Rotor Powered Battery Charger

Senior Project

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Acknowledgments

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Abstract

Today's society is pursuing a "greener" way of living. This project uses this idea to electricity from one's everyday use of a car. The purpose of this project is to convert the mechanical energy from the rotor in the wheels to electrical energy. A vehicle is always consuming energy in its many moving parts, with so many moving we can make use one of them to convert the mechanical energy into electrical energy. The wheels of the car are moving most the time the car is on so the rotor on the wheels will be an ideal place to capture the mechanical energy. The converting energy will allow for a person to drive car while also reusing the electrical energy to charge a battery. By reusing and recycling this energy, this project will provide a "greener" way of traveling by car.

I. Introduction

Faraday's law of induction states that the induced electromotive force, emf, is equal to the change of the magnetic flux through a closed circuit, with respect to time [1]. There are two different ways to change the flux, one is by altering the magnetic field by changing the current, like in a transformer, and the other way is to move the circuit through the magnetic field. By changing the flux an induced voltage is created as a result of the emf. The induced voltage when loaded will produce a current and therefore power and as the power changes with respect to time energy is also being supplied. This electrical energy is converted from mechanical energy in the case of Faraday's Law, but the electrical energy can be stored for future use, i.e. energy harvesting.

With the push for renewable energy going strong these days, magnetic circuits could be on the rise to help convert mechanical energy from certain products into electrical energy and store it. The harvesting of energy is continually building as the push to find more sources of renewable energy are at an all time high. Consumers are more looking for ways to cut their energy consumption down or to store excess energy, to be used later, as a way to offset the high prices of energy sources like fossil fuels. With the price of fossil fuels at record highs of 2008 still fresh in the minds of consumers, it makes sense to continue the research and designing products that will provide financial relief to the consumers and also help to create a cleaner environment. Some of the most popular ways of harvesting energy today have been through solar cells and wind power; but these things are very huge and must be secured and not able to move. Magnetic circuits can be used to harvest energy on a more portable scale; in everyday devices that are in need of energy constantly, usually supplied by a battery of some sort. Magnetic circuits can help to provide portable energy harvesting and will give a much needed relief to the

consumers and the environment. This project is aimed to build a system which can provide energy harvesting from mechanical energy to electrical energy via magnetic fields.

II. Background

There are all ready a few products on the market today that use Faraday's law to harvest energy through magnetic circuits. Examples are the forever flashlight (as shown in Figure 2-1), a crank flashlight, and EZ Crank radio.

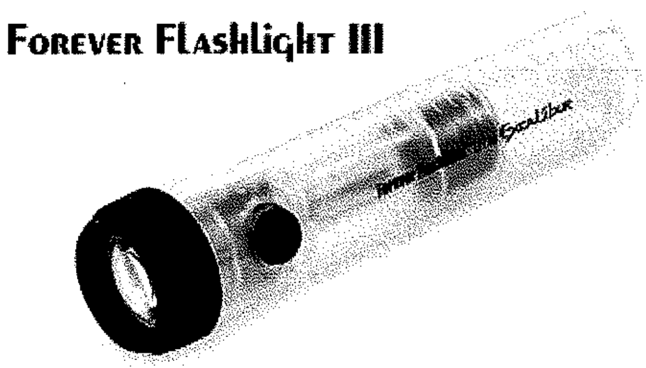

Figure 2-1: Forever Flashlight [2]

These devices are portable and can be used whenever, as long as the battery is charged. In a forever flashlight the magnet inside the flashlight is being shaken back and forth between a conductive copper coil and therefore the flux is changing which causes a voltage to be induced. This induced voltage is used to charge a capacitor and the energy stored in the capacitor powers the light just like a battery would. Both the crank flashlight and EZ Crank radio have a crank that a person must turn to be able to power them. The crank is attached to gears and once turned the gears are connected to a small alternator to charge a capacitor or batteries. The capacitor or battery then runs the flashlight or radio. These products harvest energy, on a small scale, through the laws of electromagnetism [3]. Moreover, according to their manufacturers these devices will work in tens of years from now.

Magnetic circuits used in the above products prove to be useful in cutting down on battery cost since a capacitor is being used instead of batteries. This also saves the environment from the improper disposal of batteries which can cause environmental issues.

Power Electronics is a way to control the flow of energy, with the use of switches, to meet specific requirements needed by the user in the most efficient manner [4]. The output can be in terms of desired voltage, current, or frequency. For this project a desired voltage is needed to be met of at least 1.8 V to charge the AA batteries, therefore power electronics will be used to provide for the most efficient way to get an output voltage of at least 1.8V. In power electronics there are usually feedback controllers to help minimize the error for the desired output. Efficiency is a huge constraint for this project because converting mechanical power to electrical already causes lots of losses in the form a mechanical losses, losses from the copper coil, and frictional losses.

The objective of this project is to follow the concept of using a magnetic circuit to draw and store energy for later use. The magnetic flux will be created from movement of the magnetic field on the car's rotor. The energy produced while the car is moving will be used to charge small size batteries via power electronics. Hence, this device will be most useful particularly to those people who do daily commute in their car while at the same time harvesting the readily available energy from their moving car to charge batteries.

