Project Proposal and Feasibility Study (PPFS)

Engineering 339 Senior Design

Team 8: Batteries Not Included

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Abstract

Tire Pressure Monitoring Systems (TPMS) enhance automobile safety by keeping drivers informed of their tire pressure. A problem with the pressure sensors is their reliance on battery-power; batteries eventually wear out. The goal of *Batteries Not Included* is to design and build an alternative energy source that provides reliable, longer-lasting power to the sensors. Magnetic induction is the proposed solution to the problem of powering the sensors. This design essentially converts the kinetic energy of the rotating wheels to electric energy by passing a coil through a magnetic field; relative motion of a coil in relation to a magnet produces current in the coil which can power the pressure sensors. Calculations show that the design is feasible. Alternative design solutions were considered; however, this study reveals that magnetic induction is the most practical and cost-effective choice.

1. Introduction

Tire Pressure Monitoring Systems are becoming more and more popular on vehicles each year. They are an important safety feature that helps to prevent accidents caused by blown tires. A TPMS offers real-time monitoring of tire pressure so that the driver can be notified if a slow leak has occurred. Figure 1 shows a typical TPMS [2]. Current systems use wireless sensors located inside the tires to send pressure readings to a receiver; the reading is then displayed to the driver. A downside with these sensors is their limited battery life and consequent necessary battery/sensor replacement work. Battery or sensor replacement is either a hassle for the user to carry out or an expense that the user must pay in order to further use the TPMS. The goal of this project is to develop an alternative energy source for pressure sensors that will last longer than conventional batteries. Thus, the proposed power system should significantly extend the working life of pressure sensors, perhaps to second and even third owners of vehicles. The proposed design should also alleviate the burden of system maintenance by eliminating the need for battery replacement.

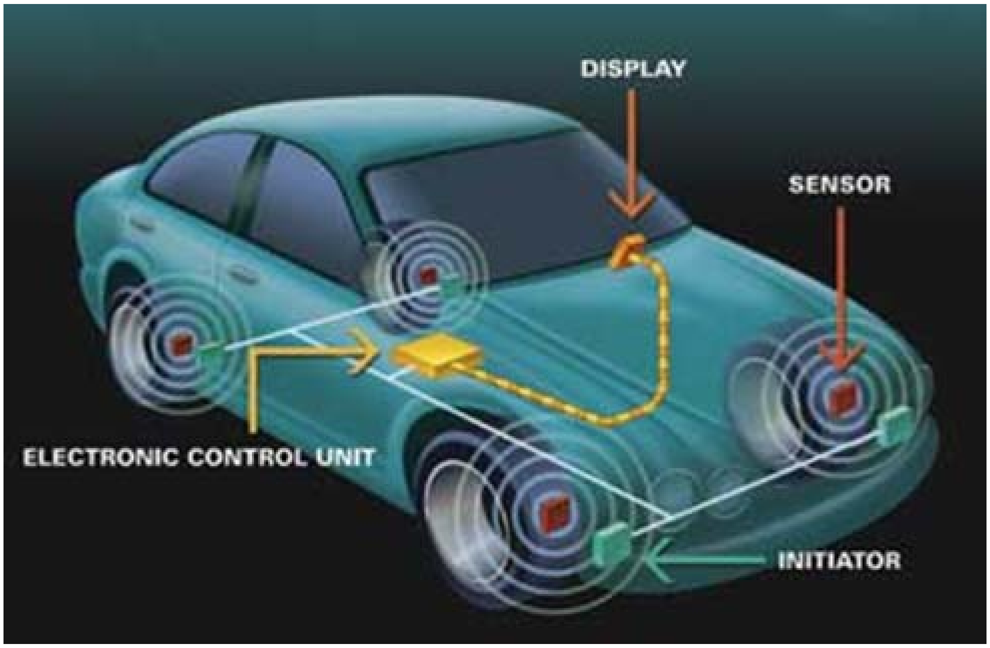

Figure 1. A Typical Tire Pressure Monitoring System [1]

2. Project Goal

The goal of this project is to eliminate the need for batteries on TPMS sensors. An alternative energy source for pressure sensors that will last longer than conventional batteries is desired. Thus, the proposed power system should significantly extend the working life of pressure sensors. The new design should also alleviate the burden of system maintenance by eliminating the need for battery replacement.

The challenge in this project is to design a method to generate, use, and store enough electric power to enable the tire pressure sensor to operate continuously. Once the power system has been created, it needs to be attached to the rim inside the tire and field tested. Challenges also lie in the mechanical setup of the power system as the proposed design should not interfere with any other existing vehicle systems. The complete product could be used in a variety of tire applications in the commercial automotive market. Figure 2 shows a typical setup of the tire pressure sensor [4].

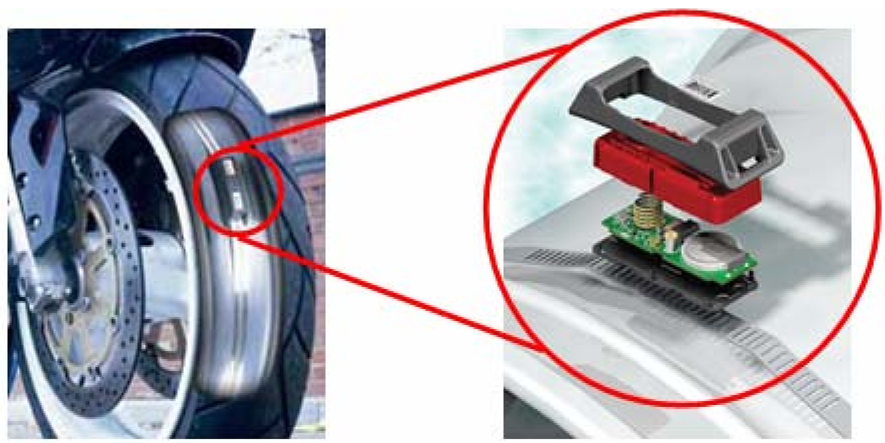

Figure 2. A TPMS Sensor [2]

3. Project Objectives

The objectives for this project are threefold. First, our main goal is to attain battery-free tire pressure sensor operation. This will hopefully extend the working life of pressure sensors significantly. Complementing the goal of battery-free sensor operation is the need for an innovative mounting solution to hold the proposed power system. The mounting implementation must be both robust and easy to replace. Finally, the power system along with its mounting apparatus must be priced competitively. A tire pressure monitoring system incorporating the proposed power system must not be significantly more expensive than current models. An explanation of design functionality and design requirements will more fully articulate our project objectives.

3.1 Design Functionality

The proposed power system's functionality must be specified. Sensors using the alternative power system must run as they are intended to when using battery power. Mounting will have great influence on the strength and rigidity of the system.

3.1.1 Increased Operating Life of Sensors

Regardless of the solution design chosen, the main purpose of the project is to increase the operating life of a tire pressure monitoring system. The working lifetime of the sensors should be extended by the realization of a new power generation system. An extended working lifetime of the tire pressure monitoring system should allow both original and successive vehicle owners to benefit from this safety feature.

3.1.2 Continuous Sensor Operation

The proposed design must implement continuous sensor operation; continuous operation includes the initial start of the vehicle. A driver should be able to know his or her tire pressure before they leave the house. Ideally, design solutions will use energy generated from the motion of the automobile (energy that is normally wasted) to power tire pressure sensors. Regardless of the solution design chosen, the system will require some type of external power storage which will allow the sensors to give an initial reading before the vehicle has moved.

3.1.3 Alternative Energy Operation

The final design must include an alternative energy source for sensor operation. The idea of a rechargeable battery is in consideration, but this design would still require an external energy source for battery charging. The power source chosen will ideally use kinetic energy associated with a moving vehicle to power the sensors, eliminating the need for a battery. The power source must be able to operate the sensor continuously. Any option chosen to power the sensor must provide for an increase in the system's working lifetime.

