PARASITIC POWER HARVESTING FROM THE EXPANSION OF THE HUMAN CHEST DURING RESPIRATION

by:

William Arora

December 11, 2002

Department of Electrical Engineering / MIT Media Lab

Massachusetts Institute of Technology
Cambridge, MA 02139

Abstract

The goal of this project was to design a system to harvest enough energy from the human body to power a cell-phone under normal, daily use circumstances. Research has already been done in this field of parasitic body power harvesting [1], and identified the areas of the body where significant power may be harvested: leg motion and footsteps from walking, arm motion, chest expansion during respiration, blood pressure, and body heat. Devices have been built that capture energy from human footsteps through piezo-electric insoles [2]. These devices generate power on the order of several milliwatts, which is not enough to power a cell-phone, and only provide power when the user is walking. The final design of this project attempted to harvest power from the chest during respiration. This was accomplished via a strap tied around the chest connected to an induction generator. This design was chosen because the source of power is constant (people are always breathing), the method of power harvesting was non-intrusive (people already wear bra straps), and the method of conversion into electrical energy was efficient. The finished prototype generated 109 [mW] of power and it is estimated that with design improvements could generate up to 1 [W] of power.

Table of Contents

List of Figures and Tables

1 Introduction

This paper describes the design of a device that parasitically harvests power from the human chest during respiration and converts it into electricity. It is a solution to the challenge of the parasitic power harvesting field; namely to convert energy expended by the human body into electricity without requiring the body to perform any abnormal activity. The device is a parasite in that it feeds off the wasted energy of the human body during but does not require any special activity or body motion.

The field of power harvesting becomes useful as computing technology shrinks in size and power usage. Devices that can be carried on the body and that consume approximately 1 [W] of power are ideal candidates to be powered from the body. The cell phone is a current example of such a device because it is carried in the pocket and consumes 600 [mW] during operation [3], and 170 [mW] over an entire day. Currently 67.2 million people in the United States own cell phones and this number is growing rapidly [4]. An additional 19 million people in the United States own personal digital assistants which are also devices that can be powered from the body. The goal of this project was to design a parasitic power harvesting system that could meet the power requirements of a cell phone, i.e. produce 170 [mW] of power.

Two main design criteria exist for power harvesting devices. The device must be ergonomic, and capable of generating enough power. The final design was derived from these criteria and consisted of a chest strap connected to an induction generator. A prototype was constructed that provided a load on the chest similar to that of a bra strap, and the generator worn on the back was able to produce 109 [mW] of power. While this does not meet the 170 [mW] requirement stated earlier, it is estimated that with improved construction the device could realistically produce 300 [mW] of power.

2 Design Criteria and Possible Implementations of a Useful Parasitic Power Supply

This design challenge contained important criteria from many different disciplines including electrical engineering, mechanical engineering, and ergonomics. The following set of design criteria are general and apply to all power harvesting devices:

1. The device must be worn comfortably, unobtrusively, and not place an excessive load on the user.
2. The device must produce enough power for a cell-phone. Cell-phones have a maximum power rating of .6 Watts according to the .
3. The device must produce power at a constant rate throughout the entire day, regardless of any activity the user may be engaging in.

The possible sources of power from the human body have already been defined in previous research [1]. They include: body heat, respiration, finger motion, arm motion, blood pressure, and footsteps. To date, the only source that has been significantly investigated is footsteps because of the large amount of power expended by the body when walking (57 Watts) [1]. However, harvesting power from the walking motion violates criterion 3, because it is not a constant source of power. Similarly, arm motion and finger motion were ruled out because they violated criterion 3. Harvesting power from blood pressure violates criterion 2, because it may place an excessive and potentially lethal load on the heart. Harvesting power from body heat violates criterion 1, because a special full body suit must be worn. The solution of respiration was chosen by this elimination process and because it satisfies the three criteria. It requires a chest strap to be worn (just as a bra strap is worn), it has the potential to produce more than 1 Watt (Eq. 1), and produces power at a constant and uninterrupted rate.

The following calculation provides an estimate for the amount of power that may be harvested via a chest strap. The data used in the calculation were taken from empirical measurements of the body.

