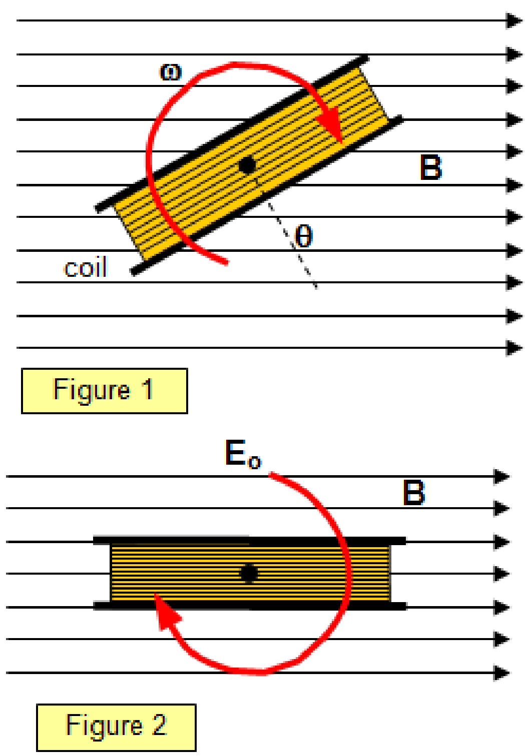

Figure 8: Magnetic Field Lines Induced from Current flowing through Conductive Coil




(a) Orthogonal Relationships Between Magnetic and Electric Fields




(b) The Right-hand Rule Relating to the Direction of the Induced Magnetic Field




(c) Motion of the Coils Used in the Final Models

Figure 9: Magnetic Field Lines driving the Motor-Generator Kit

# 4 Construction

The team was given several weeks to spend on constructing the motor-generator set.

## 4.1 Brainstorming Phase

Construction for the motor-generator project began with a very simple prototype to demonstrate an understanding of electromagnetic induction. A simple copper coil was balanced on conductive paper clips connected to a battery supplying direct current via breadboards. Ceramic magnets were placed under the coil. When the circuit was completed, the coil would rotate due to the induced magnetic fields in it. When the power source was replaced with a voltmeter, the coil was manually rotated to induce up to 40 mV.

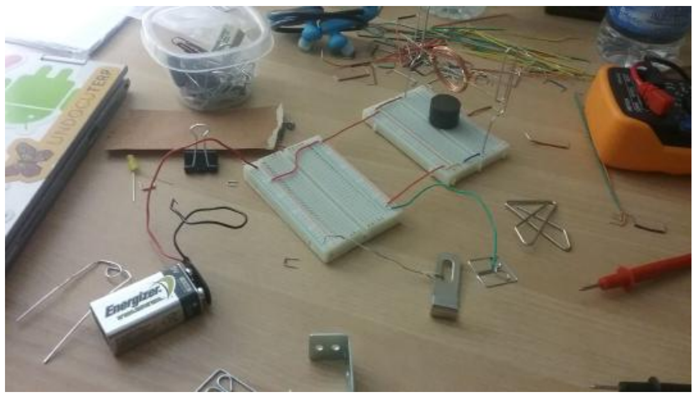


Figure 10: Simple Prototype

## 4.2 Multiple Trials

Creating a model with a spinning coil appeared feasible, until the team realized its lack of mechanical engineering skills and its lack of experience with machine tools beyond a power drill. The coil was upgraded, along with the strength of the magnets and the input power. However, due to an unbalanced coil, poor choices of materials and a flimsy frame, the model failed to yield any results. [Figure 11]

Since balancing the coil proved to be a challenging task by itself, the neodymium magnets became the rotating apparatus in the next design. Magnetic wire was used to coil around an iron hook, with the magnets attached to the armature. Theoretically, the magnetic fields rotating perpendicularly through the coils would generate current. The design however failed to generate sufficient current through the narrow strip of coils. [Figure 12]

A different orientation of the coils were tested and quickly discarded. [Figure 13]

