Shake Power Bank

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Approved: Michael Momot Date 5/1/2020
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Abstract

When conducting outdoor activities such as hiking or camping, enthusiasts find it difficult to charge their electronic devices due to the limited availability of energy sources in the wilderness. To combat this problem, we decided to create a shake-to-charge portable battery called, Shake Power Bank, that can be charged using only mechanical means, or in other words, human power. We utilized Autodesk Inventor to design the case that would hold all the electrical components and used 3D printing technology to create the outer case. Additionally, we used our knowledge of Faraday's Law to design the electronics that would allow for the shaking motion of the device to create an electric charge, thus powering the portable battery held inside the case. The resulting product was intended to be portable, easy to use, and a product that could potentially be sold to the masses for use during outdoor activities, or during any such time where access to an outlet is not available. Furthermore, we strove to make a product that would be safe for the user as well as safe for the environment, and were pleased with the fact that our device only uses human power and avoids the dangers of utilizing non-renewable energy sources. Due to extraneous circumstances related to the COVID-19 pandemic, we were unable to produce a final working product; however, the final cost estimate for the device was $122.72 which was under budget. Although a final product was not created, we were able to conduct a few tests on our latest design iteration before being sent home for the remainder of the semester and received promising results regarding both functionality and ergonomics. With that said, additional testing would need to be conducted to truly determine the success of the device.

Definition and Objective of the Project

The scope of this project focused on finding a solution to the problem of energy usage and more specifically, the disadvantage that arises for outdoor enthusiasts. When going hiking or doing any other outdoor activities, a problem arises due to the lack of energy that is accessible in the wilderness. With the amount of electronic devices ever increasing in this digital world, many outdoor enthusiasts need access to electrical energy to charge their instruments, whether that's a phone, camera or flashlight, these are essential tools that aid in outdoor activities. Due to the fact that the outdoors offer no direct access to electricity, our group was tasked with designing a way to create an electric charge using mechanical means. In other words, the objective was to create a way for outdoor enthusiasts to make an electrical charge using human power. Additionally, our goal was to create a working prototype and final product that could theoretically be found in stores and sold to these enthusiasts.

With the task assigned, our group decided to focus on solving this problem by specifically creating a shake-to-charge portable battery. Our product has a portable, lithium-ion battery inside that can be charged by shaking. We used our knowledge of Faraday's Law, which states that a voltage is generated when the magnetic environment of a coil of wire is changed, to design a way to generate electricity. In simpler terms, we understood that passing a magnet through a coil of wire would induce a voltage that can be used to charge the lithium-ion battery. So we designed a product that, when the user shook the device, had a magnet pass through a copper coil of wire and generate an electric charge which could then be used to deliver charge to the battery. Furthermore, we connected a USB outlet to the battery so that many different devices could be charged. We decided on this design because we knew the versatility associated with a USB port and its ability to be compatible with almost all electronic devices.

Significance of Project

The Shake Power Bank addresses an issue many outdoor enthusiasts face while in the wilderness: a lack of electrical power sources. The use of this device can also be extended to any environment or situation in which there is little or no access to electric power, such as during a black-out. This device offers a quick and easy to use solution. The user simply shakes the hand held device to create and store charge in the internal battery. Then, any device that uses a USB charging connection can be powered. While this would not be an efficient source of mass commercial power, this gadget would be more than sufficient in charging a phone, tablet, or similar devices in a time of need.

Renewable energy sources have been utilized more and more in recent years as people look to move away from the use of fossil fuels and other non-renewable energy sources. While these alternative energy sources have proven to be extremely useful innovations, they also have their disadvantages. Many require expensive or bulky equipment and can only be used in certain areas or situations. Solar energy for example cannot be harvested and used at night or in dark places, wind can be unpredictable and unreliable, and hydroelectric generators need water. Even if using a small solar, wind, or hydroelectric generator, the right conditions are required to actually generate sufficient energy. Our shake-to-charge device uses human powered mechanical means to generate energy. By relying solely on human motion, the use and effectiveness of this device is not dependent on the environment, meaning it can be used anywhere and by anybody. The only limiting factor in terms of energy production is human fatigue, as the user will eventually get tired of shaking the device. Our solution is a portable, easy to use device that utilizes a virtually unlimited source of renewable energy, is unhindered by the environment in which it can be used, and does not rely on bulky or expensive equipment.