3.1.4 Innovative Mounting Technique

The design must provide a strong, robust solution for mounting the new power system. In addition, the power system must be easy to replace in the event that it is damaged. Furthermore, inherent pitfalls seen in current sensor designs must be avoided. For example, current sensors mounted in the valve stem are often broken when tires are being replaced. The valve stems are cracked to release pressure from the tire, which in turn damages the sensors and requires them to be replaced. The new design must include a mounting solution that allows tires to be serviced and replaced without damaging the sensors.

3.2. Design Requirements

In addition to meeting the specified design functionality criteria, successful completion of this project requires the implementation of certain requirements inherent to designing a battery-free tire pressure sensor. Market factors such as pricing, consumer need, and vehicle system interference must be considered. Federal laws must also be considered and obeyed.

3.2.1 Competitive Industry Pricing

Mass-production of the proposed design must be economically feasible. The increased safety benefits of a battery-free tire pressure sensor will only be realized in the market if the product can be produced at a cost low enough to make it economically viable for production companies. The aspect of price is extremely important to consumers and, in turn, automotive suppliers; this will be a large focus of the design.

3.2.2 Design Serviceability

Due to the fact that serviceability is a major issue with existing systems, this will be a large focus of the design work. The final design must be robust, but it must also be easily replaceable if damaged. The design must function in such a way that damage to the system components is not an issue during vehicle services such as tire replacement.

3.2.3 Vehicle Systems Effects

The final design can in no way impede vehicle performance. Research must be done to insure that introducing the new power generation design to the vehicle will not affect performance of anti-lock braking systems (ABS), normal braking systems, wheel rotation, or other important vehicle operations. Effects on the vehicle will be different for each design, so this will be a factor that helps narrow down the design alternatives to a final option.

3.2.4 Transmission Signal Considerations

Due to the fact that the sensors transmit wireless signals, they are regulated by the Federal Communications Commission (FCC). Changes in sensor design can in no way affect the sensors' compliance with FCC regulations. Signal integrity is also important for the functionality of the tire pressure monitoring system. A power generation system creating any adverse effects on a sensor's transmission of data to the driver's display inside the vehicle is not desirable.

4. Alternative Solution Designs

After several brainstorming sessions, the design team considered possible alternative solution designs. The proposed solutions below represent the most reasonable ideas generated by brainstorming sessions. All alternatives generate power for the tire pressure sensors by converting energy produced by normal automobile operation to electric power. The following power generation ideas will be expounded upon in this section: magnetic induction, piezoelectric power generation, thermal energy recovery, wind power generation, and pressure-induced power generation.

4.1 Magnetic Induction

The kinetic energy of the rotating wheel can be converted to electrical energy. Electromagnetic induction could be used for this energy conversion. If a magnetic field is moved in close proximity to a coil, a current is induced in that coil. Motion of an automobile wheel could be used to induce a current that could potentially power a pressure sensor.

The electrical aspect of this design is obvious; enough electric power must be generated in order for a tire pressure sensor to function normally. The mechanical aspect of this solution is mounting the power generation system. There is a significant challenge in the mounting of both the magnet and the coil. Our initial solution would be to mount the magnet on top of the caliper, which is stationary in relation to the spinning wheel. A coil would be mounted on the inside of the rim parallel with the magnet so that as the wheel spins, the coil passes by the magnet and induces a current. Leads off the coil would pass through the wall of the rim and connect to the sensor inside. (see Figure 3 below)

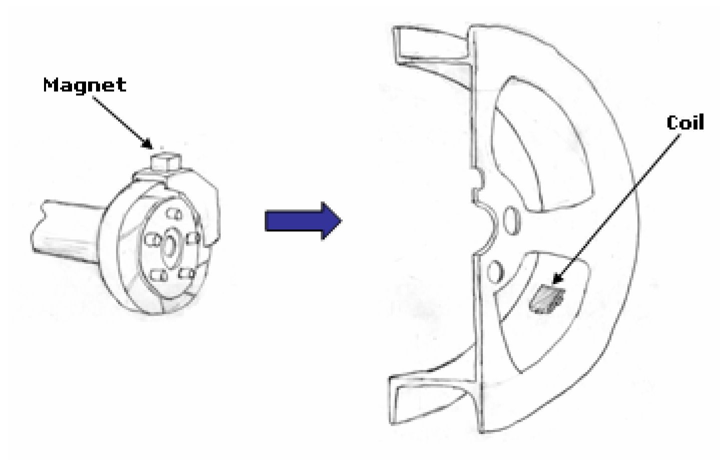

Figure 3. Magnetic Induction Design Solution

4.2 Piezoelectric Application

Another option for the conversion of kinetic energy is the conversion of wheel vibration and rotational energy to electricity. A piezoelectric device could be mounted in the suspension system or wheel of the vehicle. Piezoelectric devices produce electric energy when they are mechanically stressed. Using this technology, road vibration and wheel rotation could be used to power the pressure sensor.

For the piezoelectric option, the challenge in mounting would be to find a way to place the whole sensor inside the tire and retain proper wheel balance. Due to the nature of the energy conversion, there would be no need for wires to pass through the wall of the rim. Instead, the piezoelectric device would be mounted inside the rim, presumably mounted opposite the sensor so that the wheel could be more easily balanced. This power system would be able to take advantage of vibration of the wheel, the rotation of the wheel, and/or the air pressure inside the tire to produce electric power. (see Figure 4 on the next page)

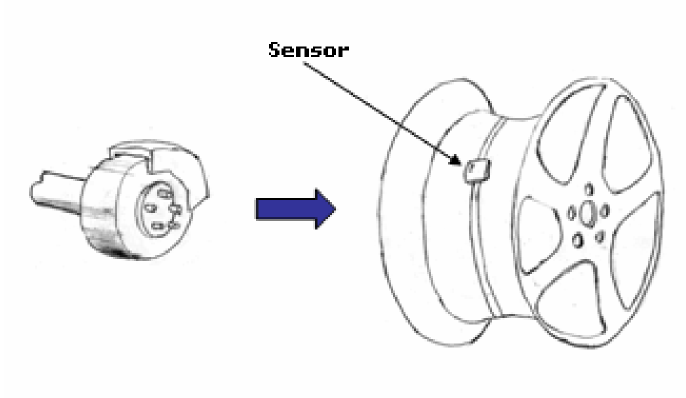

Figure 4. Piezoelectric Power Generation

4.3 Thermal Energy Recovery

Another option considered is that of converting heat energy associated with braking activity to electric energy. Thermocouples are a proposed means of accomplishing this energy conversion. A thermocouple is a pair of dissimilar metals joined together which produces a voltage when the two sides of the metal junction are exposed to different temperatures. Brake pads and rotors are hot under normal driving conditions. If one side of the thermocouple could be mounted inside or next to the brake pad, and the other side of the thermocouple could be mounted in an ambient temperature environment, perhaps enough electric energy could be produced to power the tire pressure sensor. An auxiliary system would be desirable for use when the brakes are not hot.