Change in chest circumference during relaxed breathing (L) = 5 [cm / breath] = .05 [m / breath]

Rate of breathing during everyday activity (R) = 1 [inhalation and exhalation / 6 seconds]

= 2 [breaths / 6 seconds] [1]

Maximum load sustainable on chest without causing discomfort (F): 100 [N]

Estimated generator efficiency (Eff): 75%

$$P = F \times L \times R \times Eff = 1.25 \text{ Watts}$$

(Eq. 1)

The result of this estimate shows clear potential for a chest strap system to power a cell-phone that consumes .6 [W] of power. It is even more convincing when the time averaged power consumption, <P>, of the cell-phone is realized (again based on empirical measurements):

Maximum realistic cell-phone usage during one day (T_u): 4 [Hours]

Amount of time chest strap is worn during one day (T_t): 14 [H]

$$\langle P \rangle = .6 \text{ [W]} \times T_u / T_t = .17 \text{ [W]}$$

(Eq. 2)

Therefore if an effective circuit can be developed to charge a small battery that is capable of delivering .6 [W] for 4 hours, the effective power requirement on the chest strap generator is reduced to .17 [W] (Eq. 2).

[1] Power can be harvested from both the expansion and contraction of the chest, each of which counts as a breath

3 Design Criteria and Possible Implementations of a Chest Strap Power Harvesting System

Now that the chest strap solution has been chosen, additional criteria must be established and met to ensure optimal design. First, the reason why an induction generator was decided upon was because it is the only known method of converting mechanical energy into electrical energy with a high enough efficiency. This decision results in a system with two components: the chest strap, and the generator. Separate design criteria exist for each.

3.1 *Generator Design Criteria*

The design criteria for the generator follow from the original design criteria established in section 2.

1. The generator must be thin enough to not encumber a user wearing it on her upper back. Emprical tests show that objects thicker than 9 [mm] bother people when worn.
2. The generator must be optimized to run at a low speed, because the force of chest expansion is not constant and not enough to keep a generator spinning at speeds over 6 [Hz].

3.2 *Evaluation of Possible Generator Designs*

Several generator designs were evaluated to solve this design challenge. Each is discussed separately in the following sections, which discuss them in order of least successful to most successful. For reference purposes, the following basic equations of electromagnetic induction is provided:

$$I = q_{total} \times (v \text{ X } B)$$

(Eq. 3)

$$V = -N \times d\phi/dt$$

(Eq. 4)

$$\phi = \int B \, dA$$

(Eq. 5)

Where I is current, q_{total} is the number of electrons in the wire, v is velocity, X denotes cross product, B is magnetic field strength, V is voltage, N is the number of coils, ϕ is magnetic flux density, t is time, and A is the area perpendicular to the flux.

3.2.1 *Chest strap coil with inner sliding magnet*

This design attempts to merge the generator into the strap itself. The advantage of this is that a separate generator would not need to be worn. The strap is made of a flexible magnet, a ferro-fluid, or chain of inflexible but thin magnets and wrapped around the chest. Surrounding this magnet loop is a thick coil of wire. Chest expansion and contraction will slide the magnet loop through the coil, as shown in Figure 1.

Figure 1. Design of an inductive magnet-coil chest strap.

Unfortunately, two factors reduce the efficiency of such devices well below the criteria standard. First, flexible magnets and ferro-fluids are very weak; their field strength is on the order of 10^2 Gauss (G) and will not generate enough voltage in an induction system (see equations 4,5). Second, even if stronger, inflexible magnets are chained into a loop, the average velocity that they will travel at relative to the surrounding coil is 5cm / 3s = .017 m/s (data from section 2). Equation 2 shows that not enough current will be produced to generate significant power.

Along the same lines of the flexible magnet chest strap, a design was considered in which a flexible magnet the size of the entire human back was considered. A sheet of layered wire loops could move around over this magnet through some mechanism. The hypothesis was that increasing the area through which the coils cut the magnetic flux would generate more voltage. However, tests that were conducted with 8.5 x 11 [Inch^2] flexible magnetic sheets and 8.5 x 11 [Inch^2] sheets of layered wire loops failed to generate voltage greater than 1 [mV]. This is again attributed to the low field strength of the magnet and low velocity of the coils.

It follows that because these designs are not feasible, a system that transfers power from the chest strap to a separate generator via a pulley system must be used.