Constraints of the Project

There are 4 major constraints to the project and our design. First, our design requires kinetic human motion to power. As a result of this design choice, the ability to generate power is limited due to the fatigue and muscular endurance of the user. The second constraint is that the ability to charge on the go is limited by the fact that our design does not include a removable power source. We use a rechargeable battery, however it is intended to remain inside of the case instead of constantly pulled out and replaced by another, uncharged battery. A power bank can be connected via the USB output, however our design does not contain a place to store the power bank or the wires for purposes of weight. The third constraint is that our design has limited power output. Only one USB connector is present for a charging output and thus only one device can be powered at a given time. Adding additional connectors while maintaining the power output would require more coils and a stronger magnet. In order to keep the weight low so as to not contribute to the first constraint, we chose to make the design to have only one output. The last constraint to our design is that we had limited resources at our disposal for prototyping, limited development time, and a limited budget ($400). For our case, we chose to use 3D printing as it was readily available in the University of Virginia's Mechanical Engineering Department. Additionally, 3D printing allows for fast and easy prototype changes to be made for relatively cheap (only pay for cost of materials). However, with other manufacturing methods more readily available at our disposal, and additional time and money for the project, we would have designed the case using injection molding, which bears a heavy upfront cost in making the mold and disadvantageous for prototyping. This would have reduced the cost of our prototype and would have reduced the time for making the case as well.

Design Details

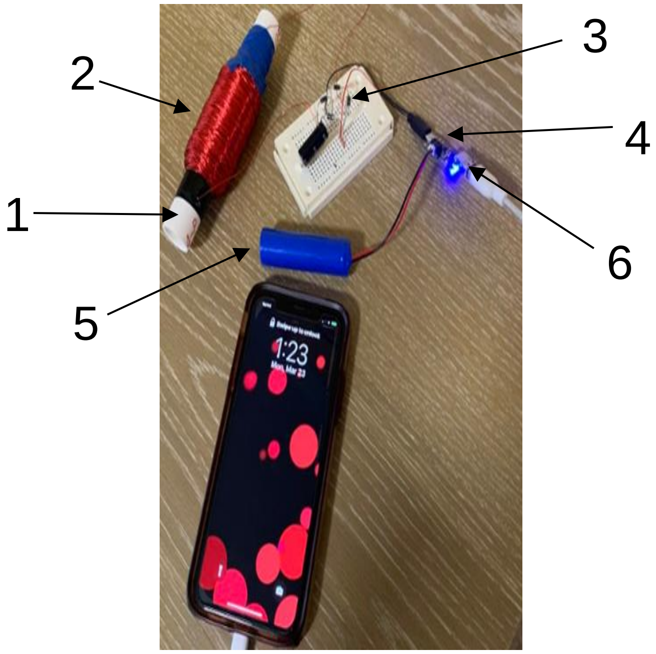


Figure 1: Electronic component assembly

The main function of this device is power generation, which is performed by cylindrical nickel-plated neodymium magnet that is allowed to slide freely inside a tube made of PVC plastic (1). This tube is surrounded by hundreds of coils of magnet wire (2). The two ends of the wire connect to a rectifier circuit (3), which converts the alternating current from the induction system to a direct current, using a 1000µF/25V capacitor and four diodes. This current is then fed into a Powerboost 500 board (4). The board serves three functions: standardizing the voltage coming from the rectifier, connecting the rectifier to the battery, and connecting the battery to the USB charging port. The power storage device is a cylindrical lithium-ion battery (5) which accepts power converted to 3.8V by the board. When a device is connected to the USB port on the board (6), a 3.8V current is drawn from the battery and converted to the standard 5V USB output by the board. This describes the full electronic functionality of the device.

Figure 2: Full casing with lid

Components of the device are contained within a hard-plastic outer shell, consisting of two stacked, hollow cylinders of different diameters and a circular cover. The first cylinder is longer and serves as the handle for the device, containing most of the wire and tube that the magnet resides in. The second cylinder is shorter, has a larger diameter than the first, and sits on top of the first cylinder, containing the rest of the magnet chamber at its center and the chambers for the rest of the components around the outer radius. The wall that comprises the outer diameter also contains two threads for the screws that attach the cover. The cover has a diameter equal to that of the second cylinder, with a rectangular hole for access to the USB port and two holes for the screws. To reduce wear on the case, padding is adhered to the top and bottom of the PVC pipe holding the magnet. A padded foam material is adhered to the outside of the first cylinder comprising the "handle" to improve grip and ergonomic comfort. Tolerance calculations for dimensions were calculated for the case based on the tolerance of the 3-D printer. For this version of the design, the case and lid were both 3-D printed out of ASA plastic.