The mounting for the thermocouple approach would require that a wire be run through the wall of the rim. The idea behind this approach would be to mount the joint end of the thermocouple to the rotor or brake pad. The thermocouple would be run down the rotor to a contact that would join to a similar contact on the inside of the wheel. The thermocouple voltage signal will travel up a lead to a point below the sensor. A hole could be drilled through the rim, and the power signal of the thermocouple could be applied to the sensor. (see Figure 5 below)

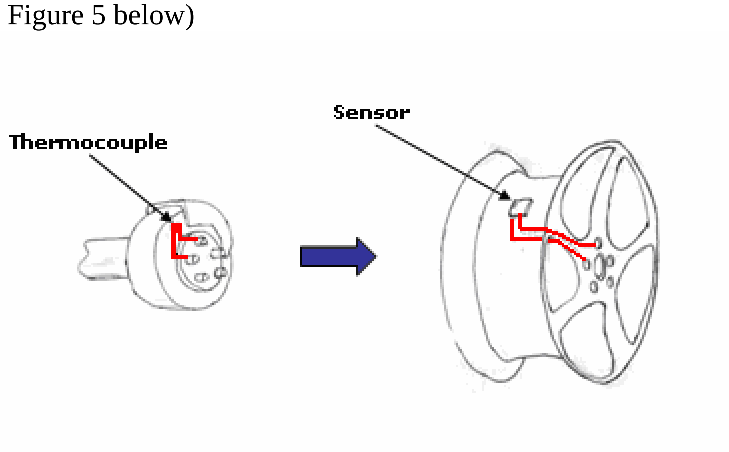

Figure 5. Thermal Energy Recovery Power System

4.4 Wind Power Conversion

Wind power generation was proposed as a solution to the problem. Brakes are often cooled by directing air from the front fascia to the brakes via air ducts. "Wind" is created in the ducts by the relative motion of the vehicle in with respect to the air around it. A small turbine could be placed in a brake duct. As the wind spins the turbine, the rotational energy of the turbine could be used to power a small electric generator. This generator could potentially power a pressure sensor and charge an auxiliary power storage element. Auxiliary power will be necessary as the turbine will not rotate when the automobile is stopped.

Mounting the wind power system would be product specific. Applications would be limited to vehicles with openings in the front fascia large enough to accommodate the fan-generator unit housed in an air duct. Transmitting the power to a rotating object, such as an automobile wheel where the tire pressure sensor resides, requires some application of motor brushes. This could be done via caliper – rotor interaction. (see Figure 6 below)

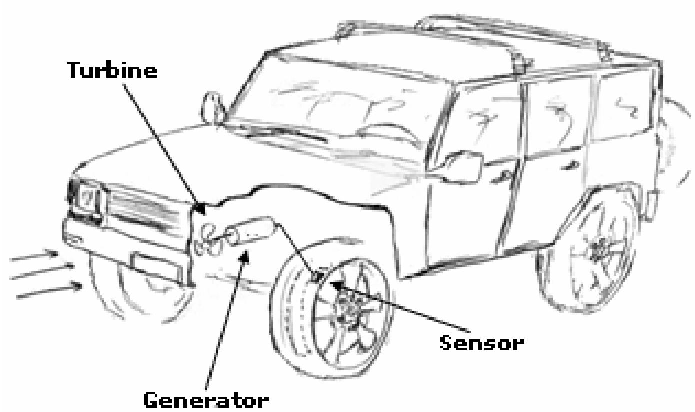

Figure 6. Wind Power Generation System

4.5 Pressure Induced Power

Another option was found in the Engineering Index research database: the abstract for a journal article mentioned a way to change a physical pressure signal directly to electric power. Not many of the details on this option are known as the Hekman Library did not have the article; it had to be ordered through inter-library loan. A guess is that this device could be a form of sensitive piezoelectric technology. When pressure is exerted on the device, a proportional voltage is produced.

The mounting solution for this approach would largely depend on the size of the device itself. If the device is very large, additional calculations would be needed to assess the forces caused by the rotation of the wheel during normal use.

4.6 Extended Battery Life

Should the aforementioned solutions prove unfeasible, a method to drastically increase battery life will be implemented. Power generation methods explained above could be used to charge a sensor's rechargeable battery.

5. Feasibility Study

The alternative solutions presented above were researched in order to gage the viability of each. Component cost and power generation capability were the most important factors in deciding whether or not a design was feasible. Design complexity was another factor considered.

5.1 Magnetic Induction

Research into the feasibility of the power induction solution proved to be fruitful. Wire used for the coil is assumed to be less than $10. Also, powerful magnets can be attained online for relatively low cost. About 10in.^{2} of magnetic material can be bought for $15.30 [1] (see Appendix 2). Thus, it seems that this option is economically feasible. The magnetic material has a rating of N40, which corresponds to a magnetic field strength of 12,600 – 12,900 Gauss. Preliminary power generation calculations indicate that this option does give adequate power generation. See Appendix 1.a for preliminary calculations and magnet specifications.

5.2 Piezoelectric Application

Research into piezoelectric devices has shown that this option is not economically feasible. Piezoelectric devices online range in price from $200 to $1000. This price is unacceptable for production purposes because one of the reasons for this project is to make a tire pressure monitoring system and the maintenance associated with it more economically accessible to the public. Furthermore, a $300 power generation system is too expensive considering that the tire pressure monitoring system itself costs only about $200. Consumers probably will not want to pay twice the price of a normal TPMS for a longer-lasting one. Finally, a piezoelectric device is economically unacceptable for this project because just about the entire allotted budget would have to be spent on a piezoelectric device. See Appendix 2 for sample piezoelectric device pricing.

5.3 Thermal Energy Recovery

There are different types of thermocouples that could be used to implement the proposed thermal energy recovery design. However, the type of thermocouple found to generate the most power only produces about 75mV. This does not meet average voltage requirements for tire pressure sensors, which is about 3V. See Appendix 3 for thermocouple specifications.

5.4 Wind Power Conversion

Turbines small enough to fit inside of a brake duct could not be found online. The smallest turbine found was the size of a small refrigerator. In addition to this setback, this option makes the power system design more complicated than necessary. A turbine would turn a generator, which would produce electricity. Essentially, this option transforms kinetic energy to electric energy using induction via a magnet and coil. This is basically the same idea as the magnetic induction alternative; however, this option is far more complicated. Furthermore, the connection between the generator and the sensor would be complex since electric power from the stationary generator would need to be taken to the rotating sensor. Research and thought has given rise to the conclusion that the wind power generation design only adds potential problems and complexity.

5.5 Pressure Induced Power

This article has not yet been received. This alternative solution is currently suspended indefinitely.

6. Preliminary Design

Based on comparison of the feasibility information compiled above, the magnetic induction design is going to be pursued as the solution to the problem of battery-powered tire pressure sensors. This option gives the best balance of performance, cost, and serviceability issues. The team also consulted with Professor Platt at the Calvin Physics Department, and he confirmed that the induction method is indeed feasible. The related power feasibility calculation is attached in Appendix 1.a. Although Professor Platt thinks that this design is feasible, he also thinks that getting this design right will require much testing. Correct placement of the magnet in relation to the coil will be essential for the proper function of the final design. Therefore, various placements of the coil and magnet should be tested extensively to ensure correct operation of the power system. Testing will be more extensively explained in the next section. The magnetic induction design is shown below.

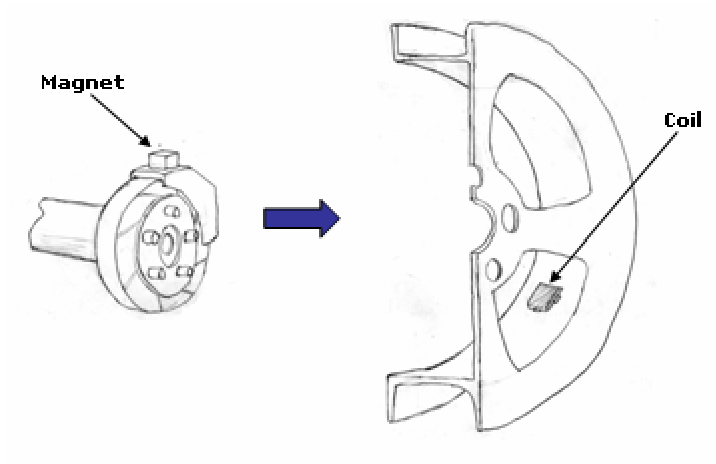

Figure 7. Magnetic Induction Design Solution

7. Test Method

The nature of our project mandates that a large part of the design process be dedicated to testing. As noted previously, Professor Platt believes that extensive testing will be necessary in order to determine proper placement of the magnet in relation to the coil. When a base test succeeds in providing an adequate voltage level to power a sensor, testing will proceed to include various market applications.

