PROJECT NUMBER P14418
POWER GENERATION FOR THE B9 BETTER WATER MAKER

Jacob Kleinberger
Industrial/Systems Engineer

Jessica Fuss
Mechanical Engineer

Chris Falanga
Electrical Engineer

Kyle Jordan
Mechanical Engineer

Elizabeth White
Mechanical Engineer

Erika Correa
Industrial/Systems Engineer

ABSTRACT

Poor water and sanitation issues in developing worlds, along with scarce and unreliable electricity create a need for a human-powered water purifying system. Safe-to-drink water is one of the scarcest resources in certain parts of the world. The Better Water Maker (BWM) was developed to assist in the reduction of waterborne illnesses. The original design is a hand-crank system attached to a seat which provides power to a pump-UV bulb system which disinfects water. The user must turn the hand crank until an LED light turns on. Once the light turns on, the user must maintain the speed of the hand crank. Due to the resistance of the electrical components in the system, it is difficult to turn the hand crank consistently for a significant amount of time. The purpose of this design project was to increase the ease of use to the end user. A new gearbox was designed utilizing three DC brushed motors in series and a gear configuration providing a gear ratio (GR) of 1:28. The circuit which regulates this voltage was designed to regulate the voltage output to 15V, which is greater than that of the existing system. The new circuit is simpler and 89% efficient which allows the most power to the pump and bulb, reducing both cost and the effort for the user. In addition to the mechanical and electrical design changes, the seat configuration was altered to incorporate a recumbent bicycle design. This allows the user to utilizing their strength with leg power rather than inadequate arm power. The original design was a hand-crank, to account for apparent cultural constraints. In reality, these cultural constraints are not accurate and a leg-powered device is suitable for this application. The original target cost of the BWM was approximately $75, and a major customer need was to reduce that cost for the purpose of mass production. The manufacturing cost for the new power generation unit is approximately $119. The results of initial testing show that the changes made to the design reduced the torque needed to pedal. In this reduction of torque, the system requires approximately 138 user input RPM to maintain the appropriate voltage to the water pump and bulb system.

NOMENCLATURE

BJT- Binary Junction Transistor
BWM- Better Water Maker
DC- Direct Current
F- Force
GR- Gear Ratio
IC- Integrated circuit
l- length
P-force by user
PCB- Printed Circuit Board
r- radius
RPM- Rotations per Minute
SM- Servo-motor
T - Torque

BACKGROUND

Statistics show that every 9 seconds another person dies from water-related illnesses (1). In total, approximately 780 million people in the world do not have access to clean water. Although people from developed countries donate towards providing safe drinking water, that is only a crutch to the current problem. The ideal solution would be something that helps individuals in developing countries have a source of safe water that can be replenished. The BWM fills that need.

B9 Plastics, a not-for-profit organization, manufactures the "Better Water Maker" (BWM), a human-powered water purification device. The BWM is currently designed as a hand-crank which provides power to a UV bulb which disinfects the water as it is irradiated. Past RIT Multidisciplinary Senior Design projects had very similar needs and requirements to ours; each has built upon the efforts of those before them. In previous iterations, the BWM had been designed with the expectation that men would be the end users. As the product was introduced to the target areas, however, it was found that almost exclusively women and children were using it. Since the generator will be used mainly by women and children, it must be re-designed to reduce the user's effort and better reflect their capabilities. During this iteration, the goal is to simultaneously reduce the effort required to power the device while reducing the overall manufacturing cost of the product.

PROCESS

Customer Requirements:

The design for this version of the Better Water Maker power generation system was driven by specific customer requirements provided by B9 Plastics and the Harbec Plastics leadership. The customer requirements were weighed to determine which were most important to satisfy and which were least important to satisfy. The weighting system was based on a 1, 3, 9 scale; 1 having the least importance, 3 having the next highest importance, and 9 having the highest level of importance. This design's most important requirements were that it be safe and easy to use for women and children, that it not tire these intended users prior to producing 2.5 gallons of water, that the product be less costly to manufacture than the current design, and easy to install by the end user. Most importantly, it would need to generate enough voltage and current to operate the bulb-pump system. Based on the customer needs, engineering requirements were developed. The team found it most important to develop a functional product designed for women at a product cost below that of the current product.