III. Requirements

The idea behind this project is to build a rotor powered battery charger. A car rotor will be used to make a permanent magnet move back and forth through a copper conductive coil. As the magnet moves, the strength of the magnetic field in the copper coil changes causing magnetic flux to change. The changing flux in turns induces a voltage which produces current when loaded. To do this the rotor will have arm attached to it which will rotate at the point connected to the rotor. The arm will be attached to a plunger with another point of rotation where the two are connected. The magnet is attached to the plunger. As the rotor spins the arm will cause the plunger and the magnet to move back and forth through the copper coil similar to a piston. A simplified diagram of the proposed system is shown in Figure 3-1.

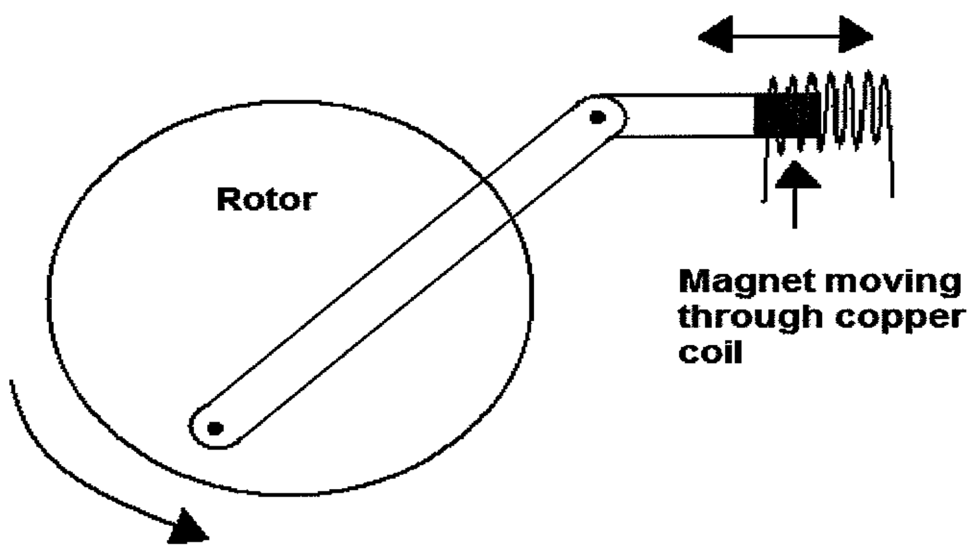

Figure 3-1: Diagram of proposed rotor design

The system for the rotor powered battery charger must be placed in an area in the car to keep it from breaking and yet in a place close enough to the rotor for the circuit to work. This requires the

circuit to be as small as possible, to fit under the car. Also the circuit should be small in size such that it can be easily assembled onto the car itself.

The voltage induced by the proposed rotor-magnet system needs to be large enough to be able to charge the batteries. This is estimated to be around 3V to charge to AA batteries. To increase the voltage, a boost converter is needed to pump up the voltage appropriate for the battery charger. The boost converter is a step up DC to DC converter, but the output of the emf from the magnetic flux is AC. There are two solutions to this: one is to replace the boost converter with a step-up transformer and the other is to rectify the output into a DC voltage. Since one of the requirements is for the system to fit under a car, the transformer isn't the best solution since they are relatively huge compared to a boost converter. Hence, the AC output voltage will go into a full wave bridge rectifier. The DC output from the rectifier can now be increased, while still being able to meet the size requirement.

The mechanical energy will be converted to an electrical energy by the proposed project through the induced voltage, and the electrical energy produced will be used to charge AA batteries. Once the AA batteries are charged the electrical energy will be used at another time and therefore energy harvesting has taken place. The main requirement for this to work is the electrical energy being large enough to allow it to be harvested. There are a couple things that could help in making sure the conversion is successful and that there will be enough energy harvested. Some of the ways to increase the energy is increasing the number of copper windings, using a stronger magnet and also decreasing the reluctances which would involve getting a wire made of more conducting material. Testing will help to figure out how much energy will be needed to supply enough to store it in the batteries.

The final project will be a working prototype to show the concept of how the system would work in a moving car. The final hardware will consist of a piece of wood which would act as the bottom

of the car where the system would be attached. A DC motor will provide act as the rotor movement from the pulley attached to the rotor. A boost converter will be the battery charger and a forever flashlight will act as the shaft and have the copper coil with the magnet going back and forth.

IV. Design

A. Mechanical Subsystem

A car rotor is pretty heavy and bulky, so for the design a model rotor will be created out of lighter material to help with transporting the rotor system. The rotor will be designed from a piece of thick plastic, since it's a strong and light material which can be easily shaped and drilled into, shown in Figure 4-1.

Figure 4-1: Plastic rotor connected to metal flange and rod.

Also the system will not be directly implemented into a car so the rotor system will have a way to be spun to help for testing and in demonstrating the final rotor powered battery charger, to rotate the plastic rotor a high torque DC motor, seen in Figure 4-1, will be used since its relatively small and will be

easy to couple to the system. The motor will be placed under the system so as to not prevent the flange from moving.