Variation in the application for tire pressure monitoring systems is quite significant. Systems could be applied to a wide range of vehicles with tires including the following: semi-trucks, light trucks, cars, motorcycles, and trailers. This range of applicable vehicles has a wide variety of wheel sizes and brake setups. Extensive testing of the new system will prove that the magnetic induction idea is practical, robust, and easily adaptable to a variety of vehicles.

The two major factors described above that warrant extensive testing mandate a versatile testing apparatus. Initial testing will focus on the functionality of the system. Once required functionality is attained, subsequent testing will proceed to account for variations in vehicle application.

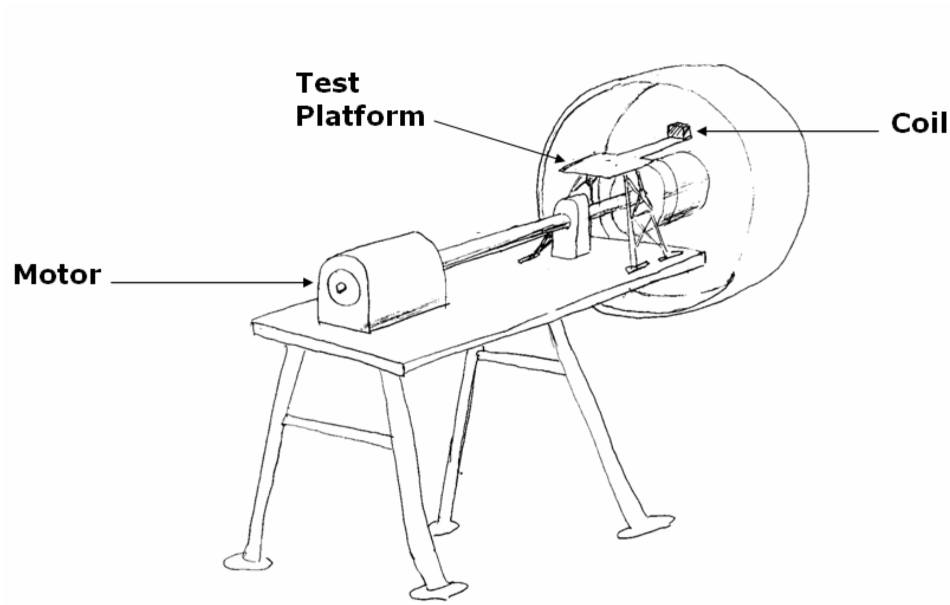

Figure 8. Test Apparatus

7.1 Test Apparatus Construction

The proposed test apparatus will allow variation of the position of the coil by using an adjustable platform shown in Figure 9 below. The coil will be attached to the adjustable platform, and a magnet will be affixed to the inside of a rim.

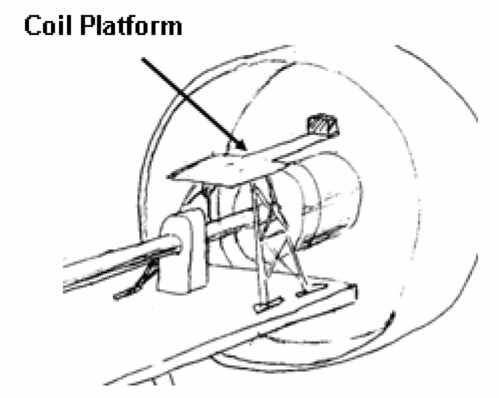

Figure 9. Adjustable Test Platform

A motor is an integral part of the test apparatus. Due to the wide variety of vehicle applications, it is necessary to test the magnetic induction design at various wheel speeds. The motor obtained for testing is a 1/8 horsepower electric motor with variable speed. The variable speed motor runs over a range from 0 to 1750 rotations per minute (RPM). For a 25.6 inch diameter tire, this variable motor speed is analogous to vehicle speeds of 0 to 135 miles per hour. A plot of the conversion from RPMs to MPH is shown below. Complete motor specifications can be found at the end of this section.

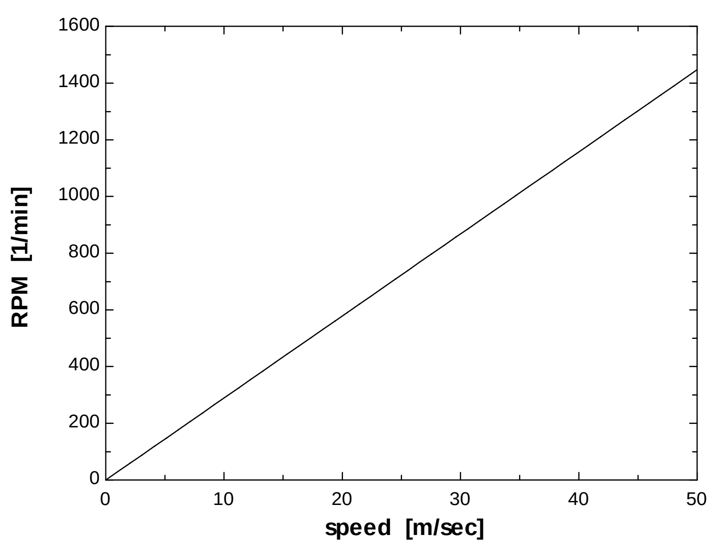

Figure 10. Speed vs. RPM Relationship

The final part of the test apparatus is the wheel attachment. Having procured three different rims for testing purposes, individual hubs will be built for each rim. The hubs will be attached directly to the motor using a long shaft, a coupling joint, and a support bearing. The joint will be secured to the shaft and the hubs using woodruff keys and set screws. This will allow testing of all the rims using the same apparatus. The hubs will be CNC machined steel disks with wheel studs installed to match the bolt patterns of the test rims.

7.2 Test Procedure

A large number of variables mandates an accurate and easily repeatable testing procedure. A list of test parameters was compiled. These parameters were broken down into three main categories: coil parameters, magnetic parameters, and rim size.

There are five major coil parameters. First, the coil diameter will be varied. Coil diameter refers to the diameter of the windings of the coil. A larger diameter corresponds to more flux passing through the coil, but it also requires more space inside the rim. The second parameter to vary is the number of turns in the coil. Again, more turns in the coil correlates to more magnetic flux and consequently more current. The relationship between magnetic field strength and the number of turns in the coil is shown in Appendix 1.b. A consideration must also be made for wire thickness. It is unsure as to how wire thickness affects the current generated in the coil. However, thickness of the wire will have direct influence on the overall size of the coil. Another consideration concerning the coil is what type of protective coating to use. There are a variety of options including the use of a coated wire, a corrosion resistant wire, or an epoxy resin potted coil. It is unsure as to how differences in wire coating will affect the induction of the coil; however, these alternatives will be tested. Finally, one of the largest difficulties concerning the coil will be the connection between the coil and the sensor. Different connection methods will be tested for their strength, durability, and functionality.

Magnet parameters will also be varied during testing. Mounting location will be a large issue. The distance between the magnet and coil is an obvious testing point. The size, strength, and shape of the magnet will also affect performance and must be taken into consideration. The use of multiple magnets to increase field strength is something that has been considered, but Calvin College Physics professors have stated that magnetic fields do not combine proportionally. This adds another dimension of complexity to the testing as multiple magnets do not give predictable fields. As with the coil, a protective coating or mounting solution for magnets must also be researched and tested when system testing begins.