Engineering Requirements:

The engineering requirements, similar to the customer needs, were scaled on a 1, 3, 9 weighting system. The team used a House of Quality analysis to determine the most important requirements and gain a better understanding of the relationship between the customer needs and the engineering requirements. These requirements were then developed with the better understanding of the customer needs. From that, ranges and goals were determined. All of these requirements were confirmed by all the stakeholders before any of the design work began. Of these the most important requirements were cost, power generated, and effort required. The requirements can be found in Table 1.

	Function	Importance	Units	Range	Goal Value	CN Fulfilled	Proof of concept
ER1	Cost	9	USD	0-200	150	CN7, CN8	Analysis and sourcing
ER2	Generated Power	9	W, V	23-29	27.5, 14.3	CN1, CN14, CN17	Analysis and testing
ER4	Training Time	3	minutes	30-May	10	CN16	Testing
ER5	Ease of Repair	3	minutes	20-60	30	CN7, CN10, CN16	Testing
ER6	Effort Required	9	Heart rate	Low to Medium Intensity	Low Intensity	CN2, CN12, CN13	Testing
ER7	Weight	3	lb	<50	45	CN3, CN4, CN16	Weighing total package
ER8	Number of Installers	3	People	3-Jan	1	CN3, CN7, CN10, CN16	Testing
ER9	Number of Tools	3	Tools	3-Jan	1	CN7	
ER10	Unit Life	3	Gallons Treated	>180,000	>180,000	CN5, CN6, CN9, CN10, CN15, CN16	Analysis
ER11	Support User	9	lb	40-200	130	CN5, CN12	Testing
ER12	Can Hook Up to 12V Car adapter	9	Binary	Yes	Yes	CN14	Sourcing and Analysis

Table 1: Engineering Requirements developed by P14418

Design Process:

The process began by first investing time into conducting benchmarking research. This process produced options that included a treadle pump used in parts of India and other nations for the purposes of irrigation, solar panels, and actuation of a solenoid. The current product in production, as distributed by B9 plastics to communities in developing countries, was hand-powered. Although fairly successful, this design required a lot of effort and was difficult for users to operate. The general thought was to change the product to one that would instead be leg-powered, since the legs are generally much stronger than the arms. In the earlier stages of the project, fear of a cultural stigma against women bicycling kept groups from considering that option. Apart from the original concern, no evidence has been found to support the existence of such a stigma, so our group was able to consider a bike-pedal design as an option.

Some time was spent debating whether or not the treadle pump was viable after initially making a decision on going forward with the bike-pedal design. The treadle pump design followed the idea of an elliptical trainer device to drive a gear that would potentially power the UV pump. This was deemed to be an inferior design based on the thought that treadle bicycles had been designed and implemented early in the 20th century. Chain-driven bicycles are now more popular because you can get a more significant amount of power out of it than the treadle design. The main goal again of the project again was to produce power with less effort.

A Pugh analysis was conducted to decide which option would be best suited in meeting all engineering requirements. Using this quantitative decision technique the bike-pedal design ranked highest. Two options for powering the UV bulb were compared for the bike-pedal design: a direct-drive and a chain-drive. Table 2 shows the comparison.

	Pros	Cons
Direct Drive	Simple, Cheap,Lower Torque	Forces on Generator
Chain Drive	Higher RPM, Adjustability, Thinner	More Components, Difficult Setup, Lost Efficiency

Table 2: Brief summary of the pros and cons of direct drive and chain drive

A direct drive design was chosen. The research conducted proved this would be the most practical approach for this application. A gearbox would house a drive shaft turning a series of gears that would subsequently drive the motors. In order to provide the necessary amount of power to the UV bulb, three motors rated at 12V were chosen to achieve a power output of 15 Volts to the pump and UV bulb, down from four motors initially. This would require the user to pedal at approximately 110 revolutions per minute (RPM) to power the device. Another change that followed this design was a wider track for the gearbox. Originally the track was intended to be constructed out of a 2x4 wooden plank. To accommodate the size of the motors and the gearbox, the size of the track increased to a 2x6 wooden plank. This would allow the components in the gearbox to fit, although increasing the width of the gearbox and plank too much would cause pedals to be too far apart. Having the pedals far apart would create a less than ideal position for pedaling and may have reduced the maximum power the user could produce. A 2x6 plank served as the correct medium to accommodate both purposes.