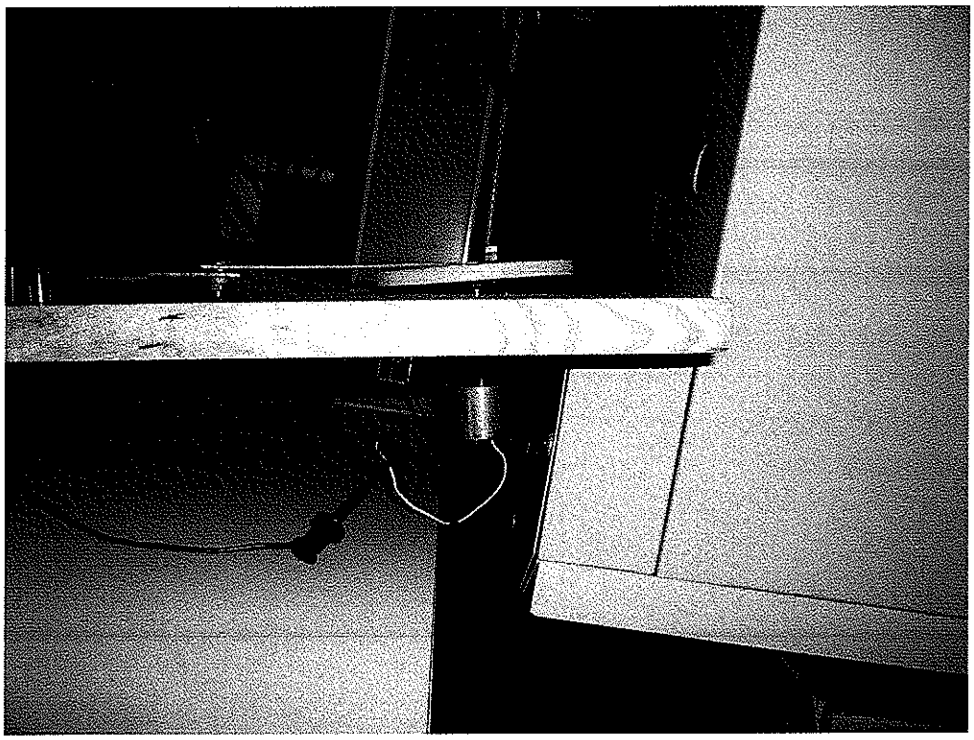

Figure 4-2: DC motor under the system being supplied a DC voltage

As the plastic rotor spins, the arm will be attached to a point on the designed rotor at which the arm will be able to rotate, the arm will be a flat metal flange which will allow for a hole to be drilled so it can be attached to the plastic rotor. This arm is attached to a plunger at a point at which the arm will rotate but the plunger will be secured, so it can only move back and forth, the plunger will a small metal rod to allow for it to move back and forth through the casing that houses the magnet. As the rotor turns the arm will rotate around the rotor and the since it's attached to the plunger, the plunger will move back and forth as the distance changes as the arm moves to the other side around the rotor. The plunger is

then attached to the magnet and when the plunger moves back and forth the magnetic field in the copper coil is changing causing the flux to change.

B. Electrical Subsystem

The electrical subsystem begins at the copper coil which is then attached to a full wave rectifier to change the induced voltage in a DC voltage; this is shown in Figure 4-3.