3.2.2 *Parallel disc generator*

This generator design consists of two closely spaced plates able to spin freely on a ball bearing shaft (Figure 2). It was motivated from the thickness criteria and the efficiency criteria. It is the thinnest possible generator since it involves only two parallel plates. In addition, the magnets are able to spin freely and continually in the same direction if a ratchet system is used. This improves the efficiency of the generator because the magnet plate acts as a flywheel to store the work of the user's respiration in kinetic form until it is converted into electrical energy by induction.

Figure 2. Side view and front view of the parallel disc generator.

Equations 4 and 5 can be used to calculate the voltage that this generator will produce, assuming that the magnets and coils are circular in shape and placed along the inside perimeter of the generator (as shown in Figure 2).

$$V = -n \text{ x } N \text{ x } d(B\text{x}A)/dt$$

$$= -n \text{ x } N \text{ x } A \text{ x } B \text{ x } d(\cos[\pi nft])/dt$$

$$= n^2 f \pi N A B \sin(\pi nft)$$

$$\langle V \rangle = (n^2 f \pi N A B) / 2$$

(Eq. 6. n is the number of coils, f is the frequency of rotation, and $\langle\rangle$ denotes time average)

Equation 6 shows that the output voltage is proportional to the number of coils squared, and the area of the coils. As the number of coils increases, their area decrases. The maximum voltage is produced when the number of coils approaches infinity and their area approaches zero. However, an analysis of equation 2 in this situation shows that the current generated will go to zero and therefore no power will be generated. This is because the number of electrons that are moved is proportional to the area of the area of the coils as well. Maximum power is therefore proportional to the total working area of the generator squared. Geometric analysis proves that this area is greatest with four circular magnets. However, this leaves too little room in the center for a ball bearing device and ratchet system. Using six will leave enough room in the center for the necessary mechanical components and only reduce the efficiency by 6%. Motors with this design can often be found in old 5.25 inch floppy disk drives. A disassembled disk drive motor was used as a generator to test this design, and produced a time averaged power of 5 [mW] at 3 [Hz]. This could be improved if stronger magnets were used in the motor.

3.2.3 Concentric cylinder generator

This design consists of an outer magnet cylinder which spins about an inner cylinder of coils, and is depicted in Figure 3. The outer magnet ring is attached to a plate and the ball bearing shaft. It is rotated by the chest strap pulley and ratchet system. The inner coils are attached to a separate plate and the outer edge of the bearing so that the magnet ring can spin freely around the coils.

Figure 3. Front and side view of the concentric cylinder generator.

Essentially, this generator is the same as the parallel disc generator but with different topology. Each coil covers less area but can have more depth and therefore more turns.

Furthermore it is possible to put a second magnet ring inside the coils to increase (double) the strength of the magnetic field that passes through the coils without adding to the thickness of the generator (see Figure 4).

Figure 4. Front view of concentric cylinder generator with inner magnet ring.

The main advantage of this design over the parallel disc generator design is that the entire volume of this generator is used for power generation, and there is no wasted space. This is partly because magnets of cylinder wedge shapes are readily available whereas magnets of a circular wedge shape are not. The volume in between the interstices of the magnets in the parallel disc generator design is wasted space that is not generating power.

An additional advantage is that the concentric cylinder design allows for thicker magnets to be used without increasing the thickness of the generator. Thicker magnets have much larger field strengths and therefore produce more voltage across each coil. If thicker magnets were used in the parallel disc generator, the thickness of the entire generator would increase.

The preceeding analysis of possible induction generator designs led to the decision to build a prototype using the concentric cylinder design. A detailed description of its construction is in section 4.1; the results which measure its power generation ability are in section 5.

3.3 *Chest Strap Design Criteria*

The design criteria for the chest strap again emerge from the ergonomic and efficiency requirements:

1. The strap must distribute the load of the generator evenly across its length and width, and lie flat against the chest. The width should be approximately 1.9 [cm] in order to distribute the load over a large enough area so that the user does not experience discomfort.
2. The component of the strap that transfers the work of the chest expanding to the generator must deliver at least 99% of this energy to the generator. Therefore, it must not absorb energy, it must not have elastic properties.
3. Any component of the strap that is not transerring work from the chest motion to the generator must not place any additional load on the chest or impede the chest motion in any way. This is because all the work should be done in the generator. This component should not absorb more than 5% of the work done by the chest.