Late in the design phase, concerns arose about using plastic for the case. Initially, the design had six sides of PVC sheets for the case. Due to the nature of a gearbox, issues arose around how to best assemble it, whether or not deflection would occur, and the risk to the integrity of the final product. For prototyping purposes, the most efficient material to work with would be aluminum. Rectangular aluminum tubing would provide four permanently secured and strong sides. Only a top and bottom would need to be manufactured. Once again solely for prototyping purposes clear acrylic was chosen as the material for the top and bottom covers. The machine shop on site at RIT allowed machining of all parts with convenience in mind.

RESULTS AND DISCUSSION

Subsystems:

The design was separated into three subsystems. The gearbox was the main subsystem; the electrical and the seat and track systems were supportive of the functionality of the gearbox.

Gearbox:

The gearbox was designed with cost, strength and functionality in mind. The current system is constructed with injection molded crank-arms and shaft connected to a 192-tooth plastic gear. This main gear is mated with four pinion gears which are press-fit to the shaft of each Mabuchi RS-555VC-3754 DC motor (generating motor). This allows the user to produce water by cranking the system at approximately 104 RPM (as measured during previous testing). It was extremely tiring to maintain high RPM coupled with high torque for longer than a minute. The torque of the motor is multiplied by the $(GR)^2$ at the drive-shaft. This is why the hand crank system is difficult to turn for a long period of time. The speed of the motor shaft is linearly related to the amount of voltage being produced. So the higher the GR, the more voltage is being produced for the same user-input RPM. In order to characterize the motor and model our new system, we created a test using a servo-motor (SM). The test utilized a SM attached to a test-stand provided to us by Dr. Kempski in the Mechanical Engineering Department of RIT. First, we had to characterize the testing motor. By using a strobe light, we were able to record the RPM of the shaft and derive a linear equation which calculated the RPM versus the output voltage (effectively determining the specifications of the SM). The equation for this relationship is:

$$y = 79.49x - 3.2826; \text{ where y = RPM and x = SM Output Voltage} \qquad (1)$$

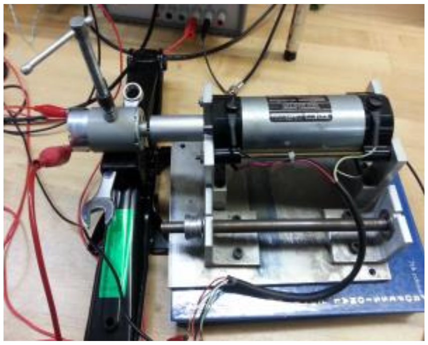
A shaft collar was machined to mate the shaft of the SM to the shaft of the generating motor in order to characterize the output voltage of the Mabuchi RS-555VC-3754 versus RPM at the shaft. Figure 1 is a picture of the test setup which includes the servo-motor setup, the generating motor, a C-clamp, a scissor jack, a power source and a voltage meter. Once the test was running, we recorded the output voltage of the SM, and the output voltage of the generating motor. Using Equation 1, the RPM was calculated. Using Equation 2, and the resistance of 7.5 Ohms to represent the load[1], the power being provided to the pump-bulb system was calculated for each data point.

$$P = \frac{V^2_{motor}}{R} \quad \text{;where } V_{motor} = 3 * V(\text{output}) \; (2)$$

$$V(\text{output}) = 0.0029 * \text{RPM} - 0.0128 \qquad (3)$$

Equation 3 is used to determine that the motor shaft needs to rotate at 1,961 RPM in order to provide 5V out of each generating motor. Figure 2 shows the results of the test with both power for three motors in series and voltage versus RPM at the shaft of the motor.

[1] The 7.5 Ohm resistance was characterized and identified by the Electrical Engineer, Christopher Falanga in previous system testing.