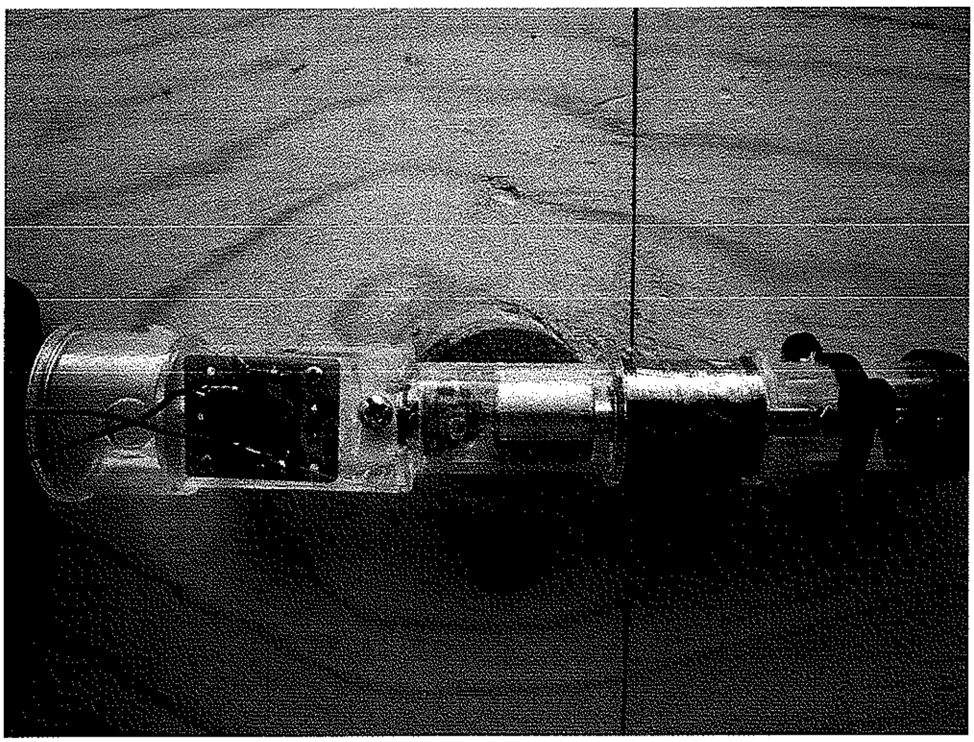

Figure 4-3: Magnet moving through the copper coil, output is connected to rectifier

The DC voltage is needed because a boost converter is being used to step up the voltage and it is a DC-DC converter. The DC output is then connected to the input of the battery charger as seen in Figure 4-4.

Figure 4-4: The input of the battery charger

The battery charger design will be from a previously designed and built battery charger but the boost converter will replace the circuitry already in the battery charger. The boost converter is needed to step-up the voltage to be enough for the batteries to charge, the boost converter is seen in Figure 4-5.

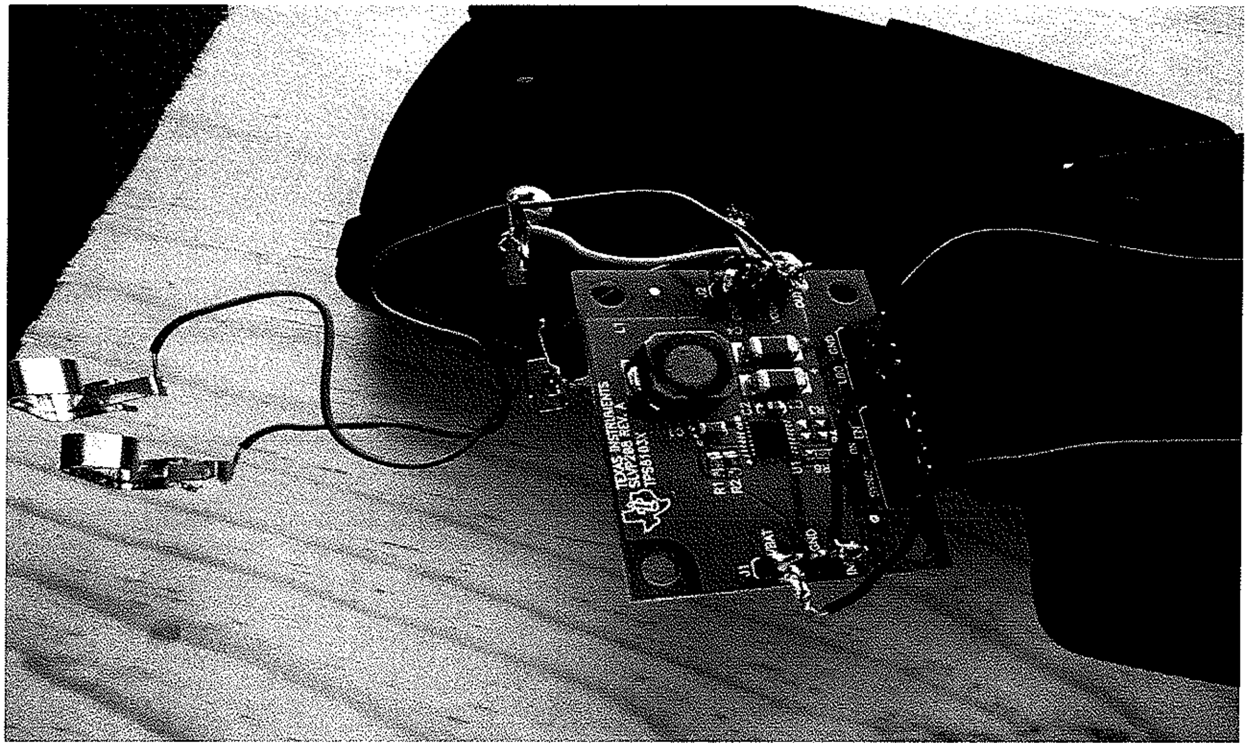

Figure 4-5: Boost converter with input from rectifier and output to charge batteries

As the rotor spins around, the arm will cause the needed movements of the magnet to charge the battery. The battery can only be charged when the rotor is moved which corresponds to a car moving. This is a requirement that has to be met.

V. Test Plans

To test the rotor powered battery charger system, the rotor will be spun, to induce the voltage needed to charge the AA batteries. Each AA battery needs a voltage of about 1.5V per battery to be able to be charged. The boost converter will step the voltage up to 5 V if the input voltage operates between the 1.5V to 5V, so the input to boost converter must be tested to check the voltage. A no load test will be performed, as seen in Figure 5-1, to check whether the output voltage is enough to provide a charge for the batteries.