3.4 *Evaluation of Possible Chest Strap Designs*

The first criterion establishes that a band, preferably similar in width to a normal bra strap band must be used so that a large area is in contact with the body for the load to be distributed over. The second and third criteria imply that there must be two components to the chest strap: a comfortable, elastic band worn against the skin and an inelastic load bearing band that must slide frictionlessly across the elastic band.

These implications led to the testing of many materials to find a pair that could be used to create such a strap. It was decided that a highly elastic tube such as a women's nylon was ideal for the non-load bearing part of the strap because it could stretch 5 cm without placing much additional load on the chest, and because it was smooth enough to let other materials pass through it with minimal friction. However, it was not a simple task to find another material that could slide frictionlessly against the nylon and also be inelastic enough to satisfy the load-bearing criterion. Many materials were tested including: silk, composite fabrics, teflon tape, dental floss, cellophane and thin plastics, and paper based strips. These materials were each tested with and without oil lubrication and fine grit sanding. The result of the tests was that a hard plastic tube was both the most inelastic and most frictionless against the nylon. It was also flexible enough to be wrapped around the chest and evenly distribute a load over its length. Figure 5 illustrates the design of this chest strap.

Figure 5. Initial chest strap design.

There are two disadvantages to this design. First, the diameter of the plastic tube was only 5 [mm], creating an effective strap width of 5 [mm]. This does not meet the 1.9 [cm] requirement of design criterion 1. Although four of such tubes could be used to make a wider strap, this results in four times the sliding friction and complicates the connection to the generator.

The subsequent redesign better satisfied the design criteria and was used in the construction of the prototype chest strap. Instead of using a load-bearing band, the design used a load-bearing cord housed in plastic sheaths. The friction of the cord against the plastic was minimal, and the cord was able to transfer the load without deforming. The plastic sheaths were spaced evenly along a spandex band woven so that it stretched in a lengthwise direction but not in a widthwise direction. Each sheath was bent into a slight mountain shape and sewn into the band so as to pull the band taut across its width. Figure 6 illustrates this design.

Figure 6. Front and top view of the final chest strap design.

The arrows in the figure show how the inward force (load) on the cord pushes the plastic sheath outward thereby stretching the strap along its width. The tension in the width of the strap serves to distribute the load of the cord evenly over the strap. The small spacing in between each sheath depicted in the front view of Figure 6 allows the strap to stretch apart when the chest expands. Section 4.3 discusses in detail the construction of this strap.

4 Description of Prototype Construction

A prototype of the chest strap power harvesting system was built using the recommended designs from sections 3.2 and 3.4. Namely, a concentric cylinder generator was constructed as well as a chest strap that incorporated the plastic sheath and cord design.

4.1 *Generator Construction*

The generator was constructed in three steps. First, the outer magnet ring was built. Second, the inner coils were wound. Third, the magnet ring and coils were assembled onto a ball bearing.

The outer magnet ring was made with eight neodymium iron boron magnets ($Nd_2Fe_{14}B$). Neodymium is the strongest known ferromagnetic material and was used for that reason. The field strength of the magnets used in this prototype was measured to be 10^4 Gauss. Each magnet had an angular width of 45^o and was cut to a height of 1 [cm]. The magnets were arranged so that their poles alternated around the ring, and glued with epoxy to a wooden plate (see Figure 7). The outer radius of this ring was 10 [cm] and the inner radius was 8 [cm].

Figure 7. Arrangement and orientation of the outer magnet ring.

Eight inner coils were wound to fit within the dimensions of the generator. Each coil was wound around a 3 [mm] thick plastic wedge shaped to fit within the 45^{o} angular width provided by each magnet (see Figure 8).

Figure 8. Isometric, cross-sectional side, and top view of a wound coil.