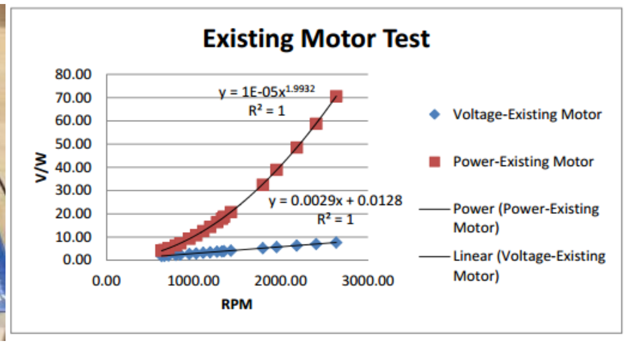


Figure 1: Generating Motor Test Setup

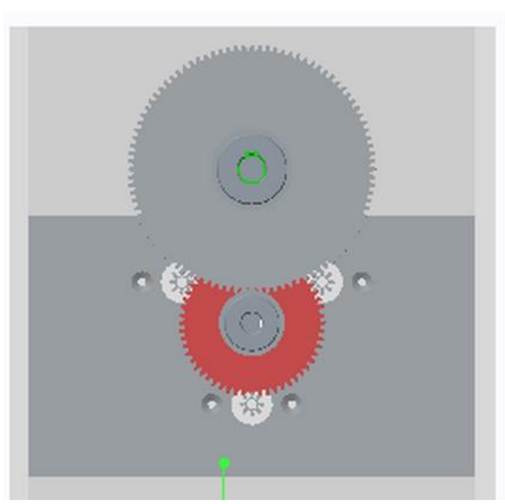
Figure 2: Mabuchi RS-555VC Motor Test Results

From the existing product to the new gearbox design, we increased the GR from 1:24 to 1:28, which would increase the voltage output per generating motor. In order to reduce the torque, the new design has three generating motors instead of the original four. In order to provide 30 Watts to the pump-bulb system, we calculated that the user would need to pedal at 70 RPM to maintain the power output. We felt this number was reasonable and proceeded with the design. After construction, we realized the RPM required to maintain the proper voltage was much higher. This is likely to be due to losses through the system such as the friction of the gear teeth not originally accounting for.

In addition to the changes in the number of motors, the gearbox was also changed to a leg-powered device in order to increase the ease of use. Based on ergonomic data, legs can produce approximately 70% more power than arms. The larger and more capable leg muscles will be utilized with the new redesign. In order to accommodate the increase in force acting on the crank arms, a drive shaft was designed to withstand 100 lb of force from the user. Figure 3 is a picture of the completed final gearbox design. There are two shafts; the main drive shaft and the intermediate shaft. The drive shaft has a 96-tooth gear and two crank arms. The shafts are held in the gearbox with flanged bearings in order to allow easy rotation. The intermediate shaft holds the 24-tooth gear and transmits its torque to the 56-tooth gear. The three motors are mounted to a piece of aluminum plate and are mated to the 56-tooth gear with 8-tooth pinion gears. In order for the gears to mesh properly, care must be taken to ensure the machining of the gearbox bearing holes and motor mount are exactly lined up. Standoffs are used to control the placement of the motor mount within the gearbox. The prototype was machined on vertical mills and lathes, but the recommendation is to use CNC machines for mass production. In order to size the shaft properly, the stall torque was used from the manufacturer's specifications and designed to be a conservative estimate. The following equations were used to determine the maximum torque at the drive shaft:

$$F_3 = \frac{T_m}{r_m} \; (4) \qquad T_3 = 3F_3 r_3 \; (5) \qquad T_2 = T_3 \; (6) \qquad T_2 = F_1 r_2 \; (7) \qquad F_1 = \frac{T_s}{r_1} \; (8) \qquad T_s = Pl_{crankarm} \; (9)$$

The subscripts are defined as: 1: 96-tooth gear; 2; 24-tooth gear; 3: 56-tooth gear; m: motor pinion gear; s: shaft. Figure 3 is a graphical representation of the gears and how they mesh within the gearbox. Figure 4 is a drawing of the entire assembly for perspective.



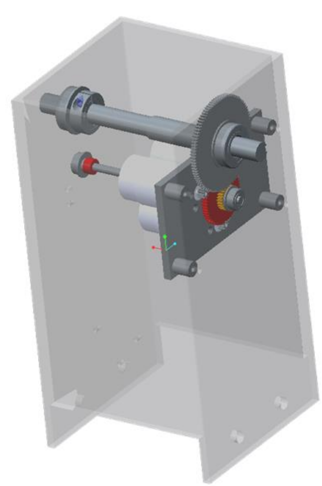


Figure 3: Gear Alignment

Figure 4: Entire Gearbox Assembly

Equations four through nine combine to solve for the torque experienced by the drive shaft. Using Equation 10 to calculate the torque of the drive shaft, Equation 11 can now be used to size the diameter of the drive shaft appropriately. The maximum torque on the shaft is 15.5 ft-lb [186 in-lb].