List of Codes/Standards

Through the project, it was essential that the equipment met certain codes and standards so the correct components would be accessible and safe. The PVC must meet ASTM D 1785 and ASTM D 2665 standards. This made sure that the inner tube that was made out of PVC was a certain thickness and permeability. The lithium ion battery had to meet OSHA Hazard Communication standards. This ensured that it was wrapped properly and tested so that it would only heat to a certain temperature after being used for a longer period of time. The standards of the screws’ threads must meet ASME B1 standards and over all the screws had to comply with ASME B18 standards. The screws needed to have a certain head and height to work with this design and be easily identifiable.

Design for Automation/Manufacturing Considerations

The top of the Shake Power Bank is shaped to have a wide, short, larger diameter cylinder that holds and protects the components surrounding the top half of a taller, slimmer and smaller diameter cylinder that holds the inner PVC tube and the magnet. The slimmer cylinder is used as a handle for the user to shake the power bank. The battery sits in the larger cylinder along with the PowerBoost and the rectifier circuit. The battery fits in a hole in one quadrant of the wider cylinder and has its wiring already separated in another quadrant of the cylinder so there are no components that can tangle easily. The rectifier circuit is kept separate by being fit snug into the third quadrant of the wider cylinder. The components used in creating the induction and the components inside the case can be assembled from the bottom up. There is a cut out that allows the coil to be connected to the PowerBoost easily and safely which is located in a hole in the fourth quadrant. The cover of the power bank and the wider cylinder are circular with a flat side so the cover can be easily oriented on the base.

Calculations for the casing are based on the maximum possible size of our components including their tolerances to make sure everything fits into their corresponding cavities of the cylinders. The casing also has been toleranced accordingly to keep material to a minimum. There are a total of eight components in all for the product and three subassemblies. The only part that is not bought is the base which is 3D printed. Along with having cavities for the components, the base also makes sure to have the correct amount of material not hollowed out for the screws to be drilled.

Explanation of Impact on the Environment

Our project takes into account the environmental impact the device will have in its use and its recycling. Our design utilizes a modular style that allows the box to be disassembled and each item to be easily removed. Such a design allows for simple replacement of any broken parts without having to throw out the entire device. Additionally, the use of a design that can be reduced to its individual components allows for more effective recycling at the end of the product's life. By having each component able to be removed, it is easier for parts to be repaired, refurbished, and used again in another unit. As a result, we can allow users value through a trade-in service of their old device, and reduce the total waste from production and disposal of each unit.

The case used in our design is 3D printed and can be easily ground up and recycled. The case was printed with hollow spaces as well in order to reduce plastic material needed for each unit. Similarly, to the case, the PVC tube in our design can also be easily ground up and recycled. Since these are our most bulky components, the total volume of our design can be greatly reduced for recycling and disposal.

Lastly, our design utilizes a rechargeable battery that is charged through human movement. Thus, power is achieved through “cleaner” methods, and the device can be recharged without having to utilize electricity made in the conventional and less sustainable methods. Along with the ability to create power without emission, we allow our users to actively take control of their own contribution towards the green movement. Unlike solar panels being placed on a roof, our device incorporates the user in its development of clean energy, and thus makes him/her feel more connected to sustainability and more likely to develop other green habits as well.

Safety

Several safety issues were considered throughout the iterative design phase of our project. All of the components making up the mechanical system and electrical circuit are enclosed in a 3D printed plastic case with a removable top that is secured onto the body of the case with screws. This design reduces the risk of allowing any small parts to be easily accessible to children, which could pose a choking hazard. This also protects the various components and systems housed inside the case from either inflicting or withstanding damage.

The magnets used in the system are small yet strong and could not only be dangerous to humans or other electronics if they were to come loose, but could also risk being damaged and changing the system’s ability to produce enough voltage for the electric circuit. The coil of wire for the electromagnet is placed inside the center of the case within its own housing. This protects the wire itself from wear and tear that could end up shorting out the turns in the coil if too much insulation is rubbed off, deeming the electromagnet useless. The battery and the electrical circuit could pose major hazards if exposed. If damaged or faulty, lithium ion batteries can fail and become unstable, causing excessive heat or other anomalies, and in extreme cases, can explode.