AWG 30 enameled magnet wire was used to make the coils. This wire has a diameter of .02.5 [cm] and a linear resistance of .3 [ohms / m], making it suitable for a small coil with a large number of turns and a low resistance. Each coil was wound until it reached 1 [cm] in height so that it would occupy the entire volume of the magnetic field from each magnet. The coils reached 1 [cm] after 450 turns were wound, and had a total resistance of $4 \pm .3$ [ohms]. The plastic wedges were then removed creating a hollow core inside each of the coils. These cores were filled with a 1:1 mixture of epoxy glue and magnetite sand to increase the field strength through the coils while maintaining a non-conductive core to minimize eddy currents. A wooden plate 1 [mm] thick was cut into a circle of diameter 7.8 [cm] (slightly thinner than the inner magnet ring) for the coils to be mounted on. During the process of mounting the coils, it was discovered that they had been wound too thickly to fit all 8 onto the plate. The final coil plate only contained 6 coils. Figure 9 shows both the intended design and actual construction of the inner coils.

Figure 9. Arrangement of the inner coils.

The generator was assembled so that the coils remained fixed while the magnet ring rotated around them. A cylindrical ball bearing with 9 [mm] inner diameter and 2.5 [cm] outer diameter was used to allow the magnet ring to turn freely over the coils. A 9 [mm] hole was drilled into the magnet ring plate, and a 2.5 [cm] hole was drilled into the coil plate. The bearing was glued into the coil plate with epoxy so that the bottom of the plate and the bearing were flush. A 9 [mm] threaded bolt was used as the shaft. It was placed through the magnet ring plate, followed by a tapered plastic washer (9 [mm] inner diameter, 1 [mm] thickness), followed by the coil plate (and bearing). A 9 [mm] nut was screwed onto both ends of the bolt to hold everything tightly together. Finally, a circular wooden backing plate was cut to the same size as the outer diameter of the magnet ring and glued to the coils. A small hole was cut into the center of this plate so that the wire leads from the coils could exit the generator. The finished assembly is illustrated in figure 10.

Figure 10. Final assembly of the generator shown from a cross sectional side view. The coil backing plate (the right-most plate in figure 10) is worn against the back. The friction of this plate on the back will hold it in place allowing the magnet ring to spin freely.

4.2 *Chest Strap Construction*

The chest strap was constructed from the latter design presented in section 3.4. A 90 [cm] long spandex band with a 2 [cm] width was used as the base strap to be worn against the skin. The band was able to stretch 5 [cm] with 2 N of force. Assuming the generator provides 100 N of resistance, this results in a 2% loss of energy.

Plastic supports 2 [cm] wide were placed every 3 [cm] along the spandex band. These supports were bent into a mountain shape and sewn into the spandex band at its width edges as shown in figure 11. The supports were made from 1.5 [mm] thick plastic and were vacuum formed over AWG 22 wire and bent into the shape shown in figure 11.

Figure 11. Integration of plastic supports onto the base chest strap.

Kevlar twine was used as the load transferring pulley wire. This twine was threaded through the plastic supports on the chest strap, and then one end was tied to the back plate of the generator. The other free end of the twine was wrapped around the shaft of the generator and tied to a hole drilled into the shaft. A diagram of the final chest strap power harvesting system in use and on the body is shown in figure 12.

Figure 12. Diagram of the prototype chest strap being worn on the body.

5 Results

The prototype generator's output capabilities were tested after it was built. It was spun at a constant speed with a drill and while each coil was connected to a 120 [kOhm] load. This high-impedence load is representative of the impedence of a charging circuit. The voltage and current through each coil was measured. The experiment was repeated with the drill running at 2, 4, and 6 [Hz]. Figure 13 shows a sample output voltage waveform and current waveform from one of the 6 coils. Table 1 lists the results of the experiment.