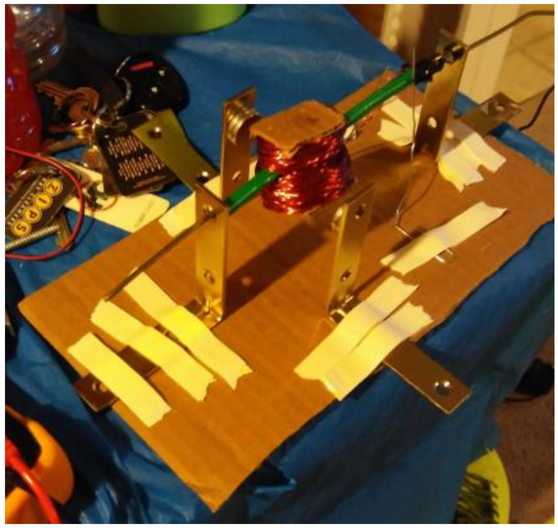


Figure 11: Upgraded Coil Model

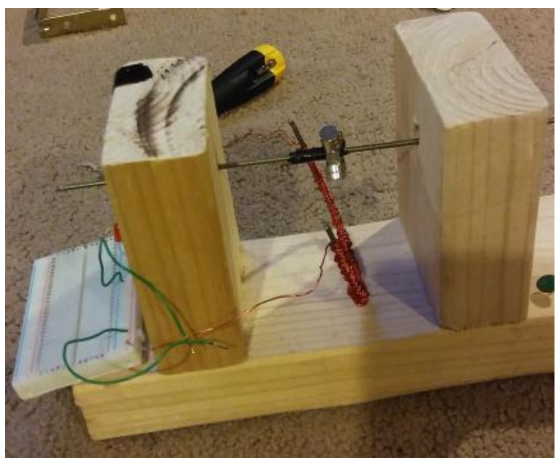


Figure 12: Spinning Magnetic Fields

Figure 13: Spinning Magnetic Fields with Coils in Multiple Orientations

## 4.3 Final Model

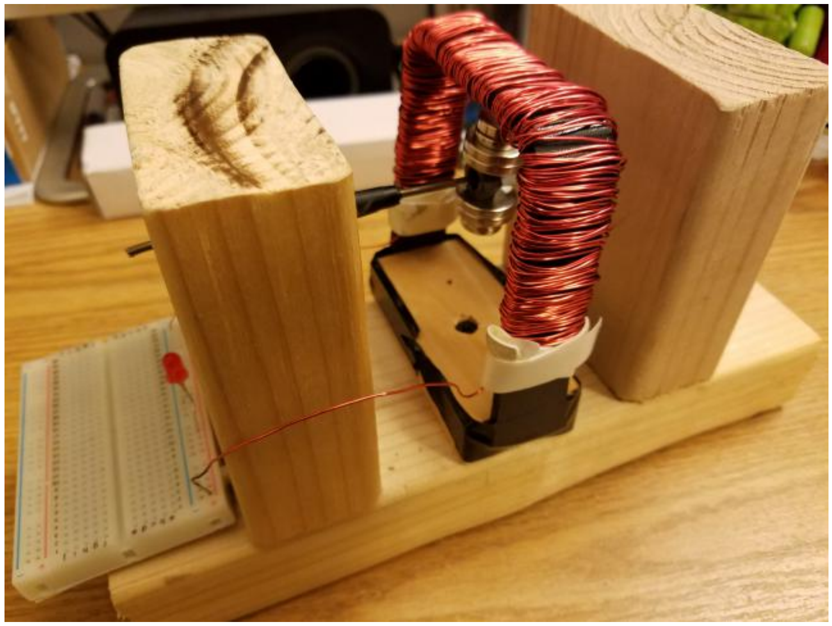


Figure 14: Final Model Demonstrated during Presentation

The narrow strip of coils was upgraded to provide more surface area for the magnetic fields to interact with. The design however did not yield results consistently. Supplying power would only cause the armature to twitch, which may be due to the wire not being tightly coiled, the wire not having ideal conductive properties as expected, or the 9 V input being insufficient. When spinning the armature, a voltmeter would occasionally read minor outputs. Nevertheless, the model failed to achieve the expected results when demonstrated during the team's presentation. [Figure 14]

