Energy Harvesting – Heated Hockey Skate Blade

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Report Summary

Hockey players are able to glide on the ice due to a thin layer of water lying between the blade of the skate and the ice itself. When players skate, that thin water layer becomes a 'snow'[1]. As the players continue to skate, the layer of 'snow' becomes thicker and thicker, making the ice harder to skate on due to the increased friction between the skate blade and the ice. The theory of this report is to show how the company Thermablade's design and concept of the heated hockey skate can be altered to improve the product. Using Faraday's Law of induction in a basic circuit could implement this theory.

Thermablade is an amazing product that broke barriers regarding skate technology, but there may be simpler and cheaper ways to achieve the same end goal of the heated skate blade. This project focuses on the needs of the many numerous hockey players around the world, ie., the cost of the product and the implementation of a new charging device. This would be accomplished by replacing an externally rechargeable battery with a linear generator.

The goals for overall performance are to statistically compete with the Thermablade and proper implementation of the system without the user feeling the physical presence of the system within the skate. The product must be 97-99% reliable since the TUUK holder is not easily removable from the boot of the skate. The cost per pair must be $150 because it will make the product more affordable for all players., and if the product is licensed the cost will be much cheaper. Another

major goal fitting the criterion of the project is licensing, if at all possible. The potential of licensing the product would benefit everyone because it would keep the costs down and the product would not have to be sold separately. The weight of the product when attached to a skate must be within 10% of the weight of the same skate with a regular TUUK holder attached [2].

The primary design involves Bauer Vapor X60 skates, using the blade as a resistor in a voltage divider to gain the heat needed to bring the blade to 41°F, or the use of a resistive strip, depending on availability, and a linear generator that is very similar to that found in a shake flash light [1]. There will also be an energy storage component of the device that will hold enough power to sustain the blade's desired temperature over time.

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Introduction

Hockey is a high intensity sport that is played on a sheet of ice. Hockey players are able to glide on the ice due to a thin layer of water lying between the blade of the skate and the ice itself. The layer of water resting on the ice is approximately 10 microns thick. The ice is set to stay at the optimal temperature of 23°F at all times through the use of a cooling system [1]. Over a period of time as the players skate, the thin layer of water becomes a type of 'snow' [3]. As the players continue to skate, the layer of 'snow' becomes thicker and thicker making the ice harder to skate on due to the increased friction between the skate blade and the ice. As a result, it is necessary for a Zamboni to resurface the ice between periods of play.

Figure 1 Typical Skate Used by Professionals and Amateurs (bauer.com)

The hockey skate has three main parts to it. The first part is the boot. The boot is where the player's foot is within the skate. The second part is the TUUK holder. In Figure 1, the TUUK holder is the black piece that is above the steel blade. The TUUK holder has a hollow inside underneath the heel and the toe of the boot. The third part is the blade. The blade is removable within modern skates, which allows for an easy swap if the blade is cracked.

Figure 2 A TUUK Holder and Steel Blade

Players dress in gear from head to toe, but the most important piece of equipment that they wear is their skates. Modern hockey skates are very lightweight and continue to become lighter, which allows the players to become less fatigued and accelerate faster. A new approach to improving the hockey skate has been pursued over the past couple of years, i.e., the heated blade [1].

Thermablade, a company based out of Canada, has recently designed a skate that heats the steel blade to a temperature that melts the ice just enough to double the micro-layer of water between the blade and the ice. The company's research shows that the heated blade reduces the starting resistance for the skater by 65-75% and reduces the gliding resistance by 50-55%. The player experiences less friction and vibration as opposed to wearing a normal skate allowing the player to be less fatigued as the game goes on and achieve higher speeds than a player would normally be capable of on an untreated ice surface. This is all accomplished through the use of a heat source originating from a rechargeable battery within the TUUK holder [1].

Figure 3 A See-Through Thermablade [1]

The improvement to be made to the skate will consider Faraday's Law of Induction, which will allow the skate to heat the blade through the motion of skating. Faraday's Law of Induction states that if a magnet is passed through a coil of magnetic wire it will induce a current on the wire. The strength of the current depends on the velocity the magnet passing through the coil, magnet strength, and number of turns (N). To implement this process, the device using Faraday's Law must be fine-tuned by taking into account many variables to accomplish the overall goal of reducing friction.

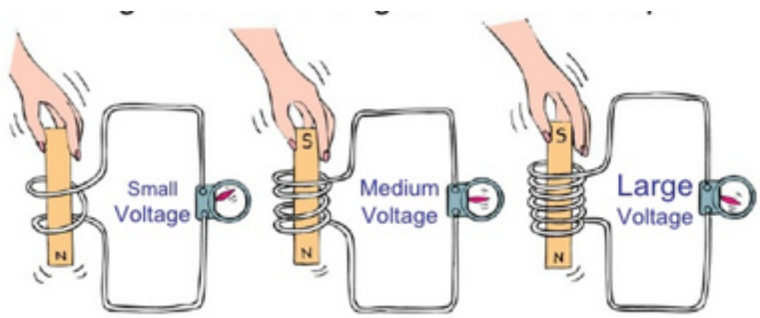

Figure 4 Faraday's Law of Induction

This report is designed to allow the reader to understand the thought process behind the design. There are many challenges that have been presented over the past term that tend to be overlooked when referring to the simple concept of heating a blade to a temperature to essentially melt ice. These challenges and the plans to overcome them are found within this report.

Background

A very brief history behind the creation and implementation of the heated hockey blade must be addressed first. Tory Weber, a man from Calgary and the inventor of Thermablade, stepped outside his house one day to get the newspaper and came up with the idea for Thermablade. His boots were placed next to the door by a heater and when he put them on he stepped outside onto a thin layer of frost, which made him take a tumble. He took the idea from his heated boots and applied it to the skate blade [1]. The device was patented in the year 2006.

Over the course of Thermablade's creation, $5,000,000 was invested over a period of five years [4]. The most important piece of information that came as a result is the increased performance on ice due to the heated blade. Thermablade realized that with their product attached to a pair of skates, performance of the skater was increased and the fatigue decreased. The basic overall design consists of a basic circuit board that is connected to a battery within the TUUK holder of the skate. The Thermablade works as a lubricant when on the ice, very similar to the way a Zamboni works.

The Zamboni is used during hockey games to resurface the ice and reduce the friction between the skate blade and the ice. All hockey players refer to this as ‘fresh ice’, and used ice is referred to as ‘dirty ice’. The Zamboni operates by using warm water and a blade to resurface the ice. The blade chops up the ice and allows the Zamboni to remove the snow on the surface, while it creates a smooth playing surface with the warm water. The warm water then freezes on top of the surface to create the fresh sheet of ice.

The Thermablade does what a Zamboni does by increasing the temperature of the blade to 41°F. When a blade at the heated temperature comes in contact with the 23°F ice surface, the temperature of the ice rises to 32°F [1]. This is very important because ice usually has a 10 micron layer of water on top of the surface, which allows the player to glide across the surface smoothly. When the Thermablade comes in contact with the ice it creates a 20 micron layer of water on top of the ice, reducing the overall friction that the player experiences[1]. A common misconception regarding the heated skate blade is that the blade will damage the ice. On the contrary the heated blade actually resurfaces the ice like a Zamboni would [4] [1].

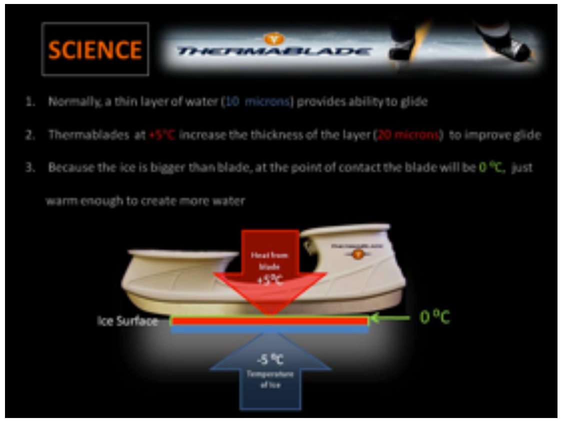

Figure 5 Ice Temperature Diagram [1]

The Thermablade research shows that heated blade technology increases gliding speed by as much as 55% and starting resistance as much as 75%. The heated blade also allows for tighter turns, which can be crucial when facing an opponent in tight spaces, and increased overall control and feel of the ice surface [1]. Thermablade also tested the vital signs of players when using a regular skate blade and found that the player used 15% less energy when wearing the Thermablade [1]. The company also looked into the vibrations a player experiences when skating, which lead to fatigue. Thermablade caused less vibration on the player's lower body, exhausting the player significantly less than the regular skate blade.