This damage can be caused by a variety of sources including improper storage, handling or use, extreme temperatures, and mechanical abuse. The electrical components of the circuit could also face damage if exposed, resulting in malfunction and possible safety threats. Damage to any of the connecting wires, battery, or PowerBoost board could render the entire circuit useless and could potentially cause other hazards such as excessive heat generation or electrical fires. Housing all of these components inside of a secure case and within their own designated compartments within the case helps to mitigate the dangers and hazards associated with each part, making the overall design safe for consumer use.

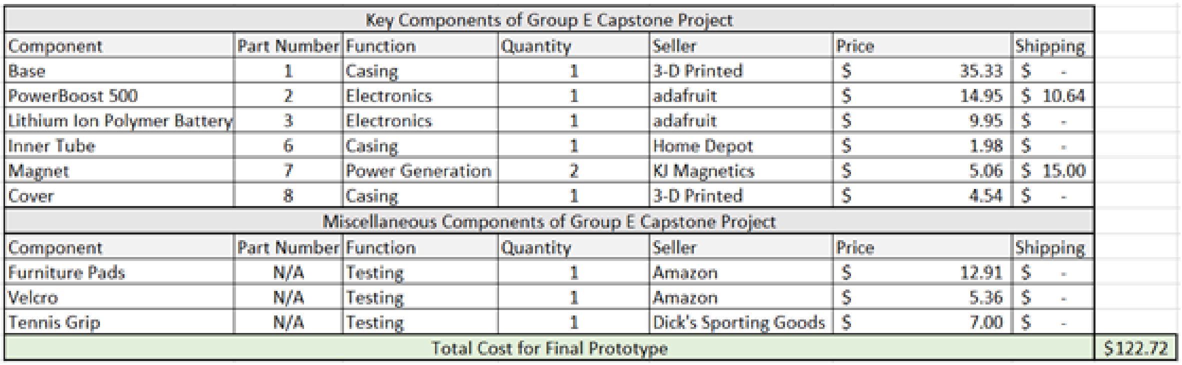
This project was designed to be a durable product, able to withstand a high level of activity. The device is made to be held in the hand and vigorously shaken in order to activate the battery charging system inside. Keeping this in mind, we focused on creating a design that could withstand damage to both the case itself and the components inside if dropped. Creating compartments for each of the different components inside of the case helps to prevent excessive movement inside the case which could damage the parts. The hard plastic of the outside of the case creates a barrier, protecting the components from outside exposure and damage. The flat top is attached to the body of the case with several screws. This keeps the two parts firmly secured together, while also allowing the top to be easily removed to inspect and fix the inner components as needed. The case is also designed to be comfortable and easy to hold, with a cylindrical handle to hold as you shake the device. We wrapped a tennis grip around the length of the handle, allowing the user to keep a better hold and reduce the possibility of the device slipping out of the user’s hand.

A prominent issue that has not been addressed in our design would be that the case is not waterproof. The outer case does provide a level of protection from outside substances getting in and disturbing the contents of the case. However, the product is not designed to be used in water and there is a risk of water seeping in through the thin crack between the body of the case and the lid. If the device were to be exposed to heavy rain or dropped in a body of water for example, there exists the possibility that the contents inside the case could get wet and be damaged beyond repair. This issue could be addressed in any future work on this product. For the purposes of our project, we decided to focus on the more glaring and relevant problems dealing with the function and durability of the design.

Cost Analysis

The total cost for the final prototype of the Shake Power Bank was $122.72, which includes the cost of shipping and all of the materials that were implemented into the final design. The cost of the copper coil, breadboard, and components for the rectifier circuit are not included, because those components were donated. Table 1 shows the breakdown of the costs for the project.

Table 1: Cost Calculations



Key Components of Group E Capstone Project							
Component	Part Number	Function	Quantity	Seller	Price	Shipping	
Base	1	Casing	1	3-D Printed	$ 35.33	$ -	
PowerBoost 500	2	Electronics	1	adafruit	$ 14.95	$ 10.64	
Lithium Ion Polymer Battery	3	Electronics	1	adafruit	$ 9.95	$ -	
Inner Tube	6	Casing	1	Home Depot	$ 1.98	$ -	
Magnet	7	Power Generation	2	KJ Magnetics	$ 5.06	$ 15.00	
Cover	8	Casing	1	3-D Printed	$ 4.54	$ -	
Miscellaneous Components of Group E Capstone Project							
Component	Part Number	Function	Quantity	Seller	Price	Shipping	
Furniture Pads	N/A	Testing	1	Amazon	$ 12.91	$ -	
Velcro	N/A	Testing	1	Amazon	$ 5.36	$ -	
Tennis Grip	N/A	Testing	1	Dick's Sporting Goods	$ 7.00	$ -	
Total Cost for Final Prototype							$122.72

The cost of the final prototype is a slight overestimate, as the final designs for the base and cover, parts 1 and 8 respectively, should have included a deeper, hollowed out section where the electrical components would be stored. This would have used less material than the base and cover that were printed for the prototype; the final casing was not 3D printed due to the semester being cut short.