The rim options will be tested by using a few sample rims as discussed earlier. Currently, testing will be done on three different rims; the exact specifications for the rims are shown in the table below.

Make and Model	Rim Size	Bolt Pattern	Lug Size
Mazda RX-7	15 x 5 inch	4 x 114.3 mm	12 x 1.5 mm
Mitsubishi Lancer	15 x 6 inch	4 x 4.5 inch	12 x 1.5 mm
Pontiac Firebird	16 x 8 inch	5 x 4.75 inch	12 x 1.5 mm

Finally, all previously mentioned test parameters will be examined using the entire motor speed range. Variable speed motor specifications for the test apparatus are shown below.

Model	Power	Voltage	Current	Misc.
Century Motors DN EMI 9-208222-01 DC Motor	1/8 Hp	115 Volt	1.12 Amp	1750 RPM Max
Boston Gear R12 DC Control Box	1/8 Hp	115 Volt	20 Amp Max	

8. Christian Perspective

A moral perspective is important in any undertaking in life, including technological design. Christian engineers in particular have an obligation to consider the ethical implications of their ideas and products. The design norms presented in lecture give a guide to conscious decision-making with respect to engineering design. Several design norms are apparent in the implementation of this particular project: stewardship, caring, and cultural appropriateness.

First, stewardship could be defined as properly managing the resources one is given. Design of a battery-free device displays this idea of stewardship through consciously trying to conserve natural resources. By designing an alternative power generation system for tire pressure sensors, the need for batteries will hopefully be eliminated, thereby reducing the amount of waste to landfills. Secondly, the project saves energy. The magnetic induction design essentially transforms energy from one form to another. The induction method increases energy efficiency associated with a moving automobile by converting kinetic energy that would normally be wasted into electric energy.

The design norm of cultural appropriateness is also evident in the new design. The pressure sensor power system could be applied to any automobile because all automobiles use pressurized tires. Most families in the United States have at least one automobile, and many have multiple vehicles. The proposed technology could easily be used by millions of American drivers if it were implemented by automotive manufacturers.

Finally, the proposed design also addresses the design norm of caring. People that cannot afford to replace their TPMS would be at a disadvantage with a conventional system. By prolonging the working life of tire pressure sensors, the new pressure sensor power system increases the safety of automobiles. In extreme cases, knowledge of tire pressure could prevent a blowout and save lives.

9. Cost Estimates

Project Expenses:		
Sensors/Sensor System		$250
Batteries		$20
Test Apparatus:		$50
Steel		(buy)
Electric motor		(borrow)
Wheels		(have)
Bearing		(buy)
Wheels studs		(buy)
Misc. hardware		(buy)
Magnets		$35
Coils/Wires		$20
Contingency expenses		$125
Total Cost:		$500

R&D Costs		
Labor		**$20/hr**
Total Hrs	(24hrs/week)	720
Total Cost		$14,400

Professor Time		**$30/hr**
	60 hrs	$1,800

Industrial consultant time		**$40/hr**
JCI	10 hrs	$400
Subtotal: Labor Cost		$16,600

Materials		
Sensors/Sensor System		$250
Batteries		$20
Test Apparatus:		$650
	Steel	$100
	Electric motor	$200
	Wheels	$200
	Bearing	$50
	Wheels studs	$50
	Misc. hardware	$50
Magnets		$35
Coils/Wires		$20
Subtotal: Material Cost		$1,625

Material Cost:	$2,125
Labor Cost:	$16,600
Project Contingency	$500
Total Cost:	$19,225

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4. Machine Design Magazine. "Where the Smart Rubber Meets the Road." *Machine Design*. http://www.machinedesign.com/ASP/strArticleID/56605/strSite/MDSite/viewSelectedArticle.asp.

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9. Varadan, Vijay K. "Design and Development of Passive MEMS-IDT Sensors for Continuous Monitoring of Tire Pressure." *Proceedings of SPIE - the International Society for Optical Engineering* 4236 (2001): 242-51.

10. Wyczalek, Floyd A. "Electric Vehicle Regenerative Braking." *Proceedings of the Intersociety Energy Conversion Engineering Conference* (1992): 3.185-90.

Appendices

Appendix 1.a: Preliminary Calculations and Magnet Specifications

$d = 0.00635$ [m]

$a = 0.25 \cdot 3.14 \cdot d^2$

$n = 500$

$t = \frac{l}{n} \cdot \left| 39.3701 \cdot \frac{in}{m} \right|$

$l = 0.0508$ [m]

$emf = 3$ [V]

$emf = n \cdot a \cdot \frac{\delta_b}{\delta_t}$

$speed = 13.4$ [m/sec]

$diam = 0.6604$ [m]

$circ = 3.14 \cdot diam$

$RPM = \frac{speed}{circ} \cdot 60$ [sec/min]

$\delta_t = \frac{l}{speed}$

$req_b = \delta_b \cdot \left| 10000 \cdot \frac{gauss}{tesla} \right|$

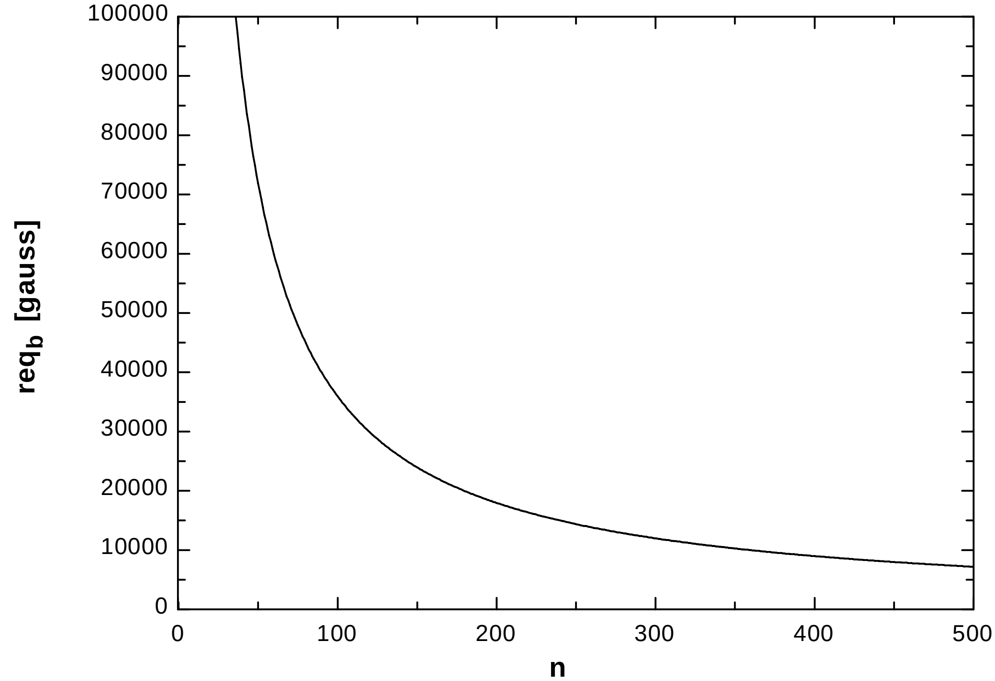
Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

$a = 0.00003165$ [m^2]	$circ = 2.074$ [m]	$d = 0.00635$ [m]	$\delta_b = 0.7186$ [Tesla]
$\delta_t = 0.003791$ [sec]	$diam = 0.6604$ [m]	$emf = 3$ [V]	$l = 0.0508$ [m]
$n = 500$	$req_b = 7186$ [gauss]	$RPM = 387.7$ [1/min]	$speed = 13.4$ [m/sec]
$t = 0.004$ [in]			