The Thermablade costs $399.99 on top of the cost of the existing skates [6]. Since Thermablade is an attachment to the skate, the product is not as widely used as it should be. Thermablade is currently making improvements on the original design and are soon releasing Thermablade 2.0. Thermablade 2.0 advancements include a removable battery, team charger, new longer lasting battery, electronics to monitor body function, quick charging system and new steel [4].

Thermablade is an amazing product that broke barriers regarding skate technology. However, there may be simpler and cheaper ways to achieve the same end goal of the heated skate blade. This project focuses on the needs of the hockey players around the world, which are the cost of the product and the implementation of a new charging device. The cost of the product must be decreased because hockey is one of the most expensive sports in existance. Skate prices have increased dramatically over the past decade and the top of the line skate is now priced just below $1000 [5]. If the player wanted Thermablade technology they would have to spend another $400 to replace an existing part of the skate that was already purchased [4]. The implementation of a new charging device would essentially make the skater unaware that the skate even contains the heating technology. The motion of the player would generate the power and he or she would not have to plug their skates into a charge in order for the device to work [2].

Hockey culture, like the sport itself, is very different than any other sports culture around the world. The sport itself is one of the fastest on the planet and also one of the most physical. The highest level of hockey, the NHL, is considering making changes to the rules of the game in order to attract more fans by increasing goal scoring [9]. A possible way to achieve this is to increase the speed of the game, which can be done through the use of the product that is being developed. The possible political ties to the research being done on this product could allow for more goal scoring at all levels of the game due to increased speed, which means more chances to score goals. Hockey would become a more popular sport around the world if a wider audience is targeted. An example of this is soccer, where players of high caliber like Cristiano Ronaldo make 17 million euros each year [6]. The highest paid hockey player is Shea Weber who makes $14,000,000, yet makes much less on endorsements than Ronaldo [7].

This product would also have a positive effect economically. The NHL and its players would benefit financially. Additionally, if the final product is licensed with a major hockey equipment brand like Bauer, which Thermablade refused to do, the technology would already be in the skate when the skate is purchased. The targeted price is under $150 after marketed. This target price can be varied whether or not the product is marketed by itself or if the product is licensed. If the product is licensed it would be advertised and implemented with new skates that come out in the market. The product could also be sold as an add on, which ideally would cost $150. The overall price of the skate and the technology would be much cheaper than that with the separate Thermablade. The product would be beneficial to the game of hockey, becoming more affordable for all hockey players, while also increasing the competitiveness and speed of the game as a whole.

Manufacturability of the product is fairly simple. There are only a few components needed to implement the design, such as a coil of wire, resistive strips, a capacitor or a rechargeable battery and a few resistors [8][9][10]. All of the components mentioned above are readily available aside from the resistive strips. The resistive strip is difficult to implement in the prototype because a roll of the tape must be purchased, which can be quite expensive [9] [10]. Each skate uses approximately 100mm of the resistive tape, therefore buying rolls could be quite advantageous when building mass quantities of the product. The end product would be very sustainable in a rough environment because it is initially cased in plastic in the TUUK holder and then foam is used to keep all of the parts in place. This is significant in the overall design.

There are clear ethical issues surrounding this topic. Thermablade has implemented the idea of a heated skate blade and created it, while this product uses the research to implement the heated blade in a different way to achieve the same end goal [11]. There could be legal implications if credit is not given to Thermablade for the research contribution [11]. Another possible issue is could be that this product makes the game too fast, resulting in more player injuries. In rebut to that point, the product would give the player more control and a better feel for the ice, thereby causing less stress to the body, as well as preventing exhaustion and muscle strain [1].

Design Requirements

The detailed specifications that created the spark for this project were the interpretation of customer requirements and desired features. These two specifications played a great deal in the flourishing of the project. The customer requirements and desired features altered the Thermablade design due to the charging mechanism. The Thermablade requires the player to remove the skates from the bag and plug them in to charge them. The process can be a hassle for a player who skates multiple times a day and this can affect the functionality of the product.

The potential users of the product are hockey players of all ages around the world. The project specifically targets the higher levels of competition, ie., the NHL, IIHL, AHL, Olympics, Juniors and College because these levels pay for the player's equipment, therefore it would be more likely that all players would have the ability to use the heated blade [9]. Younger kids could use this product, but skates are very expensive and their skate sizes change frequently. The higher level players skate almost every day and sometimes use multiple pairs of equipment, which makes it hard to have a charged skate all of the time.

The cost was also a major factor in design requirements because the device needed to be kept at a lower price in order to increase the amount of potential users. The cost of a pair of Thermablades can be considered as investing in a second pair of skates. Between that and the present market for this kind of product with major hockey brands, it was essential that this skate blade be designed to be within the skate but invisible to the user. The userfriendliness of the design is remarkable because the player would be unaware the device is there, as it charges itself based on motion to heat the blade, and the generator is within the skate when the skate is purchased. The player merely needs to skate for the product to function correctly.

The performance of the device was also very critical to the design because it must perform just as well or better than the Thermablade when it comes to on-ice statistics like increase in acceleration and gliding speeds. These statistics are very important to maintain because they are the basis for the product itself.

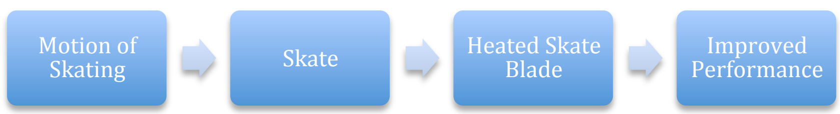

Figure 6 Block Diagram of Overall System

The specifications call for three major functions within the system for it to work as desired. The overall system will be the skate. Figure 6 shows how the system will function. The motion of skating will affect an implemented system in the skate. The implemented system will heat the blade, therefore improving player performance. The subsystems will be linear generator, power retention and heating element. All three subsystems are equally important in design functionality, as well as the connections made between them, which are shown in Figure 7.

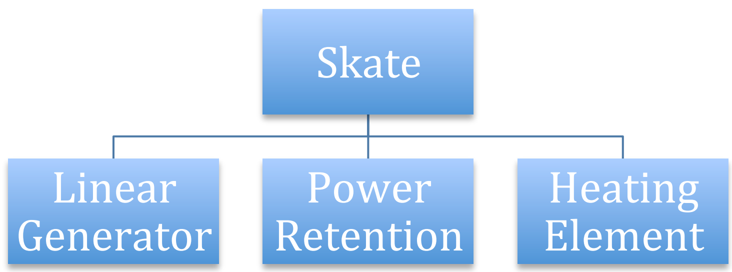

Figure 7 Block Diagram of Subsystems

The linear generator must be able to produce enough power to alter and maintain the temperature of a steel skate blade. The linear generator must use Faraday's Law of induction to induce a current on the system. The power retention system must be able to maintain the temperature of the blade while the player is sitting on the bench between shifts. This subsystem is essential because it will keep the blade warm and useful with regard to the reduction of friction. The heating element must be connected to the blade in a way that the blade is still removable and replaceable without altering the system. The heating element must be connected to the power retention system and the linear generator.

The linear generator will be a basic model of the use of Faraday's Law, meaning there must be four subsystems involved. The subsystems are magnetic wire, magnets, plastic tubing and end caps shown in Figure 8.