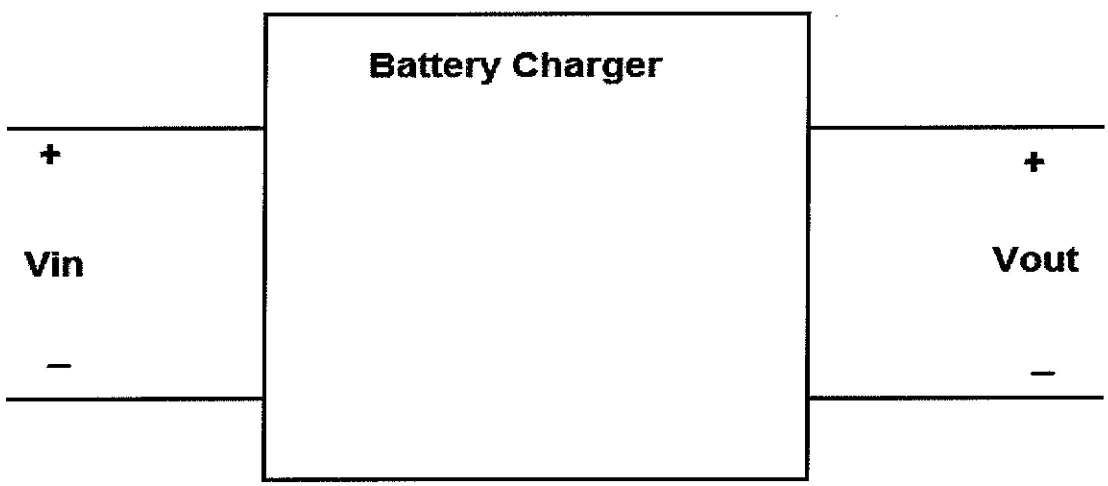

Figure 5-1: No Load Test

Once the voltage is obtained a load test will be performed, as seen in Figure 5-2, to obtain the current produced as the batteries are being charged.

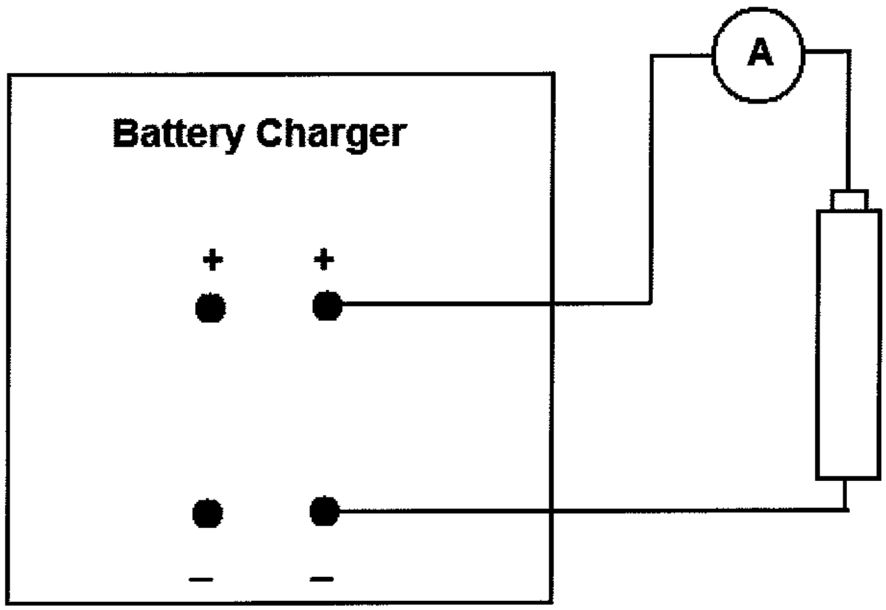

Figure 5-2: Load Test

The current will affect the time it takes the batteries to charge. So the lower the current the longer it takes the batteries to charge and the faster the current the quicker the batteries will charge. The current is related to the magnetic field intensity and the number of turns of the copper coil. Therefore, if the current is not enough for the batteries to charge in a decent amount of time things can be adjusted. The boost converter output is rated at 1 A therefore the current can't be higher than this.

A DC motor will be attached to the rotor so testing will be made easier. The DC motor is rated at 12 V, 200RPM, and 3.3 inch*lbs of torque. Since the DC motor is being used calculating efficiency from the input of the motor to the electrical output will help to see if the system can be expanded. To calculate the efficiency the DC motor will be run at the rated speed to make the input calculation easier. DC motors have a direct relationship between the applied voltage and the running speed, the output current will be measured as the input voltage is increased in steps of 1V. The output current will be

graphed with the input voltage. The output current will be used to calculate the charge time of the AA batteries to full capacity, and the relationship will be graphed on the same graph.

VI. Development and Construction

As development began there were a few problems with the original design, such as the arm getting in the way of the parts all ready on the rotor itself. So the design was altered so that a pulley system would be used with belt wrapped around the rotor and the arm attached to the pulley as seen in Figure 6-1.