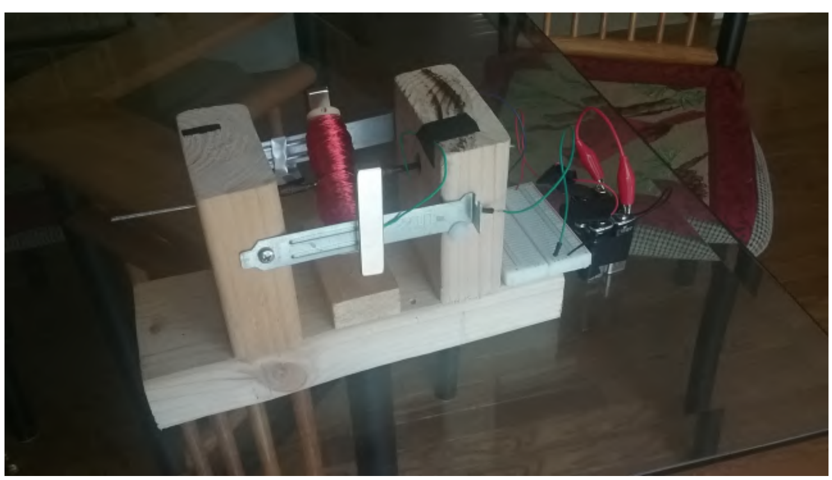


Figure 15: Last Model as a Second Attempt

After the failed attempts to build a reciprocal project, a final model was designed with the idea of spinning the coils through a stationary magnetic field. The input voltage was upgraded to 22 V, bigger and stronger

N52 neodymium magnets were obtained, and a sturdier frame was constructed. When being tested, the coil successfully spun in the magnetic field when the current was allowed to flow through. A power drill was also used to spin the armature to generate almost 120 mV. [Figure 15]

However, the model was tested with multiple members of the team manually holding the leads to act as brushes on the commutators. Constructing the brushes to build a stable, standalone model proved to be the most difficult task. Getting a conductive material to make physical contact with a simple commutator half insulated with duct tape did not appear feasible with the limited materials available. The errors caused by imperfect measurements of the angles and lengths of the brushes and their support mechanisms caused the model to fail to be demonstrated.

# References


[1] Ulaby, Fawwaz T., Eric Michielssen, and Umberto Ravaioli.
"1-1.1 EM in the Classical Era." Fundamentals of Applied Electromagnetics. Boston: Prentice Hall, 2010. 3. Print.

[2] "@. Ampère et l'histoire de l'électricité ." Parcours pédagogique — @.Ampère et l'histoire de l'électricité. N.p., 2005. Web.

[3] Ulaby, Fawwaz T., Eric Michielssen, and Umberto Ravaioli.
"Technology Brief 10: Electromagnets" Fundamentals of Applied Electromagnetics. Boston: Prentice Hall, 2010. 256. Print.

[4] M.H. Jacobi, Mémoire sur l'Application de l'Électro-Magnétisme au Mouvement des Machines, Potsdam, Spring 1835

[5] Pixii Machine
https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/pixii-machine

[6] W. Siemens, Über eine neue Konstruktion magneto-elektrischer Maschinen, Poggendorffs Annalen der Physik und Chemie, Ausgabe 101, 1857, S. 271-274

[7] Von Hefner-alteneck, Friedrich. "Friedrich von hefner-alteneck." U.S. Patent No. 495,674. 18 Apr. 1893.

[8] Ulaby, Fawwaz T., Eric Michielssen, and Umberto Ravaioli.
"4-1 Maxwell's Equations" Fundamentals of Applied Electromagnetics. Boston: Prentice Hall, 2010. 179. Print.