Understanding where the costs came from, casing, electronics, power generation, and testing is important to cutting costs in order to make the product a reasonable price for the consumer. *Figure 3* shows an in-depth cost breakdown, giving a visual representation of where costs for the Shake Power Bank came from.

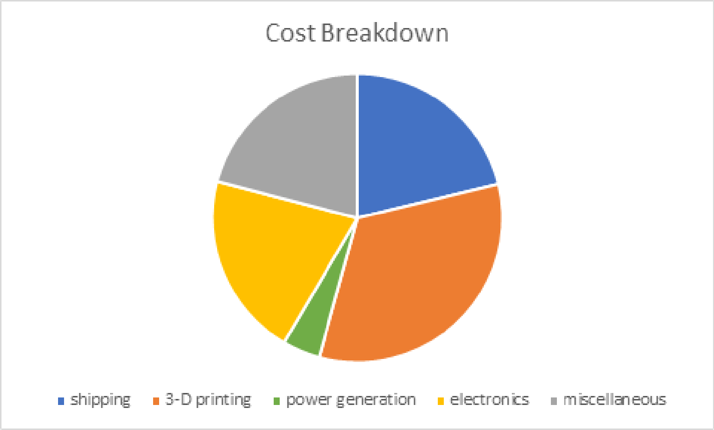


Figure 3: Pie Chart of Final Prototype Cost Breakdown

The cost breakdown shows that most of the cost for the Shake Power Bank comes from the cost of 3D printing the casing. This can be reduced by changing the method of manufacturing the product from 3D printing to injection molding. 3D printing is an effective method of manufacturing when the shape of the specimen does not work well with a mold or if only a small number of specimens are needed—injection molding is a cheaper manufacturing method when a large number of specimens are being produced. The expensive part of injection molding is purchasing the mold, but after selling a certain number of these products, the molds will be paid for and the cost of injection molding will be less than 3D printing, which has a set cost no matter how many products have been manufactured or sold. Injection molding is actually over 3 times cheaper than 3D printing in the long run, so after the mold has been paid for, changing the method to injection molding could reduce the cost of the Shake Power Bank from $122.72 to $96.14.

Additionally, the miscellaneous testing materials' cost could also be reduced, as the Velcro and furniture pads could be used on several different Shake Power Bank devices. The Velcro came in a pack of 4 and the furniture pads came in a pack of 8—assuming that only a quarter of a Velcro strip and half of a furniture pad are needed for each device—each pack of Velcro and furniture pads could be divided between 16 devices and the cost could be reduced even further from $96.14 to $79.01. Finally, each PVC pipe could create around 5 inner tubes, this would reduce the cost from $79.01 to $77.43, which would be the final cost with cost cutting measures considered. This cost breakdown is shown below in *Figure 4*.

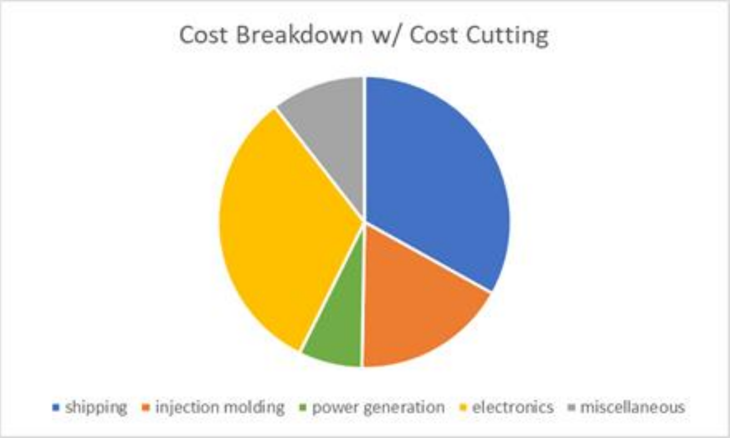


Figure 4: Pie Chart of Final Prototype Cost Breakdown w/ Cost Cutting

Product Testing

The objective of the device is to obtain a voltage from the coil and magnet mechanism of at least 3.8 V. This voltage is needed to charge the 3.8 V lithium-ion battery, which is then used to charge a device, like a cell phone, through the USB port. The goal is to obtain a voltage reading slightly greater than 3.8 V in order to ensure that even when shaking the device at a slower speed, the battery will charge. The voltage was measured for each iteration of the design, and changes were made in order to increase the voltage to an appropriate value, such as increasing the number of coils and using a stronger magnet. The results of the voltage testing are shown below in *Table 2*.