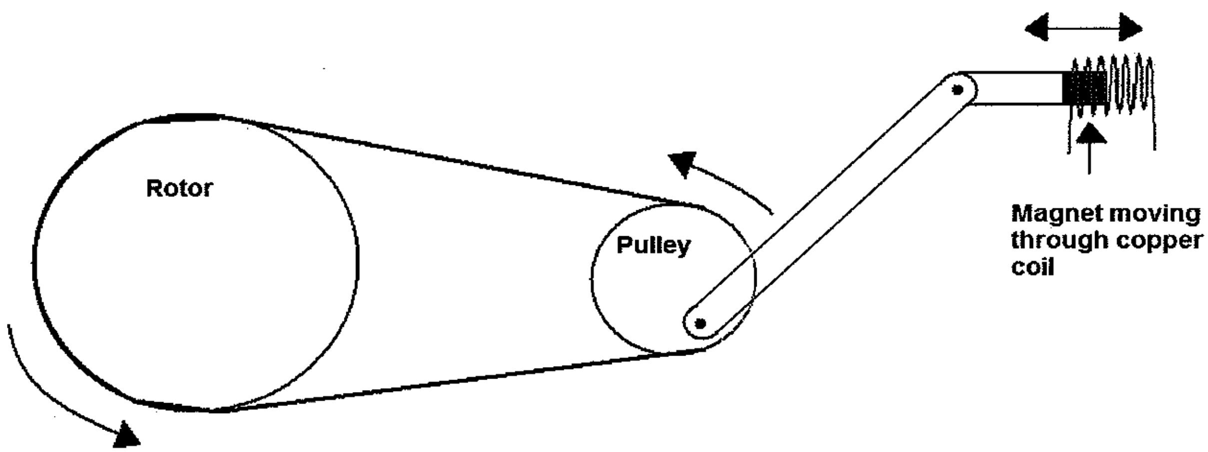

Figure 6-1: Updated System Design

As the rotor spins the belt will cause the pulley to spin and the magnet will travel back and forth through the copper coil as a result of the moving arm.

Many of the things that are used to design the system have already been designed, so instead of reinventing the wheel, these things were used. This included the boost converter and the forever flashlight which all ready had the magnet and the copper coil which made the construction go a little smoother. The forever flashlight was also used to house the magnet as it moved back and forth through the copper coil. The boost converter used is from Texas Instruments, it's 96% efficient 5 V output boost converter.

The system was constructed in two different stages, the electrical stage, consisting of the magnet, copper coil, rectifier, boost converter and battery charger, and the mechanical stage, consisting of the pulley, arm, shaft and a way to move the pulley. For the electrical stage the copper coil was all ready wound around the magnet, which was all ready in its own shaft. The copper coil leads then need to be input into a full wave bridge rectifier to get a DC input for the boost converter. The DC output from the rectifier is then soldered to the input of the boost converter. The output of the boost converter was then connected to the contacts of the battery charger; the contacts of the battery charger were taken from the original circuitry.

To construct the system to be best implemented into a car, the system was built without the rotor and on a piece of wood. The wood represents the bottom of a car so one could see how to implement the system under a car. The pulley is fastened onto the piece of wood loosely as to create enough room for rotating. Since the pulley isn't currently connected to the rotor the pulley was given a handle to crank so the pulley would rotate. As the handle is cranked the pulley rotates much like it would when attached to the rotor and causes the metal flange to move back and forth. The metal flange acts as the arm for the system and is connected to the rod that is attached to the magnet. When being rotated the arm would move around, so a guider was attached to make sure the rod only moved back and forth through the shaft. The flange is connected to the rod by a screw fit loosely as to allow rotation at the point of connection. And the rod is connected to the magnet with some epoxy as to make sure the rod doesn't get detached from the magnet while the system is in use. Figure 6-1 shows the final prototype of the proposed system.

VII. Test Results

To integrate the system onto a car, or any other rotor, the system needs to be securely fastened close to the rotor. Then a belt will be placed around the rotor and the pulley of the system to operate correctly. Once the car, or another type of rotor, starts to move, the pulley will also move causing the system to charge the batteries. To make sure the system was operating at the desired requirements testing was done.

At a 12 V input into the motor, the speed of the motor is 200 rpm and the torque is 3.3 in*lb, the output voltage is 4.94 V as seen in Fig 7-1, the output current is 454 mA.