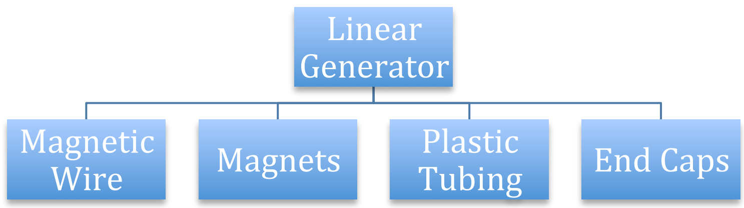

Figure 8 Linear Generator Block Diagram

The plastic tubing must be small enough to fit inside the rear compartment of a TUUK holder. This is important because it is the outer shell of the system. The magnets and the magnetic wire will be selected in order to produce enough current to heat the blade up to the desired temperature of 41°F [18]. The wire will be wrapped around the plastic tubing and the magnets will be placed within the plastic tubing. The end caps will be placed on the ends of the plastic tubing to create a housing that will be known as a linear generator.

The power retention system must rectify the voltage that will result from the linear generator and it must store and discharge the energy to keep the skate blade at the correct temperature. There are only a few choices regarding how the energy will be stored. It can either be stored using a battery, capacitor or both [1][2]. The need for this system is crucial because it ensures the blade stays at the optimal temperature for maximum on ice performance.

The heating element will also be a very simple system to implement as well, even though it is very important. The blade must receive heat through a resistance, which can be implemented using resistive wire, resistive tape or the blade itself.

The design criterion is based on the specifications discussed earlier. The goals for overall performance are to statistically compete with the Thermablade as well as proper implementation of the system without the user feeling the physical presence of the system within the skate. The product must be 97-99% reliable since the TUUK holder is not easily removable from the boot of the skate. The cost must be $150 per pair and if licensed, the cost would be much cheaper. The manufacturability must be speedy and accurate to insure the ideal performance of the skate, while keeping production cost low. The product of course must be safe. It cannot overheat and it cannot harm the user. Another major goal fitting the criterion of the project is licensing if at all possible. The potential of licensing the product would be beneficial for all, as it would keep the costs down and the product would not have to be sold separately. The weight of the product when attached to a skate must be within 10% of the weight of the same skate with a regular TUUK holder on [18].

Design Alternatives

The overall approach chosen to implement the design of the product could be accomplished in a variety of ways. The design could have the linear generator outside of the skate and on another part of the player's body, such as the glove. This method would be impractical as the player would have to get dressed in a way to enable a wire from his foot to his hand without restricting motion. The linear generator in the glove or somewhere else on the body would also not have optimal protection. The size would have to be so small it would be impossible to generate enough power or even have magnets strong enough and small enough to create any current. Putting the generator on the outside of the skate could be done with the right materials and would allow for pristine protection of the device, but the material would drive up cost and it would be much more vulnerable to devastating collisions.

The first part of the system that could drastically change the results of testing is the skate itself. Skates are marketed and sold based on model types, as well as quality. The highest quality skate, Bauer 1X for example, is the lightest skate [19]. It is also fitted with different quality steel than a lower quality skate and it also better molds to the player's foot [19]. There are a variety of other differences between high quality skates and low quality skates, but the most important ones are the weight and the quality of the steel. The optimum way to test this design would be with the latest and greatest skate on the market, but unfortunately doing so would cost $1000 and funds are not available for such a test [19]. There are also different brands of skates, so for ideal testing the design would be made to fit the universal TUUK holder, which most skates have, but some brands have a different shape TUUK holder.

There are many different ways the three subsystems can be implemented by using different parts. The linear generator could be altered in different ways, such as changing the strength of the magnet, the size of the plastic container, the gauge wire and the amount of turns the coil of wire will have. The linear generator is the most important part of the design as it will have the greatest impact on the weight of the skate. The weight of the skate is also an important variable as it is noticeable from the player's perspective. A skater will choose a model of skate based on weight because a lighter skate means less fatigue when playing. The lighter skate also means the player can move slightly faster. The wire around the linear generator cannot be a large gauge as it will add too much weight require too much scarce and valuable area inside the TUUK of the skate.

The linear generator has other parts that could make or break the design, such as the plastic tubing and the end caps. Electrical PVC would be a perfect candidate to house the magnets, but when wrapped with wire the PVC becomes thicker and harder to fit into the skate. The PVC could still be used, but the gauge of the wire and the amount of turns must complement its use. The end caps are very important to the reliability and lifetime of the linear generator. Regular PVC end caps were used during an initial testing and when the device was being shaken, the end cap shot off and the magnets flew out of the tube. The PVC end caps are also very thick and would not easily fit within the TUUK holder of the skate.

The power retention system can only be implemented in a few ways, one of them being a battery. The implementation of a battery could allow the device to function properly, but time is an important factor when considering a linear generator as a power source. The device needs to be able to heat up the blade quickly because the player only has a certain amount of time to warm up, meaning the skates have a limited time to warm up as well. If a battery were in place, the charge up time would be extensive and it would hold the charge extensively as well. The time to charge the battery and release the energy is too excessive to heat the blade in five minutes on average. The player would have to physically shake the skate in order for the blade to warm up in time, which is very impractical.

The heating element system can be created using a variety of circuit components. The Thermablade used a resistive wire, a valid way to heat the blade up. The cons about using a resistive wire to create heat are the loss of potential heat due to unused surface area and the difficulty of changing the blade if it breaks. The resistive wire is round, which means the surface area of the wire is not being used to its full potential. This makes the system inefficient because energy is lost in the system. The problem when changing the blade arises when the blade is taken out. The wire could potentially shift or move because of its shape in comparison to the edge of a hockey blade. The blade has a rectangular edge and the wire is rounded. If the wire is not snug enough with the plastic, the wire could fall out when the blade is removed.

Preliminary Proposed Design

The preliminary proposed design includes all three of the subsystems mentioned in the previous section of this report. The first part of the design was the skate. The pair of skates that will be used are the Bauer Vapor X60's and the skate that they will be tested against are the Bauer Supreme One100's, as well as the Bauer Vapor X6.0.

Figure 9 Bauer Vapor X60 (bauer.com)

Figure 10 Bauer Vapor X6.0 (bauer.com)

Figure 11 Bauer Supreme One100 (bauer.com)

These skate choices make for a simple design choice, as they are skates that are readily available, as well as an old pair of skates that can be dismantled to test the product with. The Bauer Vapor X60 will be the test pair of skates and the specs are shown in the chart below [19].

Skate Parts	Specifications
Skate Size	9
Blade Length	280mm
TUUK Holder	Tuuk Lightspeed Pro
Brand	Bauer
Hollow	5/8”

Table 1 Skate Requirements

The other pairs of skates will have like specifications besides the size of the skates. The size of the Bauer Supreme One100’s will be 9 and the size of the Bauer Vapor X6.0’s will be 7.5.

The linear generator will be designed to fit within the hollow back of a TUUK holder. The linear generator must satisfy a power requirement of 7.13 W.

$$Specific\ Heat\ of\ Steel = .452\ \frac{kJ}{kg * K}$$

$$Temperature\ Change = \Delta T = 10K = 10°C$$

$$Mass = .284\ kg$$

$$Q = mC\Delta T$$

The above equation is used to calculate the amount of power need to change temperature in a specific material.

$$= .284kg * .452\frac{kJ}{kg * K} * 10K = 1.288\ kJ$$

The equation uses the specific heat of steel, the temperature change of the blade from 23F to 41F and the weight of the average steel blade.

$$Assume\ time(t) = 180s$$

$$P = \frac{1.28kJ}{180s} * 1000 = 7.13\ W$$

From the average power over a three minute period, the voltage drop over the heating element of the system can be calculated. The three minute period is chosen because of the average warm up time before hockey games. The warm up time in most levels of hockey is around 8 minutes, but lower level hockey warm ups are 3-5 minutes. The three minute period is used in the above equations to have the blade at optimal temperature by the end of warm ups. The basic circuitry chosen is based off of a model shake flashlight.