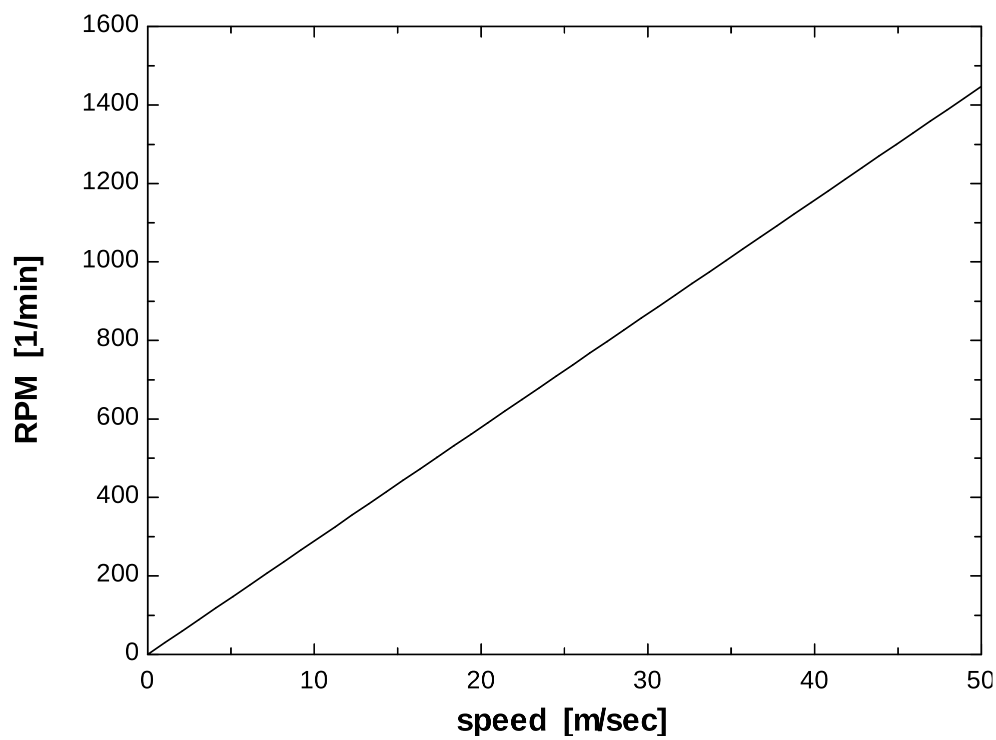
No unit problems were detected.

Calculation time = .0 sec

Appendix 1.b: Preliminary Correlations



Required Magnetic Field Strength (reqb) Vs. Number of Turns in Coil (n)



Motor Speed (RPM) Vs. Vehicle Speed (m/sec)

Appendix 2: Magnet Pricing [1]

More Info

D063A-AU ~ 1/8" Dia x 1/16" Thick NdFeB Disc Magnet, Au plated.
(1 Item = 100 magnets)
Price US$12.00

Qty 1

buy

More Info

D063B ~ 1/4" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated.
(1 Item = 50 magnets)
Price US$7.00

Qty 1

buy

More Info

D063C ~ 3/8" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated.
(1 Item = 50 magnets)
Price US$10.00

Qty 1

buy

More Info

D063D ~ 1/2" Dia x 1/16" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated.
(1 Item = 50 magnets)
Price US$15.30

Qty 1

buy

More Info

D094A ~ 1/8" Dia x 3/32" Thick NdFeB Disc Magnet, Ni-Cu-Ni plated.
(1 Item = 80 magnets)
Price US$8.40

Qty 1

buy

Appendix 3: Piezoelectric Specifications [8]

	Part Number ↓	Description	Price ↓
	Press-ICP-2300V6	10,000 psi range, .5 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$375.00** **Add to Cart**
	Press-ICP-2300V5	5000 psi range, 1 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$375.00** **Add to Cart**
	Press-ICP-2300V4	1000 psi range, 5 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$375.00** **Add to Cart**
	Press-ICP-2300V3	500 psi range, 10 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$375.00** **Add to Cart**
	Press-ICP-2300V1	250 psi range, 20 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$375.00** **Add to Cart**
	Press-ICP-2200V1	100 psi range, 50 mV/psi, acceleration compensated, .217 diameter diaphragm **...more ››**	**$385.00** **Add to Cart**
	Press-ICP-2013V	2.5 psi range, 2000 mV/psi, microphone, 78.7 db resolution **...more ››**	**$575.00** **Add to Cart**
Image Not Available	Press-ICP-2005V	50 psi range, 100 mV/psi, acceleration compensated, TNC connector, 1/8-27 NPT mount **...more ››**	**$599.00** **Add to Cart**
	Press-ICP-2011V	1000 psi range, 5 mV/psi, in cylinder engine combustion sensor **...more ››**	**$765.00** **Add to Cart**

Appendix 4: Thermocouple Specifications (Type E)

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-9.835	-9.833	-9.831	-9.828	-9.825	-9.821	-9.817	-9.813	-9.808	-9.802	-9.797	-260
-250	-9.797	-9.790	-9.784	-9.777	-9.770	-9.762	-9.754	-9.746	-9.737	-9.728	-9.718	-250
-240	-9.718	-9.709	-9.698	-9.688	-9.677	-9.666	-9.654	-9.642	-9.630	-9.617	-9.604	-240
-230	-9.604	-9.591	-9.577	-9.563	-9.548	-9.534	-9.519	-9.503	-9.487	-9.471	-9.455	-230
-220	-9.455	-9.438	-9.421	-9.404	-9.386	-9.368	-9.350	-9.331	-9.313	-9.293	-9.274	-220
-210	-9.274	-9.254	-9.234	-9.214	-9.193	-9.172	-9.151	-9.129	-9.107	-9.085	-9.063	-210
-200	-9.063	-9.040	-9.017	-8.994	-8.971	-8.947	-8.923	-8.899	-8.874	-8.850	-8.825	-200
-190	-8.825	-8.799	-8.774	-8.748	-8.722	-8.696	-8.669	-8.643	-8.616	-8.588	-8.561	-190
-180	-8.561	-8.533	-8.505	-8.477	-8.449	-8.420	-8.391	-8.362	-8.333	-8.303	-8.273	-180
-170	-8.273	-8.243	-8.213	-8.183	-8.152	-8.121	-8.090	-8.059	-8.027	-7.995	-7.963	-170
-160	-7.963	-7.931	-7.899	-7.866	-7.833	-7.800	-7.767	-7.733	-7.700	-7.666	-7.632	-160
-150	-7.632	-7.597	-7.563	-7.528	-7.493	-7.458	-7.423	-7.387	-7.351	-7.315	-7.279	-150
-140	-7.279	-7.243	-7.206	-7.170	-7.133	-7.096	-7.058	-7.021	-6.983	-6.945	-6.907	-140
-130	-6.907	-6.869	-6.831	-6.792	-6.753	-6.714	-6.675	-6.636	-6.596	-6.556	-6.516	-130
-120	-6.516	-6.476	-6.436	-6.396	-6.355	-6.314	-6.273	-6.232	-6.191	-6.149	-6.107	-120
-110	-6.107	-6.065	-6.023	-5.981	-5.939	-5.896	-5.853	-5.810	-5.767	-5.724	-5.681	-110
-100	-5.681	-5.637	-5.593	-5.549	-5.505	-5.461	-5.417	-5.372	-5.327	-5.282	-5.237	-100
-90	-5.237	-5.192	-5.147	-5.101	-5.055	-5.009	-4.963	-4.917	-4.871	-4.824	-4.777	-90
-80	-4.777	-4.731	-4.684	-4.636	-4.589	-4.542	-4.494	-4.446	-4.398	-4.350	-4.302	-80
-70	-4.302	-4.254	-4.205	-4.156	-4.107	-4.058	-4.009	-3.960	-3.911	-3.861	-3.811	-70
-60	-3.811	-3.761	-3.711	-3.661	-3.611	-3.561	-3.510	-3.459	-3.408	-3.357	-3.306	-60
-50	-3.306	-3.255	-3.204	-3.152	-3.100	-3.048	-2.996	-2.944	-2.892	-2.840	-2.787	-50
-40	-2.787	-2.735	-2.682	-2.629	-2.576	-2.523	-2.469	-2.416	-2.362	-2.309	-2.255	-40
-30	-2.255	-2.201	-2.147	-2.093	-2.038	-1.984	-1.929	-1.874	-1.820	-1.765	-1.709	-30
-20	-1.709	-1.654	-1.599	-1.543	-1.488	-1.432	-1.376	-1.320	-1.264	-1.208	-1.152	-20
-10	-1.152	-1.095	-1.039	-0.982	-0.925	-0.868	-0.811	-0.754	-0.697	-0.639	-0.582	-10
0	-0.582	-0.524	-0.466	-0.408	-0.350	-0.292	-0.234	-0.176	-0.117	-0.059	0.000	0