$$T_s = 3T_m \frac{r_1 r_3}{r_m r_2} \quad (10)$$

$$d = \left(\frac{16n}{\pi} \left\{ \frac{1}{S_e} \left[4(K_f M_a)^2 + 3(K_{fs} T_a)^2 \right]^{1/2} + \frac{1}{S_{ut}} \left[4(K_f M_m)^2 + 3(K_{fs} T_m)^2 \right]^{1/2} \right\} \right)^{1/3} \quad (11)$$

The bending moment at the highest concentration factor was calculated to be 275 in-lb. Taking into account the concentration factors of both the shoulder and the key in the shaft, the bending moment and the torque, a size of ¾" stepped down to ⅝" was selected. This choice provides a factor of safety between two and three considering the yield strength of steel.

Consideration of the complete design was discussed and reviewed in order for the gearbox to integrate with the other subsystems, the circuit and the track. Two holes were machined through the bottom of the gearbox to allow it to seat properly over the track which was a 2x6 board. A distance of 2.4" was kept between the holes so eye bolts can fix the gearbox to the track to satisfy different heights of the users.

Three holes were machined in the gearbox for the LEDs. In addition to the holes, mounting holes were created for the board itself and another hole for the output wires to the pump-bulb system. An acrylic top was screwed in to prevent debris and moisture from affecting the meshing of the gear teeth. In order to reduce friction and noise, white grease was used on the gears.

The drawings for all the gearbox components can be found in Appendix A. Improvements may be made in the gearbox design. These suggested improvements and lessons learned can be found in the conclusion section below.

Electrical:

Housed in the gearbox is a generator control circuit. The circuit is given an unregulated input from the generating motors. The circuit outputs a regulated voltage that is capped at a 15V maximum. The circuit must also pass a maximum of 1.8A of current to the pump and bulb system. This circuit was designed and built by the electrical engineer on the team. The circuit has two main functionalities. The first is to regulate the generated input voltage. The other functionality is as a potentiometer that will drive three LEDs. The LEDs act to give a visual indication to the user regarding how much power is being generated. The first LED turns on when the output is approximately 13V, the second turns on at approximately 14V, and the third turns on at approximately 15V. The LEDs also perform a self-test when the input voltage reaches 4V and all three flash on then off. The need for the regulator circuit is to prevent an overvoltage issue with the pump and bulb unit as identified by the customer. As an added functionality, the regulator also provides a constant torque on the pedals since the torque is proportional to the power draw. The LED portion of the circuit is not required for proper operation of the system, but if the user interprets the data correctly they will know if they need to adjust the effort they are putting into pedaling.

The regulation portion of the circuit is a 15V switching regulator. A switching regulator works by rapidly turning on and off so that voltage is regulated at the output. The switching regulator in this circuit is designed using the LM2576T-15G. This integrated circuit (IC) is made by Texas Instruments and is meant to simplify the construction of a switching regulator. The chip houses all the necessary op-amps and logic that a normal switching regulator uses. To ensure proper operation additional components need to be added to the input and output stage of the chip. On the input side is a 100uF capacitor. On the output side is a low drop out Schottky diode, a 1000uF capacitor, and a 100uH inductor. The large capacitor and inductor on the output are present to store energy when the chip is in the off portion of its normal switching cycle. The Schottky diode helps reduce the circuit's switching time.

The final circuit schematic is shown in figure 5. All components described above are detailed in the schematic. The circuit detailed in this schematic is the one that was constructed on perfboard and placed in the gearbox. The specific resistor values in the schematic are such that the first LED turns on at 13V, the second LED turns on at 14V, and the third LED turns on at 15V. The proposed resistor values are as follows: R1 is 18550, R2 is 736, R3 is 714, and R4 is 10000. It will be difficult to source out resistors to match these exact resistances, so it is important to note that the only important thing is ratio of the resistance values. Any resistors that match, or come close to, the above ratio will work. The only requirement is that the series sum of all four resistors should be large to limit power loss. The schematic in figure 5 was built on perfboard and inserted into the gearbox. No printed circuit board (PCB) was ordered for the prototype. It was decided to use perfboard so the circuit could be easily adjusted if needed. The circuit is fully functional and passes the required current with no problems.