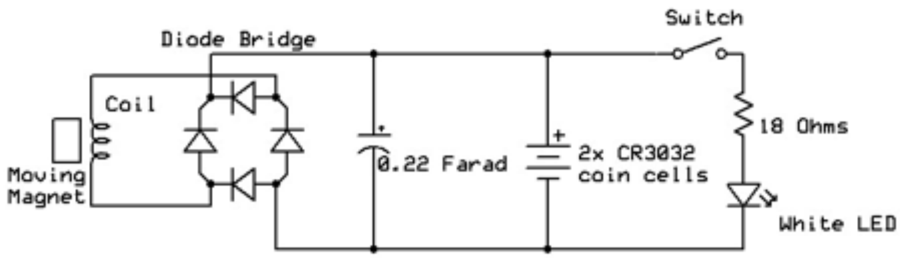

Figure 12 Circuit Diagram of Shake Light

The circuit used in the skate design will be quite similar to Figure 12. A coil will have a magnet passing through it to generate current. There will also be a full wave rectifier to rectify the voltage. There will be a 0.22F super capacitor in parallel with a resistor and the resistance of the blade in order to heat the blade to 41°F.

There are two different implementations of the heating element system that are being grappled with. The first is usage of the steel blade along with a voltage divider in order to achieve a voltage drop of 146 mV over the entire blade. This system allows for the average power to be 7.13 W using an assumption for the resistance of the blade as of now, which implements a large current on the circuit being problematic.

$$P = \frac{V^2}{R} \quad P = 7.13\ W \quad Assume\ R = .003\ \Omega$$

$$V = 0.1462\ V$$

The second design would use a resistive strip to transfer the heat from the circuit to the blade in order to increase the temperature of the blade to 41°F [7]. The resistive strip would be placed along the top of the blade. This strip would an excellent option as it would mesh with the surface area of the blade entirely. This design is tentative because of the availability of the parts. After attempting to contact the factory to get small samples, rather than large coils of the resistive strips, I continue to wait for a response. This implementation of the heating element system would be ideal.

The linear generator system will closely follow the system that is used for the shake flashlight. There will be a few differences that include the length of the plastic tube and the size of the magnet, to be placed within the system. The length of the plastic will have to be adjusted to fit within the hollow back of the TUUK holder. The length of the tube will have to be approximately 75 mm.

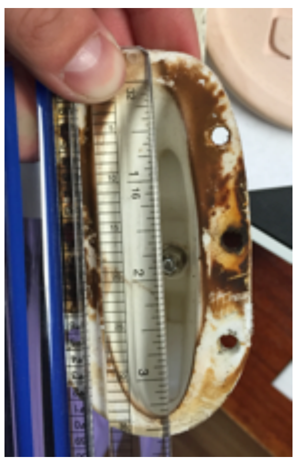

Figure 13 Back of TUUK Holder Length

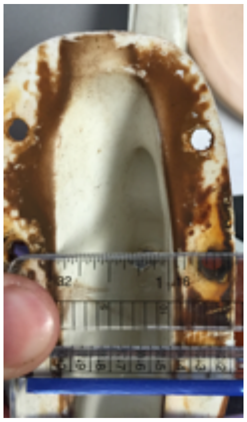

Figure 14 Back of TUUK Holder Width

The linear generator magnets will be 10mm in diameter and 1mm in width. There will be 13 of these magnets connected to one another inside the plastic tubing. The amount of magnets was solely based on the amount of space that is available within the TUUK holder. The end caps of the tubing will be the exact same as used in the flashlight. There will be rubber ends with magnets polarized accordingly in order to repel the magnet centered in the middle of the tube. The purpose of these end caps are to keep the earth magnets from shattering over time due to collisions with the plastic tubing.

Figure 15 Constructed Linear Generator Prototype

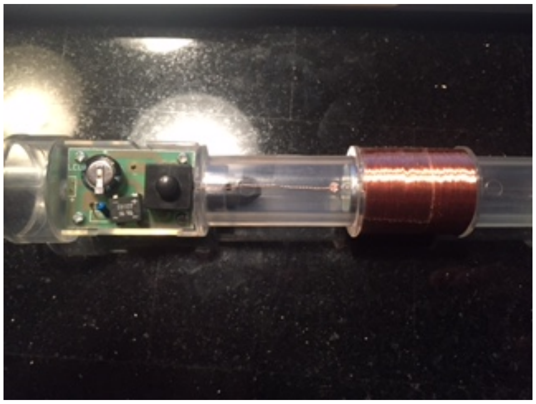

Figure 16 Shake Light Circuitry

In order to test the linear generator a system must be created to ensure the test results are as accurate as possible. This system will function similar to the wheels on an old train. The system will also replicate a motion similar to a skating motion [8]. The linear generator will be hooked up to this in order to ensure that it is being shaken at a constant rate for all tests that are being conducted. This machine will be hand crafted from wood.

Once the prototype has been completed a number of on ice tests will be conducted to assure the skate functions in the manner it is desired to. The first test conducted will measure the temperature of the blade after the skate has experienced vigorous motion and the battery has been charged up. The blade should measure 41°F in order for the ice to reach 32°F when contact is made [7]. This is a necessity to increases the layer of water between the blade and the ice to 20 microns [7].

The second test will be to determine how long the blade stays at the desired temperature after an allotted time of vigorous motion. After a minute of motion, the super cap should stay charged for at least three minutes. A minute is the length of an average hockey shift and the battery should remain charged long enough to ensure the temperature of the blades remains at 41°F. Each shift occurs approximately 2-3 minutes apart based on different coaching strategies. The super cap should hold a five-minute charge to allow the blade to stay warm if the player is seated on the bench for a longer duration than normal.

An acceleration test will be conducted by comparing the prototype to a normal skate. A distance 30' will be used to test acceleration. The same player will wear the skate and be timed from a dead stop until they make it through the finishing point. This will be conducted on a new sheet of ice and a chopped up sheet of ice. The data will be compared.

Testing gliding speed will be a similar test. The player will reach full speed and travel a distance 50', which is blue line to blue line in hockey, and be timed from start to finish and the times will be compared to the data collected by Thermablade .

Hurdles that need to be addressed include the amount of current for blade usage of Ro is way too high, can not find a suitable material for resistive strips and the linear generator size that has been tested in too big to fit within the TUUK holder

[15] [16]. During winter break, I will address these issues and be much closer to having a working prototype that can be used in on-ice testing.

Final Design and Implementations

The beginning of winter term was the point where the design of the skate needed to be finalized in order to order the last remaining parts and construct the prototype. The subsystems needed to be clearly defined and what those systems would be made of needed to be determined in order to ensure the design would function properly. No initial changes had been made to the design when winter term began, but as tests were conducted it was clear that complications in the functionality of the design indicated that alterations were necessary. The design still follows the same block diagram that is shown in Figure 7, but how the subsystems were to be constructed were altered as a result of testing.

Heating Element

Initially, the heating element of the system was going to be the skate blade in order to make the system less complex. The preliminary design contained calculations that assumed the resistance of the blade was 0.003Ω. In order to bring validity to that assumption various tests were conducted in order to measure the resistance of a blade attached to a Bauer Vapor X60 skate. Tests were done on the skate blade in order to ascertain the resistance, which included direct connection to an ohmmeter, voltage division with high resistances, and voltage division with low resistances.

The direct connection to an ohmmeter was not workable, as the resistance of the blade was too low. The blade was further tested using multiple different ohmmeters with banana cables that have been cut and had alligator clips soldered to the ends. The alligator clips ensured that there was a direct reliable connection to the blade itself.

The blade was then connected to a DC power supply in an attempt to calculate the resistance of the blade. A current of 2.15A was put through the blade and the voltage across the blade measured 0.3V.

$$V = IR$$
$$0.3 = 2.15R$$
$$R = 0.1395\Omega$$

The calculated resistance of this test 0.1395Ω, which could not be correct as an ohmmeter would have been able to read such a resistance.

As a result, a series circuit was constructed with the blade and a resistor to again determine the resistance of the blade.