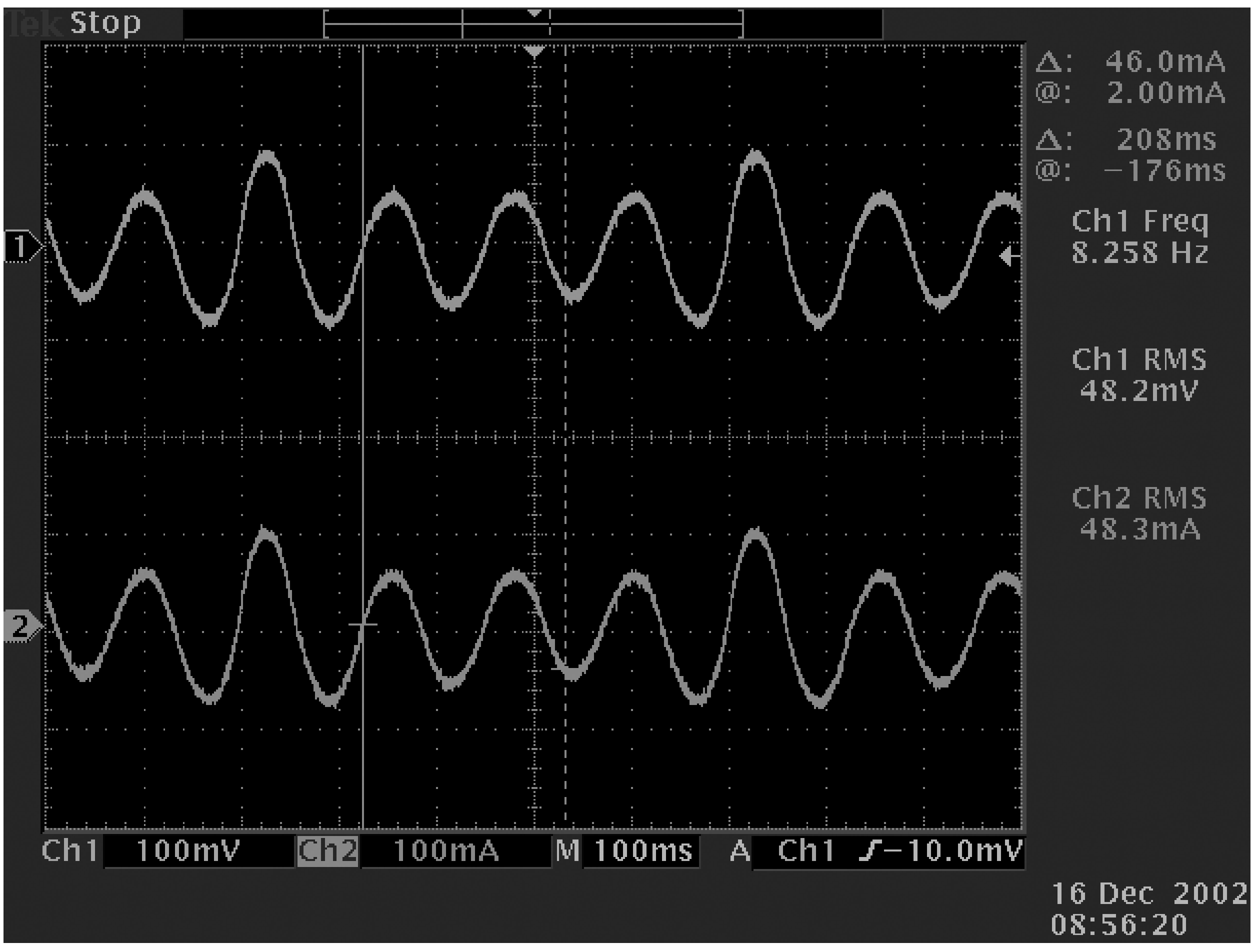

Figure 13. A sample output voltage waveform and current waveform. The waveform labeled 1 (on the left of the figure) is voltage; the waveform labeled 2 is current. The RMS value of these waveforms are on the right of the figure. The generator was being spun at 2 [Hz] when this

screen shot was taken. The reason why the frequency is printed as 8.258 [Hz] is because the coil is spinning through 8 magnetic fields during 1 cycle of the generator, and each pair of (alternating) magnetic fields produces 1 period on the ocilliscope.

Coil #	Coil Resistance [Ohms]	Frequency [Hz]	Voltage RMS [mV]	Current RMS [mA]	Power RMS [mW]
1	3.7	2	50	45	2.25
1	3.7	4	94	82	7.708
1	3.7	6	142	125	17.75
2	4.3	2	44	39	1.716
2	4.3	4	84	76	6.384
2	4.3	6	135	120	16.2
3	4.1	2	42	38	1.596
3	4.1	4	81	71	5.751
3	4.1	6	126	111	13.986
4	4	2	54	48	2.592
4	4	4	107	92	9.844
4	4	6	156	136	21.216
5	4	2	54	98	5.292
5	4	4	108	94	10.152
5	4	6	173	156	26.988
6	3.7	2	42	38	1.596
6	3.7	4	82	75	6.15
6	3.7	6	127	114	14.478

Table 1. Generator testing data. Each coil was tested individually over a 120 [kOhm] load. From the data, it can be inferred that if the coils were connected in series the net voltage at 6 [Hz] would be 859 [mV]. The average current in this configuration would be 127 [mA], and the generator would produce 109 [mW] of power.