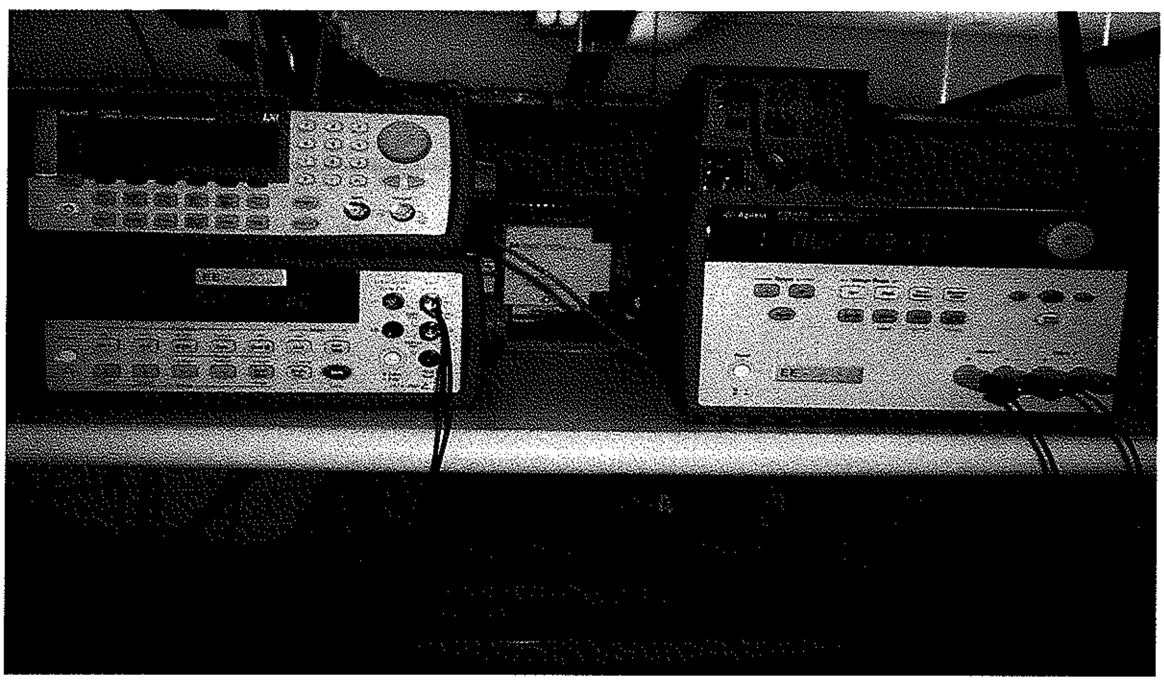

Figure 7-1: Input Voltage of 12 V and Output Voltage of 4.94 V

The input power at rated speed and voltage was approximately 7.83 W and the output power was about 2.24 W, which corresponds to an efficiency of approximately 28.6%. Converting mechanical power to electrical power results in a lot of losses which explains the efficiency being so low.

The next test was testing the open circuit voltage and the short circuit current as the motor's input voltage was increased therefore increasing the motor's speed. For the open circuit voltage measurement the output of the multi meter was placed across the terminals of the battery charger, which is the output of the boost converter, as seen in Figure 7-2.

Figure 7-2: Open Circuit Voltage Test Set-Up

The circuit didn't reach the required voltage to turn the boost converter on until the motor was run at 6V as seen in Table 7-1.

Table 7-1: The measured OC voltage and SC current as DC motor input voltage increases

Motor input Voltage (V)	Open Circuit Voltage (V)	Short Circuit Current (A)
1	0.58	0.0095
2	0.76	0.0187
3	1.03	0.0412
4	1.26	0.0556
5	1.42	0.077
6	4.79	0.141
7	4.89	0.169
8	4.94	0.226
9	4.94	0.257
10	4.94	0.302
11	4.94	0.377
12	4.94	0.454

The short circuit current corresponds to the charging current, or output current for the battery charger. The relationship between the input voltage and the short circuit current is a positive exponential relationship as shown by the graph in Figure 7-3.

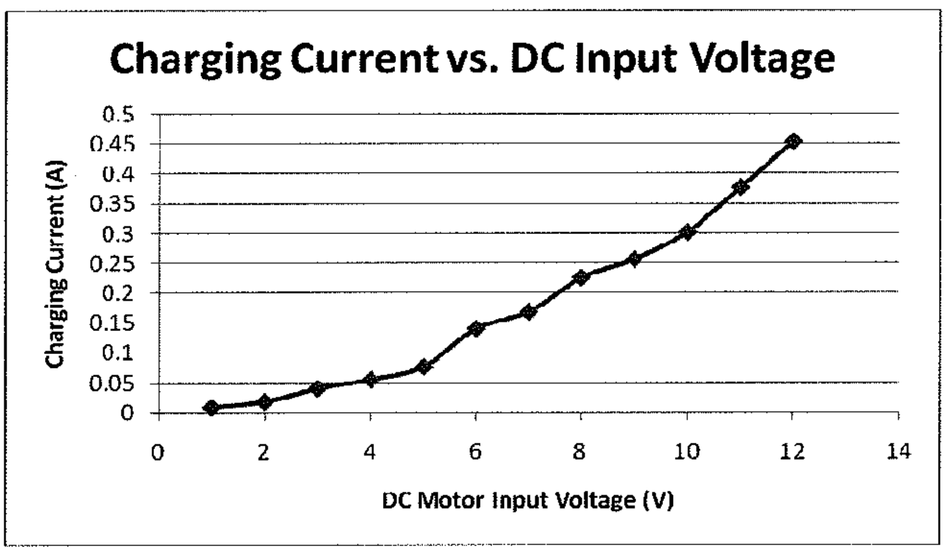

Figure 7-3: Charging Current vs. DC Input Voltage

Charging current determines how long it will take a fully discharged battery to be fully charged. For each battery, there is a charge rating that is equal to the amount of current it takes for each battery to be fully charged in one hour. To calculate the charging time for a battery to be fully charged is to take the rating and divide it by the short circuit current. For each of the batteries used in testing the rating was 1000mAH. The relationship between charging current and charging time is shown in Table 7-2.