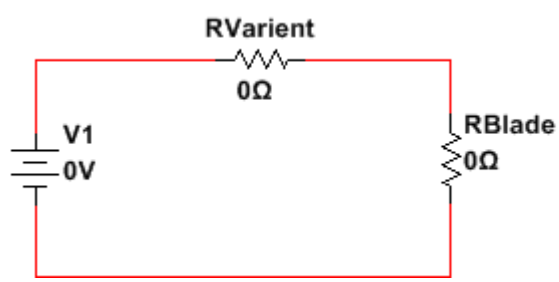

Figure 17 Circuit Design for Resistance Test

The RVarient in Figure 17 was a 1Ω resistor for the first trial conducted and V1 was 1V. The equation for voltage division was used in an attempt to calculate RBlade.

$$V_{Out} = V_{In}\frac{R_{Varient}}{R_{Varient} + R_{Blade}}$$
$$0.828V = 1V\frac{1\Omega}{1\Omega + R_{Blade}}$$

$$R_{Blade} = 0.2077$$

The output voltage was measured over RVarient and RBlade was determined to be 0.2077Ω, which was once again too large of a measurement. The same process was done with RVarient as a 1.2Ω resistor and V1 measured at 1V. RBlade was measured at 0.1.

In an attempt to match resistances within the voltage divider an additional resistor was added to the circuit, as shown in Figure 18.

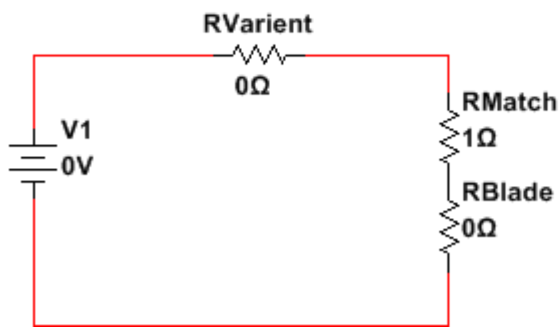

Figure 18 Resistance Matching Circuit

The same voltage division equation was used, except RBlade was now RBlade + R2. R2 was set at 1Ω. Input voltage was 0.2055 V and the variant resistor was still 1Ω. After calculation, the resistance of the blade was determined to be 0.01668Ω. This was the lowest resistance observed, but the resistance of the wires connected to the DC power supply were measured to be 0.012Ω. This meant that most of the resistance being measured involved the resistance of the wires.

As the resistance of the blade could not be determined due to the low resistance and possibility of error, another heating element had to be chosen. Ideally, a resistive strip would be used, as was noted in the preliminary design, but due to the extremely high cost of the resistive strip it was unrealistic to test with for the prototype. Instead, like Thermablade, the heating element would be a resistive wire.

Linear Generator

The linear generator design was very similar to the initial design in concept. All subsystems of the linear generator were to be used, but the system would now contain parts that were very similar to the shake light shown in Figure 16. The coil used for testing would be the exact coil from the flashlight, within the same tubing due to the end caps. The coil would be more reliable for testing as it had been made by a machine. This ensures the coil is tightly wound and allows for more turns due to the gauge of the magnetic wire. The end caps are rubber stoppers that contained magnets within them. A smoother wave was able to be captured because instead of the magnet smashing against the end caps of a system similar to the one shown in Figure 15, it would be repelled from each end of the tube. The repulsion force and the rubber covers ensured that the magnet would be introduced into an environment that would do less damage to its physical properties, therefore making the system more reliable. The magnet within the linear generator would be the same magnet in the flashlights system, as opposed to smaller individual magnets combined together.

Power Retention

The power retention system is the exact same as the preliminary design. This was based on the model circuit used in the flashlight. The capacitor would be used as the power retention system. The circuitry must include a full wave rectifier in order to ensure that all the voltage was positive.

Performance Estimates and Results

All of the components were tested using different methods in order to determine how reliable the system would be to heat the blade. These tests included various types of circuitry, simulations and numerous calculations.

Linear Generator

The linear generator was tested using the model that was constructed by hand and the linear generator that was found in the flashlight. It was estimated that the performance of the constructed generator would be much less efficient as it was made by hand and as opposed machine-made, like the flashlight generator. This assumption was made because the flashlight generator contains a coil with many more turns of a smaller gauge magnetic wire than the 28 gauge copper magnetic wire used for the handmade linear generator. The magnets were also different in both generators. The flashlight generator had one large magnet, with an unknown strength, while the constructed linear generator used 10mm by 3mm neodymium rare earth magnets.

Tests then proceeded using a machine built to replicate the motion of skating, as seen in Figure 19.

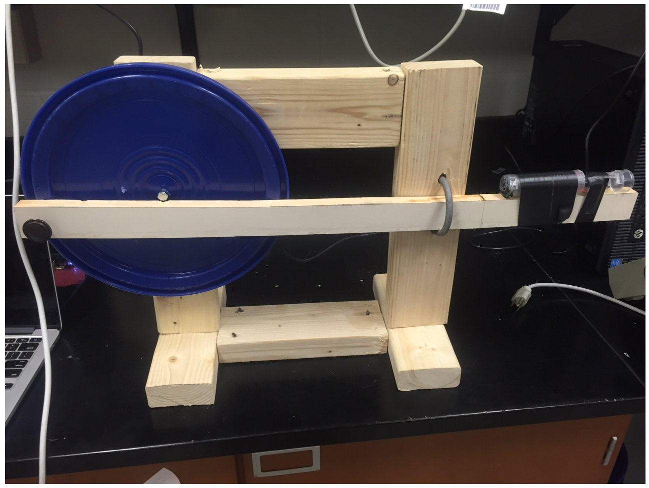

Figure 19 Crank Machine to Replicate Skating

The machine was built using wood for the frame and the arm that would hold the generator. The round wheel was made using a cover from a five gallon bucket. When the knob (seen on the left side of the white piece of strapping) was turned in a circular motion, the linear generator, secured to the right of the strapping, would mimic the motion of skating as a result.

The linear generator was also connected to an oscilloscope to measure the waveforms that were being created. Three trials were done at different rotational velocities in order to determine the voltages at different speeds. To ensure accuracy of the speeds a metronome was used at the different rates. One person cranked the machine while another waited until the waveform looked consistent. Once the waveform looked consistent that person hit RUN/STOP on the oscilloscope to hold the wave. The waveforms were captured using MATLAB's *swave* function and the data was stored. One of these waveforms is shown in Figure 20. The data was then averaged and used to calculate Vrms.

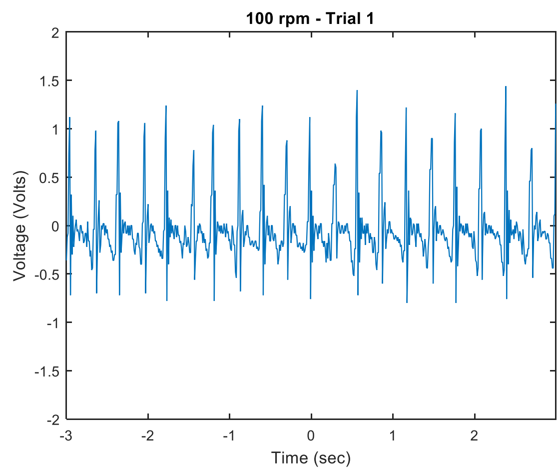

Figure 20 Waveform Collected at 100 RPM from Constructed Generator

```
plot(t1)
y1=t1(13:543);
plot(y1)
y1_rms=sqrt(mean(y1.^2))

y1_rms =

    0.1132
```

The MATLAB code used to calculate the Vrms is shown above from an example trial. The Vrms for all of the trials were averaged together to receive average Vrms values for all of the different speeds. The results can be seen below in Table 2 and the relationship between average Vrms and RPM shown in Figure 21.