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591	0
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192	10
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801	20
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420	30
40	2.420	2.482	2.545	2.607	2.670	2.733	2.796	2.858	2.921	2.984	3.048	40
50	3.048	3.111	3.174	3.238	3.301	3.365	3.429	3.492	3.556	3.620	3.685	50
60	3.685	3.749	3.813	3.877	3.942	4.006	4.071	4.136	4.200	4.265	4.330	60
70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985	70
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648	80
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319	90
100	6.319	6.386	6.454	6.522	6.590	6.658	6.725	6.794	6.862	6.930	6.998	100
110	6.998	7.066	7.135	7.203	7.272	7.341	7.409	7.478	7.547	7.616	7.685	110
120	7.685	7.754	7.823	7.892	7.962	8.031	8.101	8.170	8.240	8.309	8.379	120
130	8.379	8.449	8.519	8.589	8.659	8.729	8.799	8.869	8.940	9.010	9.081	130
140	9.081	9.151	9.222	9.292	9.363	9.434	9.505	9.576	9.647	9.718	9.789	140
150	9.789	9.860	9.931	10.003	10.074	10.145	10.217	10.288	10.360	10.432	10.503	150
160	10.503	10.575	10.647	10.719	10.791	10.863	10.935	11.007	11.080	11.152	11.224	160
170	11.224	11.297	11.369	11.442	11.514	11.587	11.660	11.733	11.805	11.878	11.951	170
180	11.951	12.024	12.097	12.170	12.243	12.317	12.390	12.463	12.537	12.610	12.684	180
190	12.684	12.757	12.831	12.904	12.978	13.052	13.126	13.199	13.273	13.347	13.421	190
200	13.421	13.495	13.569	13.644	13.718	13.792	13.866	13.941	14.015	14.090	14.164	200
210	14.164	14.239	14.313	14.388	14.463	14.537	14.612	14.687	14.762	14.837	14.912	210
220	14.912	14.987	15.062	15.137	15.212	15.287	15.362	15.438	15.513	15.588	15.664	220
230	15.664	15.739	15.815	15.890	15.966	16.041	16.117	16.193	16.269	16.344	16.420	230
240	16.420	16.496	16.572	16.648	16.724	16.800	16.876	16.952	17.028	17.104	17.181	240
250	17.181	17.257	17.333	17.409	17.486	17.562	17.639	17.715	17.792	17.868	17.945	250
260	17.945	18.021	18.098	18.175	18.252	18.328	18.405	18.482	18.559	18.636	18.713	260
270	18.713	18.790	18.867	18.944	19.021	19.098	19.175	19.252	19.330	19.407	19.484	270
280	19.484	19.561	19.639	19.716	19.794	19.871	19.948	20.026	20.103	20.181	20.259	280
290	20.259	20.336	20.414	20.492	20.569	20.647	20.725	20.803	20.880	20.958	21.036	290
300	21.036	21.114	21.192	21.270	21.348	21.426	21.504	21.582	21.660	21.739	21.817	300
310	21.817	21.895	21.973	22.051	22.130	22.208	22.286	22.365	22.443	22.522	22.600	310
320	22.600	22.678	22.757	22.835	22.914	22.993	23.071	23.150	23.228	23.307	23.386	320
330	23.386	23.464	23.543	23.622	23.701	23.780	23.858	23.937	24.016	24.095	24.174	330
340	24.174	24.253	24.332	24.411	24.490	24.569	24.648	24.727	24.806	24.885	24.964	340