Table 7-2: Charging Current and Charging Time Results

Iout (A)	Charging Time (Hr.min)
0.0095	105.16
0.0187	53.29
0.0412	24.16
0.0556	17.59
0.077	12.59
0.141	7.06
0.169	5.55
0.226	4.26
0.257	3.53
0.302	3.19
0.377	2.39
0.454	2.12

As seen from the table the more current the battery receives the faster the battery will be fully charged. There is an exponential relationship between the charging current and charging as seen in Figure 7-4.

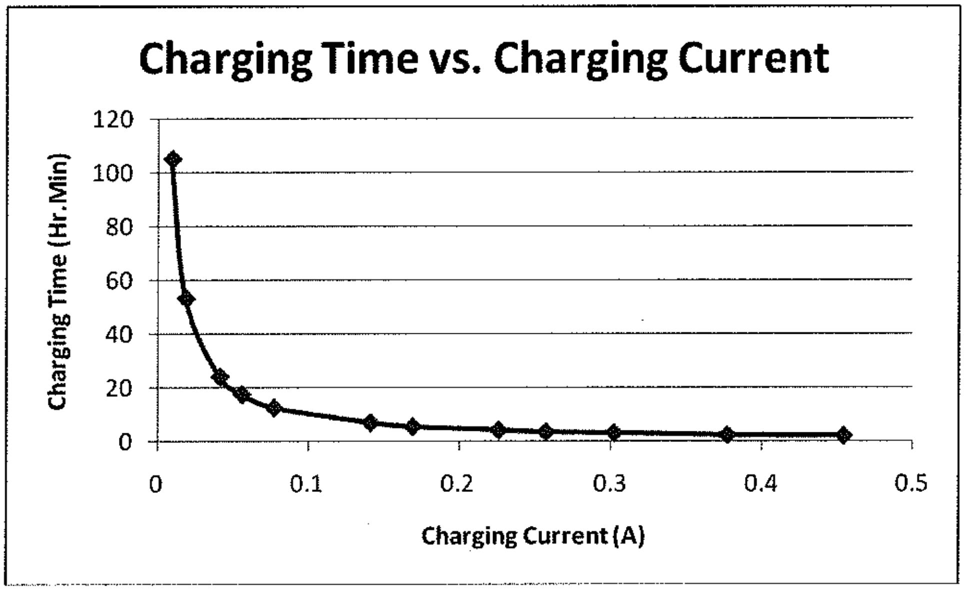

Figure 7-4: Relationship between charging current and charging time

The charging current increases as the input voltage to the DC motor increases which corresponds to the speed of the motor. Therefore as the car drives at a faster speed the batteries will charged quicker.

The data shown proves the system is producing the voltage needed to input into the boost converter to charge the double A batteries. As hypothesized the faster the motor spun the more current was produced which made the batteries charge faster. The charging time was checked by placing a fully discharged battery into the charger, the DC motor was running at 12V, and it took about an hour and 47 minutes, which is a percent error of about 20%.

VIII. Conclusion

Overall the project was a success. A constant voltage charger was created, which would allow double A batteries to charge while the rotor of a vehicle is moving whether it is a car, bike, or even an electric wheelchair. Since the charge is a constant voltage charger, as long as the system is running the voltage will be 5V. The typical AA battery is about 1.2V to 1.8V, so the 5V output for the batteries is plenty for the batteries to charge. The output voltage is higher than needed; over time this will cause the batteries to be overcharged. The faster the rotor moves, the faster the batteries charge. The positive relationship between the speed of the car and the speed of the batteries being charged means the faster the vehicle moves the quicker their batteries will charge.

A few improvements to be applied to the system would be to get a stronger magnet which increases the magnetic field which can increase the current. Another way to increase the current would be to increase the number of copper windings in the copper coil. Increasing the current will also decrease the amount of time to charge the batteries. Another useful improvement for the future would be to add a voltage detector to know when the batteries have reached full capacity. When the batteries reach full capacity a switch could be added to stop charging the batteries to prevent from over charging the batteries. Currently the charger only charges two double A batteries, an increase in the number of double A batteries to be charged would be less time consuming for the user in need of more batteries.

IX. Bibliography

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Appendices

Parts list and Cost

Battery Charger	$10.00
Metal Flange	$2.95
TI 96% Efficient Boost Converter	$50.00
Forever Flashlight	$10.00
Metal Rod	$2.00
Nuts and Bolts	$2.65
12" x 4' Piece of Wood	$3.75
Plastic Pulley	$3.35
DC Motor	$10.00

Schedule

		Rotor Powered Battery Charger																				
		Jan			February				March					April				May				June
Start	End	12th	19th	26th	2nd	9th	16th	23rd	2nd	9th	16th	23rd	30th	6th	13th	20th	27th	4th	11th	18th	25th	1st
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