Vrms/Trial	*Trial 1*	*Trial 2*	*Trial 3*	*Average Vrms*
20 rpm	0.1118	0.102	0.1042	0.1060
30 rpm	0.1384	0.1349	0.1372	0.1368
40 rpm	0.1515	0.1522	0.1549	0.1529
50 rpm	0.1826	0.1861	0.1793	0.1827
60 rpm	0.2183	0.2033	0.1966	0.2061
69 rpm	0.2241	0.2446	0.2364	0.2350
80 rpm	0.2863	0.2771	0.2959	0.2864
100 rpm	0.3464	0.3624	0.3955	0.3681

Table 2 Average Vrms from Constructed Generator

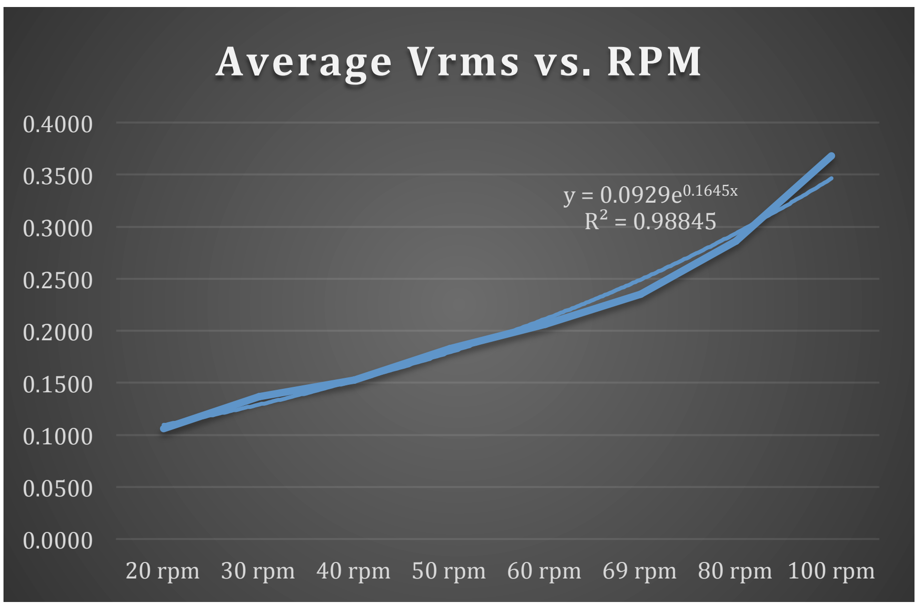

Figure 21 Average Vrms vs RPM of Constructed Generator

Identical tests were conducted using the linear generator from the flashlight. The generator was disconnected from the circuitry, therefore the voltage was not being rectified or smoothed by a capacitor.

Vrms/Trial	Trial 1	Trial 2	Trial 3	Average Vrms
20 rpm	0.8155	0.6732	0.6836	0.7241
30 rpm	0.9151	1.0654	0.6067	0.8624
40 rpm	0.895	1.2006	1.1926	1.0961
50 rpm	1.5763	1.5535	1.6119	1.5806
60 rpm	2.246	1.8539	2.1105	2.0701
69 rpm	2.9505	2.8809	2.6827	2.8380
80 rpm	3.3357	3.5339	3.44	3.4365
100 rpm	4.3466	5.0607	4.8851	4.7641

Table 3 Average Vrms from Flashlight Generator

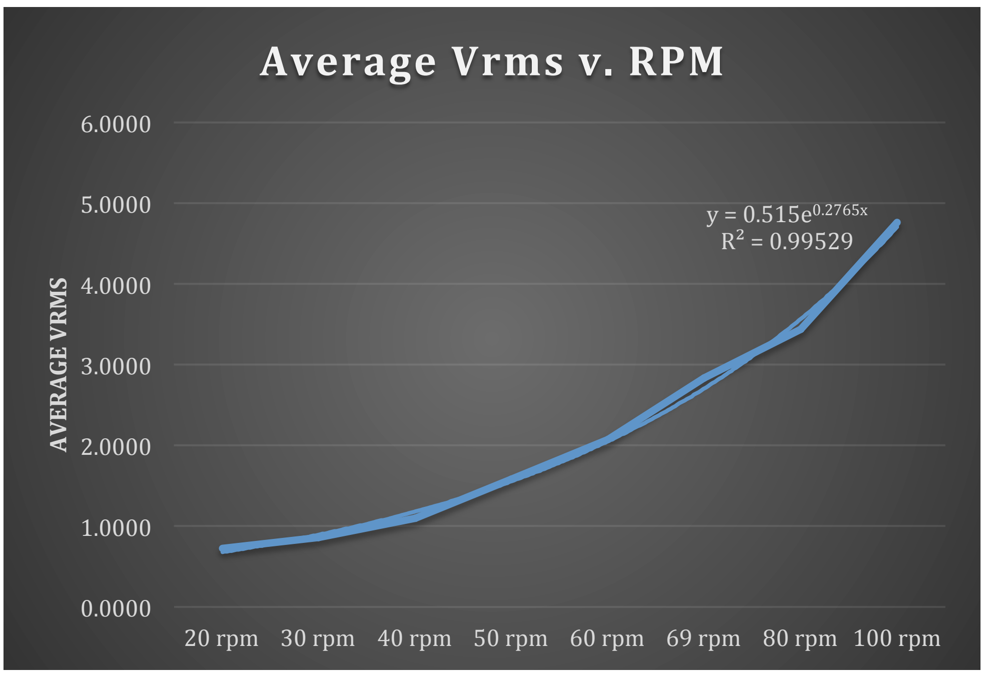

Figure 22 Average Vrms vs RPM of Flashlight Generator

The performance estimate was correct, as the flashlight generator outperformed the constructed generator substantially. The R^2 value also was more optimal with the flashlight generator, but it was questioned whether this was due to error with exact RPM in sync with the metronome. The voltage levels from the flashlight generator gave a clear indication that the flashlight generator would be used for the design.

Power Retention

The power retention system was then tested using MultiSIM circuits in combination with the waveforms collected through linear generator testing. The circuitry used was based off of the circuitry found in the flashlight. This system was chosen because the voltage needed to be rectified and the capacitor could smooth the wave, as well as store and release voltage rapidly.

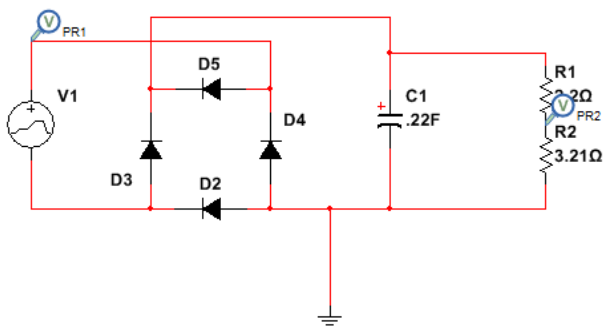

Figure 23 MultiSIM Circuit of Circuit Design

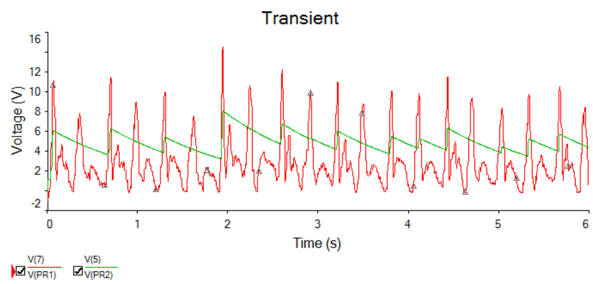

Figure 24 Input (Red) and Output (Green) Voltages Over Time

The circuit component values C1 and R1, shown in Figure 23, were chosen to be the same values that were observed on the circuit board taken out of the flashlight. The R2 value represents the resistive wire in the circuit which was taken from the items description of 3.21Ω/ft [20]. The full wave rectifier was constructed using for diodes as shown in Figure 23. The circuit was simulated using a transient mode simulation. Figure 24 shows how the input voltage from the generator is rectified and then smoothed by the capacitor. When the simulation test was run, the power retention system worked as expected.

Heating Element

The heating element was estimated to slowly heat up when connected directly to the generator without circuitry. It was necessary for the heating element to heat up 10°F. A circuit was adopted from a lab taught by Professor Buma in his ECE-363 to test the temperature of the resistive wire as current was put through it.