There was an efficiency test conducted with the regulator portion of the circuit. The test recorded the efficiency of the regulator at different input voltages. The results show that efficiency peaks at 89%. After reaching this maximum, the efficiency decreases.

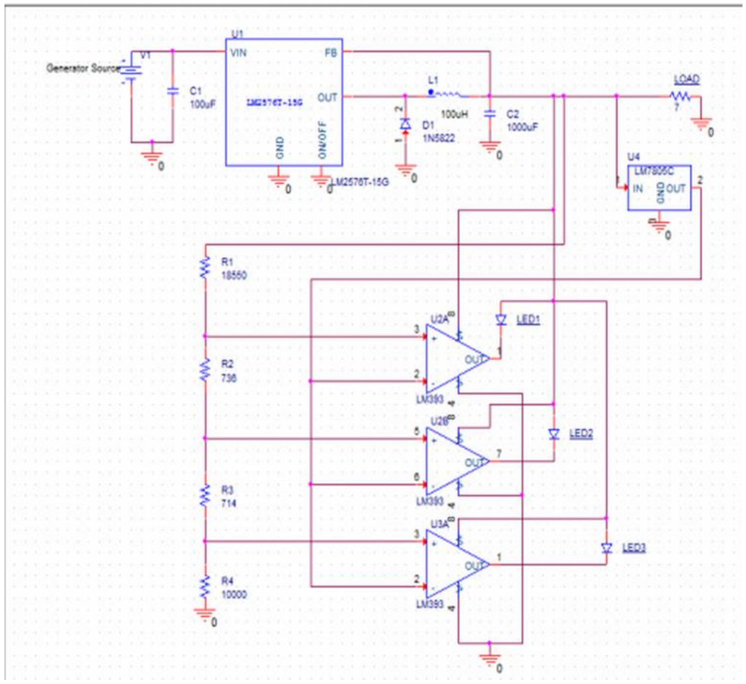


Figure 5: Final circuit schematic.

Seat and Track:

The seat and track subsystem exists to support the user during use of the device. It consists of a bucket to support the user's weight in the vertical direction, a seat back to position the user for power generation, and a track to position and secure the gearbox. Due to the large size required to fulfill the needs of this subsystem, it will need to be shipped in parts and assembled on-site by the end user. To accommodate different levels of literacy and building expertise, it was necessary to maintain simplicity in the design. Although this subsystem bears weight and requires strength, our project requires that we minimize cost; we found that it was most cost-effective to use wood for the majority of the structure. There is also benefit to the end user in this decision: in the event of failure in the seat and track subsystem, they will likely be able to find supplies locally to replace or repair it.

The seat is made up of a bucket and its lid. A wooden insert helps the bucket maintain rigidity and supports the seat back. The bucket is also meant to be filled with dirt to increase stability and also help the bucket support the user. The bucket has two holes to accept the track, another to accept the seat back insert, and the lid is also cut to fit the insert.

A 2x6 board serves as the track. The size was chosen to accommodate the end size of the gearbox; it fits between the brackets of the gearbox and discourages twisting and lateral motion. The board is drilled with .4in holes every 2.4 inches, matching the brackets on the gearbox, to accommodate the eyebolts which prevent twisting and movement in the longitudinal direction. The track is attached to the bottom of the bucket by the end user with 2 screws. The track extends 4 inches beyond the back of the bucket to prevent tipping. The track extension in front of the bucket was designed to fit 95% of the adult female population in the target areas. This statistic is based on analyses made by the team using data from PlosOne.org and disabled-world.com. The tallest woman expected to use the device would be about 6 ft tall; the median height of women in our targeted areas is approximately 5 ft 2 in. Our device was designed to accommodate people from 4 ft 11 in to 5ft 5in at least.

The seat back insert is assembled by the user after the track has been secured to the bucket. It includes two pieces of a 2x4 board, cut on an angle consistent with the designed seating angle, 30o from vertical. It also includes three pieces of plywood; two are cut to a size to sandwich the 2x4 pieces and fit inside the bucket, the other is cut to be the seat back. The user assembles the seat back insert with 7 screws.

Four metal L-brackets are included to attach the seat back insert to the track. This helps alleviate the stress seen by the bucket from the user's weight on the seat back. Eight screws first attach the L-brackets to the seat back insert, then four more attach the brackets to the track.