Table 2: Voltage Testing Results

Voltage Testing Results			
Power Generation	Coil Specs	Magnet Specs	Voltage
Running	24 AWG (~4 layers)	2- ½” diameter, ⅝” length N42	<1 V
Shaking	26 AWG (~10 layers)	2- ½” diameter, ⅝” length N42	~ 2 V
Shaking	26 AWG (~10 layers)	2- ⅝” diameter, ⅝” length N52	~ 5 V

Other design considerations that needed to be tested and meet predetermined standards were the outside temperature of the casing and since the device is designed to be handheld, the comfort of the handle was also considered. In order to ensure that the case did not get hot when generating electricity, we planned to use a temperature resistant tape to wrap the battery, PowerBoost 500, and coil, the components most prone to heating up; however, due to the design process being cut short, we were not able to complete the testing and implement this component into our design. The handle was designed to fit comfortably in the average hand and tennis grip was used to make it easier to hold and add some padding for even more comfort. The tennis grip also served to keep the Shake Power Bank from easily coming out of the user’s hand when shaking.

Conclusion

Our design has evolved over the course of this year. The initial design idea was a device that would be placed in an armband on a runner’s forearm and powered by the running motion of the user; however, we found that our design was too bulky and rectangular; also, the number of coils we would have needed to generate around 4 Volts would have made our device too heavy to comfortably fit on a runner’s arm. This initial design is shown in *Figure 5*.

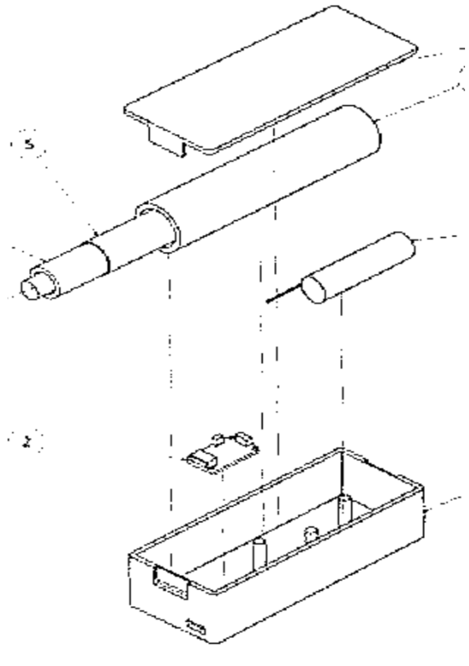


Figure 5: Initial Design

Given that the running method was not generating enough of a voltage to charge the battery, a new method of power generation was needed; our design then changed from a running device to a shaking one—the Shake Power Bank. The change in power generation method led to a change in the shape of our device as well; since the device would be hand-held, it was necessary to make the base cylindrical. This change also allowed for a reduced number of coils to generate the power, so the weight of the device went down as well. Overall, our final design is able to be made lighter, more comfortable, and more powerful—signifying that our final design improved on all of our initial design's weaknesses. The final design is shown below in *Figure 6*.

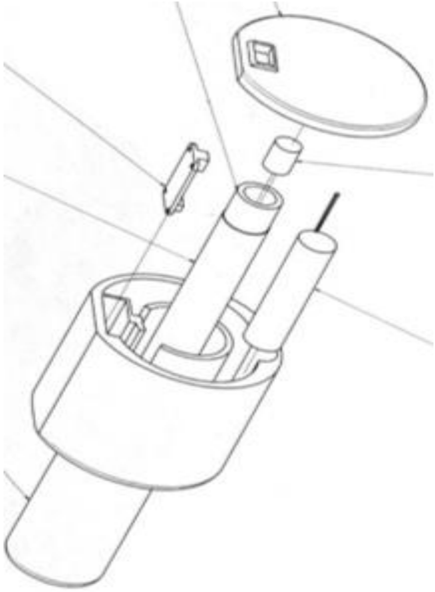


Figure 6: Final Design