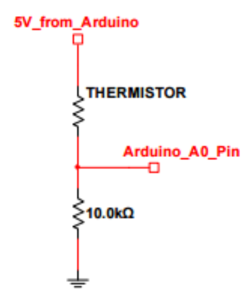

Figure 25 Circuit Adopted from Professor Buma's Lab

The 10kΩ thermistor was attached to the resistive wire, which was hooked up to the linear generator using alligator clips. The Arduino allowed for the data to be collected over time using code Professor Buma had written (referenced in the appendices). The temperature rose drastically, as seen in Figure 26. This result was very unexpected as the voltage waveform had not been rectified or smoothed.

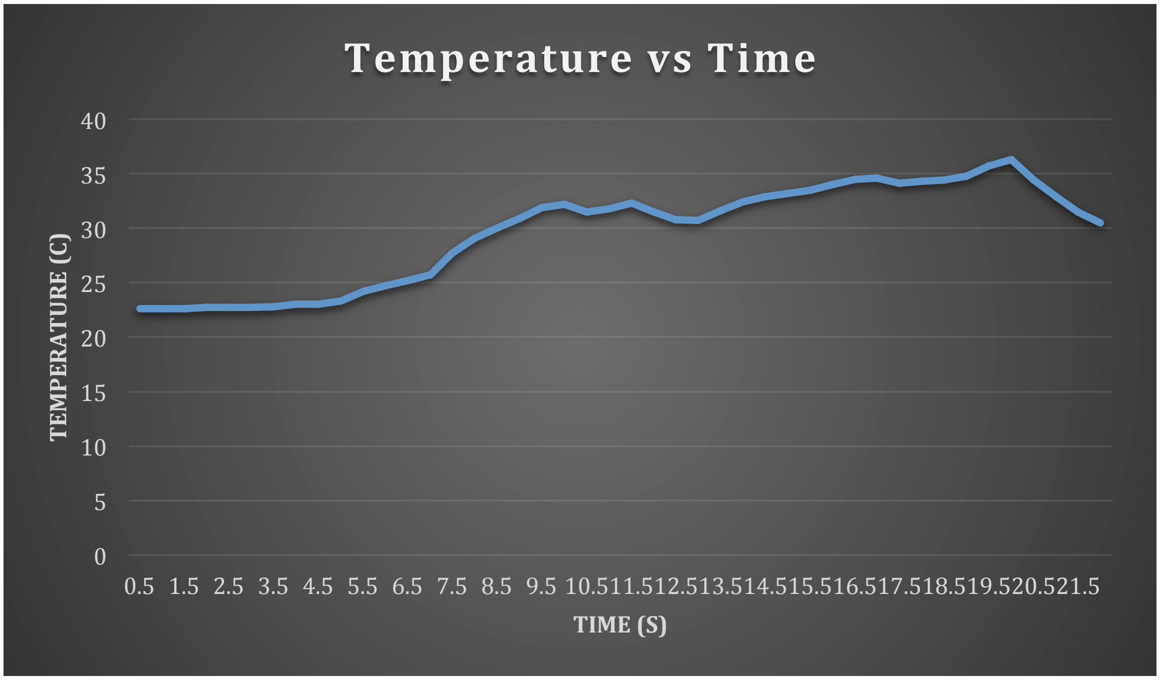

Figure 26 Temperature vs Time of Resistive Strip

Such a result was extraordinary, yet thermal calculations still need to be completed in order to show that the energy was being transferred into the blade. The blade needs to reach 41°F, meaning excessive heat transfer calculations need to be done as the blade is constantly losing energy due to the cold environment it is functioning in. This result also raised the question of whether or not a system should be put in place to limit the heat being produced by the resistive and whether it is causing the blade to become too warm.

Vrms/Trial	*Average Power*
20 rpm	0.163339816
30 rpm	0.23169276
40 rpm	0.374256118
50 rpm	0.778252644
60 rpm	1.335031781
69 rpm	2.509169222
80 rpm	3.67905338
100 rpm	7.070706049

Table 4 Average Power in Watts Using Vrms from Flashlight

The power the blade must receive over a period of three minutes is 7.13W, as shown in the preliminary design. Assuming that there is a thermal tape over the resistive wire that directs most of the heat energy into the blade, it is possible to give this blade enough power because the trails were only six seconds long. There are many assumptions that are made using this method, so additional testing needs to be done. The motion of a hockey skate is not at a constant rate due to gliding and different rates of acceleration throughout the game, making it difficult to accurately ascertain these measurements without direct on-ice testing.

Production Schedule

The design of the Energy Harvesting – Heated Hockey Skate Blade was done over a time period of three terms at Union College. There were many different phases of the design process during the project, which included developing an initial idea for a design, creating the preliminary design, and finalizing the design.

The first term involved becoming familiar with the design process as an engineer. This involved learning about and analyzing case studies, as well as giving presentations in front of peers. The brainstorming process involved choosing possible projects and narrowing them down to the one to be worked on for the next year. Once the project was chosen, research was done to implement the design project and discover possible solutions to the initial problems initially discovered.

The preliminary design began to unfold during the second term. Limits on how the project could be solved and narrow down options by conducting research and running tests. Once tests were complete, initial parts were ordered allowing for subsystems testing. The preliminary proposed design was defended in front of peers through presentations. These presentations included tests and research detailing the design and reasoning in support of its intended construction.

The last term dealt with prototyping and much more rigorous testing on the components that were being used in the design. The detail of these tests became more important to reduce error and increase efficiency of the design. The final research was defended in front of many various audiences that included peers, professors, and other interested in learning about the projects.

Numerous improvements could have been made to this process and its details, ranging from small to large. The design of the hockey skate became more complex as the research progressed. The amount of variables, ie. different ways to approach the problem, seemed to increase as the process continued. It became evident that more focus on the design of the actual skate should have occurred earlier in the process. This would have allowed more work to be accomplished throughout the entire process. There were also limits to what could be done due to the lack of knowledge with mechanical engineering topics, such as heat transfer and thermodynamics. These topics are crucial to the design's success because of the heat being transferred into the blade from the resistive wire and subsequently into the ice from the blade.

Overall, the process was enjoyable and I plan to continue to work on the design and its implementation as time goes on. Through this process I discovered that plenty of work still needs to be done and many unknowns need to be addressed in order for this design to be successful.

Cost Analysis

The cost analysis of the design must only take into account the products that would be used for the design. There were more parts purchased than what is shown in Table 5, but will not be included in the final design. The product's net cost would be $40.18, a very desirable amount, as it can keep the cost of the product below the desired $150. If the product is not put into the skate the cost will go up because the product would have to be sold separately.

Part	Purpose	Quantity	Overall Cost	Quantity Used	Cost of Implemented
26 Gauge Nichrome Round Wire	Heating Element	100'	$6.99	1'	$0.07
Duralight Freedom Shake Flashlight	Linear Generator/Circuitry	2	$19.99	2	$39.98
Red Devil Minimal Expanding Foam Fill	Secure Structure	12oz	$13.27	1/12 oz	$0.13
TOTAL					**$40.18**

Table 5 Cost Analysis

The gross cost of the product is difficult to determine as further research must be done, manufacturing costs need to be taken into account, and other costs need to be taken into account. If the product is produced on a mass scale that will drive down the net cost of $40.18, leaving financial resources to be utilized in other parts of the process, such as research. The gross cost of the product should stay well under $150, but if it rises above $150 it is still much cheaper than the $400 Thermablade. Overall, the product is very cost effective in comparison to what would be its competing product.

User's Manual

The user of this product has no interaction with the components when in use, aside from the benefits received while skating. The product would quietly function while the user skates and plays their game, all the while reaping the benefits of becoming a faster player with less stress on their bodies.

A person performing maintenance on the skate would have to know how to place the heating element back within the skate properly. Once the blade is removed from the skate the heating element is revealed. Contact needs to be made with the blade when the new blade is put into the TUUK of the skate in order to ensure optimal performance.

If the blade is not heating up correctly, the skate must be dismantled by removing the TUUK from the boot and the foam must be scraped away to reveal the circuitry. The circuitry would have to be analyzed by someone with an electronics background to troubleshoot and diagnose the problem with the circuit.