°C	0	1	2	3	4	5	6	7	8	9	10	°C
350	24.964	25.044	25.123	25.202	25.281	25.360	25.440	25.519	25.598	25.678	25.757	350
360	25.757	25.836	25.916	25.995	26.075	26.154	26.233	26.313	26.392	26.472	26.552	360
370	26.552	26.631	26.711	26.790	26.870	26.950	27.029	27.109	27.189	27.268	27.348	370
380	27.348	27.428	27.507	27.587	27.667	27.747	27.827	27.907	27.986	28.066	28.146	380
390	28.146	28.226	28.306	28.386	28.466	28.546	28.626	28.706	28.786	28.866	28.946	390
400	28.946	29.026	29.106	29.186	29.266	29.346	29.427	29.507	29.587	29.667	29.747	400
410	29.747	29.827	29.908	29.988	30.068	30.148	30.229	30.309	30.389	30.470	30.550	410
420	30.550	30.630	30.711	30.791	30.871	30.952	31.032	31.112	31.193	31.273	31.354	420
430	31.354	31.434	31.515	31.595	31.676	31.756	31.837	31.917	31.998	32.078	32.159	430
440	32.159	32.239	32.320	32.400	32.481	32.562	32.642	32.723	32.803	32.884	32.965	440
450	32.965	33.045	33.126	33.207	33.287	33.368	33.449	33.529	33.610	33.691	33.772	450
460	33.772	33.852	33.933	34.014	34.095	34.175	34.256	34.337	34.418	34.498	34.579	460
470	34.579	34.660	34.741	34.822	34.902	34.983	35.064	35.145	35.226	35.307	35.387	470
480	35.387	35.468	35.549	35.630	35.711	35.792	35.873	35.954	36.034	36.115	36.196	480
490	36.196	36.277	36.358	36.439	36.520	36.601	36.682	36.763	36.843	36.924	37.005	490
500	37.005	37.086	37.167	37.248	37.329	37.410	37.491	37.572	37.653	37.734	37.815	500
510	37.815	37.896	37.977	38.058	38.139	38.220	38.300	38.381	38.462	38.543	38.624	510
520	38.624	38.705	38.786	38.867	38.948	39.029	39.110	39.191	39.272	39.353	39.434	520
530	39.434	39.515	39.596	39.677	39.758	39.839	39.920	40.001	40.082	40.163	40.243	530
540	40.243	40.324	40.405	40.486	40.567	40.648	40.729	40.810	40.891	40.972	41.053	540
550	41.053	41.134	41.215	41.296	41.377	41.457	41.538	41.619	41.700	41.781	41.862	550
560	41.862	41.943	42.024	42.105	42.185	42.266	42.347	42.428	42.509	42.590	42.671	560
570	42.671	42.751	42.832	42.913	42.994	43.075	43.156	43.236	43.317	43.398	43.479	570
580	43.479	43.560	43.640	43.721	43.802	43.883	43.963	44.044	44.125	44.206	44.286	580
590	44.286	44.367	44.448	44.529	44.609	44.690	44.771	44.851	44.932	45.013	45.093	590
600	45.093	45.174	45.255	45.335	45.416	45.497	45.577	45.658	45.738	45.819	45.900	600
610	45.900	45.980	46.061	46.141	46.222	46.302	46.383	46.463	46.544	46.624	46.705	610
620	46.705	46.785	46.866	46.946	47.027	47.107	47.188	47.268	47.349	47.429	47.509	620
630	47.509	47.590	47.670	47.751	47.831	47.911	47.992	48.072	48.152	48.233	48.313	630
640	48.313	48.393	48.474	48.554	48.634	48.715	48.795	48.875	48.955	49.035	49.116	640
650	49.116	49.196	49.276	49.356	49.436	49.517	49.597	49.677	49.757	49.837	49.917	650
660	49.917	49.997	50.077	50.157	50.238	50.318	50.398	50.478	50.558	50.638	50.718	660
670	50.718	50.798	50.878	50.958	51.038	51.118	51.197	51.277	51.357	51.437	51.517	670
680	51.517	51.597	51.677	51.757	51.837	51.916	51.996	52.076	52.156	52.236	52.315	680
690	52.315	52.395	52.475	52.555	52.634	52.714	52.794	52.873	52.953	53.033	53.112	690
700	53.112	53.192	53.272	53.351	53.431	53.510	53.590	53.670	53.749	53.829	53.908	700
710	53.908	53.988	54.067	54.147	54.226	54.306	54.385	54.465	54.544	54.624	54.703	710
720	54.703	54.782	54.862	54.941	55.021	55.100	55.179	55.259	55.338	55.417	55.497	720
730	55.497	55.576	55.655	55.734	55.814	55.893	55.972	56.051	56.131	56.210	56.289	730
740	56.289	56.368	56.447	56.526	56.606	56.685	56.764	56.843	56.922	57.001	57.080	740
750	57.080	57.159	57.238	57.317	57.396	57.475	57.554	57.633	57.712	57.791	57.870	750
760	57.870	57.949	58.028	58.107	58.186	58.265	58.343	58.422	58.501	58.580	58.659	760
770	58.659	58.738	58.816	58.895	58.974	59.053	59.131	59.210	59.289	59.367	59.446	770
780	59.446	59.525	59.604	59.682	59.761	59.839	59.918	59.997	60.075	60.154	60.232	780
790	60.232	60.311	60.390	60.468	60.547	60.625	60.704	60.782	60.860	60.939	61.017	790
800	61.017	61.096	61.174	61.253	61.331	61.409	61.488	61.566	61.644	61.723	61.801	800
810	61.801	61.879	61.958	62.036	62.114	62.192	62.271	62.349	62.427	62.505	62.583	810
820	62.583	62.662	62.740	62.818	62.896	62.974	63.052	63.130	63.208	63.286	63.364	820
830	63.364	63.442	63.520	63.598	63.676	63.754	63.832	63.910	63.988	64.066	64.144	830
840	64.144	64.222	64.300	64.377	64.455	64.533	64.611	64.689	64.766	64.844	64.922	840
850	64.922	65.000	65.077	65.155	65.233	65.310	65.388	65.465	65.543	65.621	65.698	850
860	65.698	65.776	65.853	65.931	66.008	66.086	66.163	66.241	66.318	66.396	66.473	860
870	66.473	66.550	66.628	66.705	66.782	66.860	66.937	67.014	67.092	67.169	67.246	870
880	67.246	67.323	67.400	67.478	67.555	67.632	67.709	67.786	67.863	67.940	68.017	880
890	68.017	68.094	68.171	68.248	68.325	68.402	68.479	68.556	68.633	68.710	68.787	890
900	68.787	68.863	68.940	69.017	69.094	69.171	69.247	69.324	69.401	69.477	69.554	900
910	69.554	69.631	69.707	69.784	69.860	69.937	70.013	70.090	70.166	70.243	70.319	910
920	70.319	70.396	70.472	70.548	70.625	70.701	70.777	70.854	70.930	71.006	71.082	920
930	71.082	71.159	71.235	71.311	71.387	71.463	71.539	71.615	71.692	71.768	71.844	930
940	71.844	71.920	71.996	72.072	72.147	72.223	72.299	72.375	72.451	72.527	72.603	940
950	72.603	72.678	72.754	72.830	72.906	72.981	73.057	73.133	73.208	73.284	73.360	950
960	73.360	73.435	73.511	73.586	73.662	73.738	73.813	73.889	73.964	74.040	74.115	960
970	74.115	74.190	74.266	74.341	74.417	74.492	74.567	74.643	74.718	74.793	74.869	970
980	74.869	74.944	75.019	75.095	75.170	75.245	75.320	75.395	75.471	75.546	75.621	980
990	75.621	75.696	75.771	75.847	75.922	75.997	76.072	76.147	76.223	76.298	76.373	990
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Appendix 5: Preliminary Task Breakdown and Schedule

Task Specification	Duration	Start Date	Completion Date
Project Defined	11 days	10/17/2005	10/31/2005
Project Objectives Defined	13 days	9/12/2005	9/28/2005
Project Poster Displayed at Station	3 days	9/28/2005	9/30/2005
Project Slide Complete	3 days	10/3/2005	10/5/2005
Alternative Solutions Defined	5 days	10/17/2005	10/21/2005
Research Alternative Power Solutions	5 days	10/17/2005	10/21/2005
Magnet and Coil	1 day	10/17/2005	10/17/2005
Piezoelectric	1 day	10/18/2005	10/18/2005
Heat Conversion	1 day	10/19/2005	10/19/2005
Wind Power	1 day	10/20/2005	10/20/2005
Others	1 day	10/21/2005	10/21/2005
Project Web Site Live	3 days	10/17/2005	10/19/2005
Preliminary Task Specs	2 days	10/14/2005	10/17/2005
Preliminary Evaluations of Feasibility	10 days	10/17/2005	10/28/2005
Preliminary Budget	2 days	10/28/2005	10/31/2005
Refined Task Specs	5 days	10/31/2005	11/4/2005
Preliminary Project Schedule	2 days	11/4/2005	11/7/2005
Project Brief for Industrial Consultant	6 days	11/7/2005	11/14/2005
Monthly Budget Report	2 days	11/11/2005	11/14/2005
PPFS Work	68 days	9/7/2005	12/9/2005
Problem Statement	11 days	9/7/2005	9/21/2005
Proposed Solutions	11 days	9/21/2005	10/5/2005
Feasibility of Proposed Alternative Solutions	11 days	10/6/2005	10/20/2005
Budget Estimates	11 days	10/21/2005	11/4/2005
Preliminary Design	27 days	11/3/2005	12/9/2005
Electrical	14 days	11/3/2005	11/22/2005
Mechanical	14 days	11/22/2005	12/9/2005
Design Implementation	14 days	10/17/2005	11/3/2005
·Electrical Power System	14 days	10/17/2005	11/3/2005
·Circuit Design	7 days	10/17/2005	10/25/2005
·Simulation	7 days	10/17/2005	10/25/2005
·Real World Implementation/Testing	14 days	10/17/2005	11/3/2005
·Mechanical Mounting System	14 days	10/17/2005	11/3/2005
·Force Analysis	7 days	10/17/2005	10/25/2005
·Thermal Analysis	7 days	10/17/2005	10/25/2005
·Simulation/Prototyping	14 days	10/17/2005	11/3/2005
·Real World Implementation/Testing	14 days	10/17/2005	11/3/2005
·Electrical/Mechanical System Integration	7 days	10/17/2005	10/25/2005
·Prototyping	7 days	10/17/2005	10/25/2005
·Total System Testing	7 days	10/17/2005	10/25/2005
·Final Product	7 days	10/17/2005	10/25/2005
Final Report	14 days	10/17/2005	11/3/2005
·Comprehensive Design Analysis	11 days	10/17/2005	10/31/2005
·Power System	10 days	10/17/2005	10/28/2005
·Mounting System	11 days	10/17/2005	10/31/2005