All screws use the same tool and each application has been pre-drilled to facilitate assembly with hand tools, as electricity is not expected in the use area.

Conclusions and recommendations:

In conclusion, the prototype design reduced the torque required to turn the system. The system is now more robust, and can handle a higher torque along the shafts. The problem with reducing the torque was that now it requires the user to pedal at a faster rate, overall not making it too much easier to use. The metal gears do not provide a smooth motion, which make it difficult to provide consistent power. It is fairly easy to overcome with practice but does reveal a design issue. It is very discouraging to the user to continue once the flow of water ceases. Formal testing of the device was limited due to time constraints. During our limited testing, most subjects reported feeling tired from the fast pedaling required. In retrospect, an additional motor could have alleviated effort required of the user but would have increased the total product cost. Effort and cost were ultimately a tradeoff. More in depth research could possibly reveal ways to achieve both a low cost while reducing the effort to the user. These competing requirements were a challenge and optimization has not been achieved.

Test subjects from the RIT ImagineRIT Innovation and Creativity festival noted that their feet were slipping off the pedal and the seat was unstable. A possible suggestion would to add straps to the pedals to prevent the user's feet from slipping. The unstable seat was caused by misuse but should be addressed in providing a stable product. A more successful aspect of the design included the gearbox repositioning method. The eyebolts were fairly easy to remove and reinsert. Those visitors who did produce water were satisfied in accomplishing the task without tiring themselves excessively. The visitors who were unsuccessful in producing water found themselves pedaling faster than the successful users. These people experienced more interruptions in their pedaling due to feet slipping off of the pedals or lack of consistency in pedaling.

No data was obtained on the ease of assembly or the clarity of the user manual. This was once again due to time constraints. No data was collected comparing the current BWM to the prototype developed during this iteration of the project.

There were several constraints on this project that made it difficult to satisfy the engineering requirements. These constraints had a large impact on the design of the product. The manufacturing cost requirement of $75 and the effort required were the main requirements that our team had trouble meeting. The team could have utilized closer communication with the costumer once the cost became an issue. Using a change control process with the specifications, the customer and team could have agreed on a reasonable cost target. The final design has a manufacturing cost of $119. The voltage requirement was set as approximately 13 volts to 15 volts transferred to the sanitation system for a consistent five minutes, without tiring the user. The majority of women and children who tested the prototype were not able to produce the desired amount of water (formal testing data is provided). From that testing data, it was shown that the product did not meet the engineering requirements for effort.

One recommendation for the next group would be to try and further optimize the ease of use of the product. This function of comfort would depend on two variables, the torque required to turn the system and the speed at which it needs to be pedaled to produce enough energy. These variables are directly affected by the generating motors and the gear ratio. The gear ratio is exponentially related to the torque (resistance) seen by the user. The motor also has its own specifications for torque and voltage output versus RPM. It is recommended to test several generating motors to optimize the voltage output and torque keeping cost and availability in mind.

Focusing on the electrical side of the design it is recommended that future teams or projects not pursue the three LED voltage level indicator. It is difficult in practice to get the resistor values to match the desired ratio that turns the LEDs on at precise voltages. LEDs are not needed on the gearbox at all. The LED on the pump unit is enough for the user to go by. This LED is hardwired to turn on exactly when the pump is receiving enough power, so it is much more precise than any LEDs on the gearbox could ever be. By completely removing the LED portion of the circuit the complexity and size of the circuit is reduced. The circuit space is already limited due to the regulator portion being made up of several large components, ie. a heatsink, inductor, and several capacitors.

As a team, there were lessons learned throughout the process. It is important to adhere to a project plan. Unexpected events will occur and having appropriate time set aside in the project plan will prevent a team from becoming derailed. The members need to be accountable for action items. There should be a change process and review process in place to prevent future mistakes. Keeping thorough and open communication through all team members is essential to have a properly integrated product. When changes are made without everyone's knowledge, the system's functionality can be compromised.

References:

(1) Estimated from "Water.org." Waterorg. N.p., n.d. Web. 08 May 2014. <http://water.org/water-crisis/water-facts/water/>.

(2) Richard G. Budynas - J. Keith. Nisbett - Shigley's mechanical engineering design - New York, NY - McGraw-Hill - 2011 - Ninth Ed.