The entire chest strap system was also tested for feasibility. The strap was worn just below the chest at the height of the sternum and the pulley was tied around the back to the generator. A normal inhalation was able to spin the generator at 4 [Hz] and a large inhalation was able to spin the generator at 6 [Hz]. By the end of each full breath (inhalation and exhalation) the generator had stopped spinning and rewound the pulley around the shaft. Thus, each subsequent inhalation spun the generator in the opposite direction.

6 Discussion

The theoretical design of the generator presented in section 3.2.3 meets and exceeds the design criteria. However, the actual construction of a prototype according to this design did not; the generator was not able to produce 1 [W] of power, or even the 170 [mW] of power demanded by the cell phone. This was mostly due to difficulty in construction which led to the following problems: the outer magnet ring was not perfectly circular in shape; only 6 of the 8 inner coils would fit onto the coil plate; magnets to form an inner magnet ring could not be found or made. These problems led to a magnetic field of less than half the strength that was anticipated, and reduced the maximum voltage that could be produced by 1/4 since only 6 coils were used.

Additionally, for the chest strap power harvesting system to be practical, components must be introduced into the design so that: the magnet ring spins as a flywheel; the load on the user's chest is constant; the generator is spun with the exhalation as well as the inhalation. The current chest strap design only spins the generator on the inhalation, and the direction of spin alternates with each inhalation. A spring system is necessary to equalize the load on the inhalation and exhalation. The spring must be twisted so that it assists the user on the inhalation and then applies additional force to her chest on the exhalation. Instead of having to bear a 200 [N] load on the inhalation and a 0 [N] load on the exhalation, a 100 [N] load is maintained during both cycles of respiration. Along with the spring, a bi-directional ratchet system must be constructed so that the generator is spun in the same direction regardless of whether the pulley line is being pulled out during the inhalation, or being pulled in by the spring (exhalation). This will allow the generator to spin constantly in one direction as a flywheel. These components will be carefully designed in the next iteration of this project.

From the results it can also be seen that the power produced varies linearly with rotational frequency. That is, the faster the generator spins, the more power is produced. The current generator spins at a low frequency because that is all that can be achieved with a compact pulley / shaft system. The frequency is so low that by the time the user takes a second breath, the generator has already stopped spinning. Introducing a gear mechanism to spin the generator faster might substantially improve the generator's potential. The reason why gear boxes were not used in this initial design is because they are large and introduce more inefficiency. However, the next iteration of the design will probably investigate the challenge of building a thin and efficient gear box with an approximate gear ratio of 1:10. The increased spinning speed would not only increase the power output of the generator, but also ensure that the generator would have enough momentum to keep turning in between breaths.

.In conclusion, the design and construction of a chest strap power harvesting system has demonstrated that parasitically harvesting power from the human chest during respiration is feasible. The first prototype was able to generate .1 [W] of power and measured in size less than 2 [cm] thick. It is expected that after incorporating all of the design suggestions made in this discussion, and with more precise construction, the generator will be capable of producing 1 [W] and will shrink in thickness to 1 [cm]. Once this is accomplished, the device will be useful and beneficial to all users of cell phones and other low power electronic devices.

7 References

[1] T. Starner, "Human Powered Wearable Computing," IBM Systems J., vol. 35, nos. 3 and 4, 1996, pp. 618-629.

[2] N. Shenck, "A Demonstration of Useful Electric Energy Generation from Piezoceramics in a Shoe", MS thesis, Dept. of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, Mass., 1999.

[3] U.S. General Accounting Office, Report on Mobile Phone Health Issues. Washington, DC: Office of General Accounting, May 2001.

[4] K. Shaw, "Network World Mobile Computing Newsletter," [Online document], 2002 Sep 9, [cited 2002 Dec 16], Available HTTP: http://www.nwfusion.com/newsletters/mobile/2002/01550383.html