Future Work

The Energy Harvesting – Heated Hockey Skate Blade needs further investigation, research and testing in order to optimize the product.

Mechanical Engineering

This is a product that entails a great deal of mechanical engineering. In order to successfully show that the product would be able to heat the blade to a temperature of 41°F when in contact with a 23°F ice surface many thermal calculations need to be done with reference to heat transfer and thermodynamics, something I lack experience in. Complications also arise with transfer between the resistive wire and the blade. The resistive wire must be able to transfer enough heat to the blade, as the blade loses energy while in contact with the ice frequently.

A system that limits heat may also need to be developed in order to ensure the blade or the resistive wire does not overheat, which could take away the optimal advantage the player gains by using the product. Again, this issue needs to be addressed using complex thermodynamic and heat transfer equations.

Component Research

Different combinations of the components used within the linear generator should be investigated in order to reach the optimal heat needed once the mechanical engineering equations have been worked out. Any possibility of testing the system with the resistive strip as opposed to a resistive wire would be optimal, as it would transfer heat better considering the surface area of the blade that needs to be covered.

Testing

On ice testing should be done once all of the research is completed and the parts are chosen to ensure that the device is inconspicuous while in use. This would also provide confirmation that the acceleration and glide speeds have increased due to the heating of the blade using a linear generator.

Conclusions

Thermablade is a company that creates skate add-ons to improve a player's performance. Its downside is the exorbitant cost of the product and the player having to plug his skates into a wall outlet to charge. Using Faraday's Law of Induction can implement the same technology at a more reasonable cost without the need to consistently charge the skate to reap its benefits.

The Energy Harvesting – Heated Hockey Skate Blade uses Faraday's Law of Induction in combination with a linear generator that fits inside the TUUK of the skate to supply current to a resistive wire. The resistive wire heats the blade to the desired temperature of 41° and the player experiences faster acceleration and glide speeds without even knowing it.

The goals set for the design were clearly laid out. The cost of the product needed to be reduced drastically, it needed to statistically compete with Thermablade's performance, keep the devices physical presence unknown, and be extremely reliable. Throughout the process there were many obstacles to overcome due to the complexity of the data that needed to be collected. This unfortunately limited the developed prototype. Steps were made towards the goals set at the beginning of the project and will continue to be sought hereafter. One of the initial goals was affordability, and that goal has been met. The net cost of the product was $40.18, with the gross cost well below $150, the standard cost for a comparable.

Although there were many roadblocks, much progress was made towards a working prototype. The circuit components have been tested and will be implemented in a complete design. The components include the resistive wire that will be tested for heat transfer and the power retention system that contains the super capacitor and full wave rectifier. Two linear generators were tested, revealing what the generators' traits should be. The thermal dynamic and heat transfer problems will be address in the future, and provide the missing information needed before the design is sealed in the skate.

Overall, I look forward to working toward the completion of a final product. An abundance of work must be done before that occurs, but the final product could potentially revolutionize the game of hockey. This has been a great experience and I have learned a lot about myself and the world of engineering. The potential to make a difference in the game of hockey, the game I love, keeps the dream alive.

Acknowledgments

A special thank you to Professor Luke Dosiek and Mike Geiger for their assistance, encouragement and support throughout the design process. None of this would have been possible without their cooperation. I offer my sincere thanks and appreciation for their time and efforts in helping facilitate this project.

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Appendices

Code Written by Professor Buma for Thermistor Lab

```
/*  Reads the temperature from a 10k thermistor. A 38 kHz PWM output is produced if the
 *  temperature exceeds the setpoint.
 *
 *  The thermistor is assumed to be in a voltage divider circuit powered by +5V
 *  from the Arduino (+5V, Rth, 10.0k, GND).
 *
 *  The "extended" Steinhart-Hart Equation is used to compute temperature.
 *  The "math.h" library is needed for the log function.
 *  It is assumed that Rth=10kohm at T = 25 degC.
 *
 *  The PWM is produced with "Timer2", where the registers are programmed
 *  to output "phase-correct PWM" with the top limit determined by OCR2A.
 *
 *  Thermistor code is adapted from www.vernier.com/arduino
 *
 *  PWM code is adapted from  http://www.righto.com/2009/07/secrets-of-arduino-pwm.html
 *
 *  Written by:  TB  08/28/15
 *
 */

#include <math.h>           // need this library for "log", "sq", and "pow" functions in temp calculation

#define PIN_Thermistor 0      // Assign Pin 0 for thermistor measurement

int TempSetPoint = 27;          // deg C (modify this if necessary)
int TimeBetweenReadings = 1000;    // in ms
int PWM_state;                  // 0=off, 1=on

// setup() is only performed once at the beginning of the program.

void setup()
{
  pinMode(3, OUTPUT);        // Configure Pin 3 to be OUTPUT (rather than INPUT)
  PWM_state=PWM_output(0);     // Initially set PWM_state = off

  Serial.begin(9600);        // start the serial monitor
  Serial.println("Temperature Readings taken using Arduino");
}

/*  loop() is where we do stuff over and over again.
 *  For this program, we want to:
 *  (1) measure the thermistor voltage
 *  (2) compute temperature
 *  (3) produce PWM (if necessary).
 */

void loop()
{
  int ADCreading;                // raw ADC measurement (0 to 1024)
```

```
 float Temp;                    // computed temperature (in deg C)

 ADCreading=analogRead(PIN_Thermistor);      // read ADC value at the A0 input
 Temp=Thermistor(ADCreading);      // compute temperature -- see "Thermistor" function at bottom

 // below is basically a finite state machine (PWMstate = off or on)

 if (PWM_state==0)                // currently PWMstate = off
 {
  if (Temp>TempSetPoint)
  {
   PWM_state=PWM_output(1);       // turn on PWM if Temp > SetPoint
  }
 }
 else                          // currently PWMstate = on
 {
  if (Temp<TempSetPoint)
  {
   PWM_state=PWM_output(0);       // turn off PWM if Temp < SetPoint
  }
 }

 // now print stuff on the serial monitor

 Serial.print("SetPoint = "); // display set point
 Serial.print(TempSetPoint);
 Serial.print("\t");

 Serial.print("Temp = ");
 Serial.print(Temp,1);   // display temperature to one decimal place
 Serial.print("\t");

 Serial.print("PWM = ");
 Serial.println(PWM_state,1);
 delay(TimeBetweenReadings); // delay by TimeBetweenReadings (e.g. 500 ms)
}

// Need to define the "Thermistor" function that computes temperature.

float Thermistor(int Raw)
{
 int R0 = 10000;
 int R25= 10000;
 float Rth;
 float LogR;
 float Temp; // Multi-purpose variable to save space.

 float A = 3.354016E-3;
 float B = 2.569850E-4;
 float C = 2.620131E-6;
 float D = 6.383091E-8;

 Rth = R0*(1024.0/Raw-1);       // Convert raw ADC value to Rth -- the ".0" after 1024 is important!
 LogR = log(Rth/R25);          // Compute log(Rth/R25)
 Temp = 1 / (A + B*LogR + C*sq(LogR) + D*pow(LogR,3));  // Compute Temp
```

```
 Temp = Temp - 273.15;  // Convert Kelvin to Celsius

 return Temp;                    // Return the Temperature
}

// Define the "PWM_output" function that produces PWM and returns 0 (off) or 1 (on)

int PWM_output(int enable_PWM)
{
 if (enable_PWM==0)
 {
   TCCR2A = 0;      // clear TCCR2A bits
   TCCR2B = 0;      // clear TCCR2B bits
   return 0;
 }
 else if (enable_PWM==1)
 {
   TCCR2A = _BV(COM2A0) | _BV(COM2B1) | _BV(WGM20); // configure TCCR2A bits of Timer2
   TCCR2B = _BV(WGM22) | _BV(CS20);         // configure TCCR2B bits of Timer2
   OCR2A = 210;                    // set OCR2A top value (determines frequency)
   OCR2B = 52;                     // set OCR2B value (determines duty cycle)
   return 1;
 }
}
```