(Power+ Gen)

Knee Energy Harvester

Group 5

Senior Design II

Shan Islam

Seion Bailey

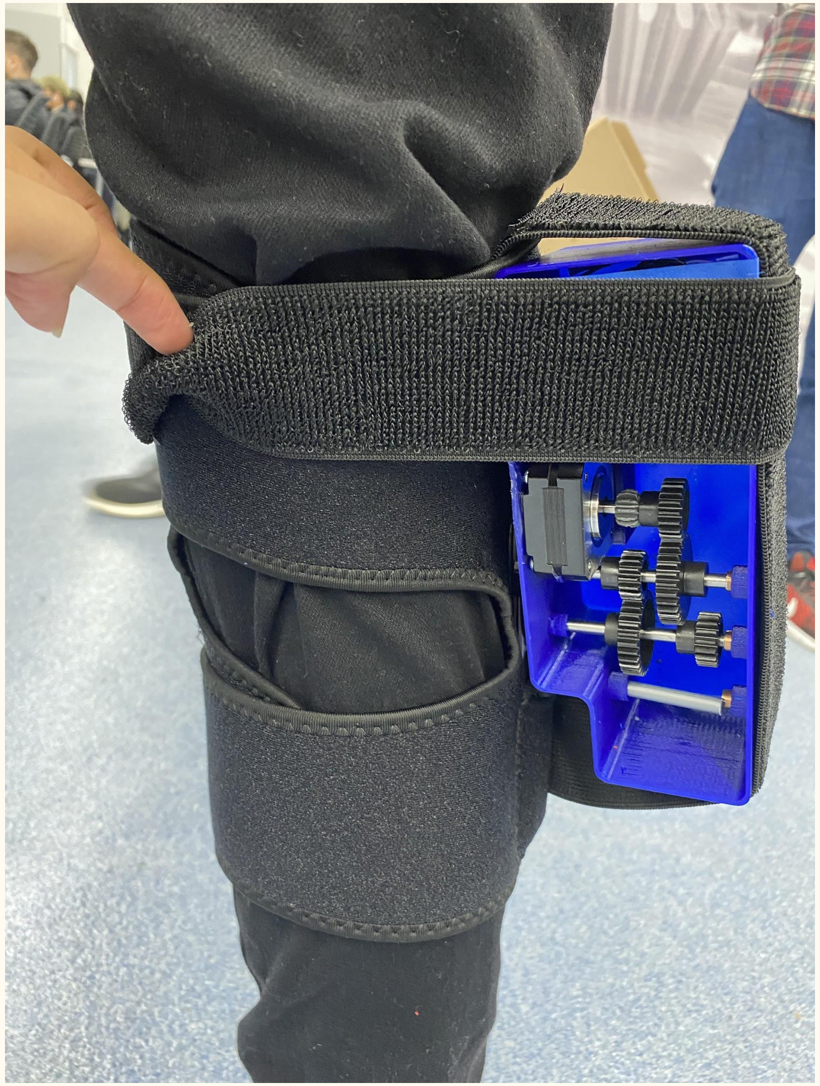
Vinicius Quintela

Zhaohan Yang

Saugat Lamichhane

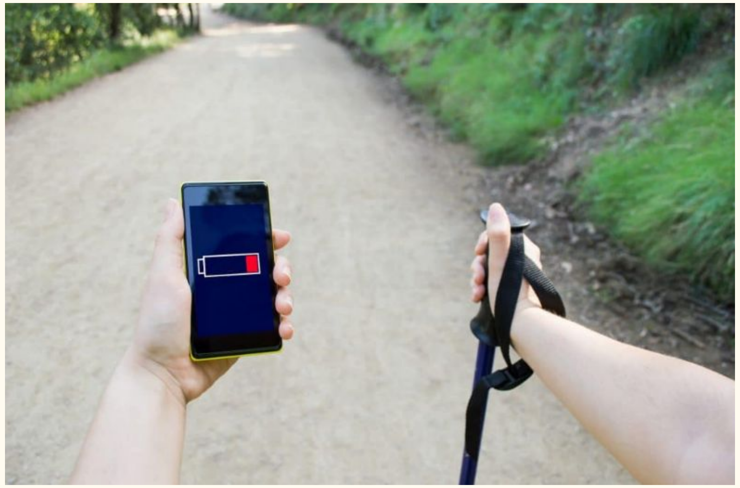
Outline of the Project

- ➢ Purpose
- ➢ Goal
- ➢ Conceptual Design
- ➢ Manufacturing
- ➢ Assembly & Testing
- ➢ Issues
- ➢ Conclusion
- ➢ Future goals



Have you ever found yourself in these situations?

- ❏ Low Charge
- ❏ No access to charging port
- ❏ Travelling by foot



- ❏ Potential Solution: Biomechanical Knee Energy Harvesting.
- ★ With our device you can hike the most challenging terrain with a continuous supply of energy that will be harvested through the motion of your knee.

Why knee energy harvesting?

- Human energy generation: foot, knee, hip, arm, center of gravity (CoG)
- We targeted the body part that produces the most negative work and thus, the most potential energy (regenerative harvesting)

Joint/Motion	Work (J/step)	Power (W)	Max Moment (Nm)	Negative Work (%)
Foot strike	1–5	2–20	-	50
Ankle	33.4	66.8	140	28.3
Knee	18.2	36.4	40	92
Hip	18.96	38	40–80	19
Elbow	1.07	2.1	1.2	37
Center of gravity (*COG*) *	10	20	-	-

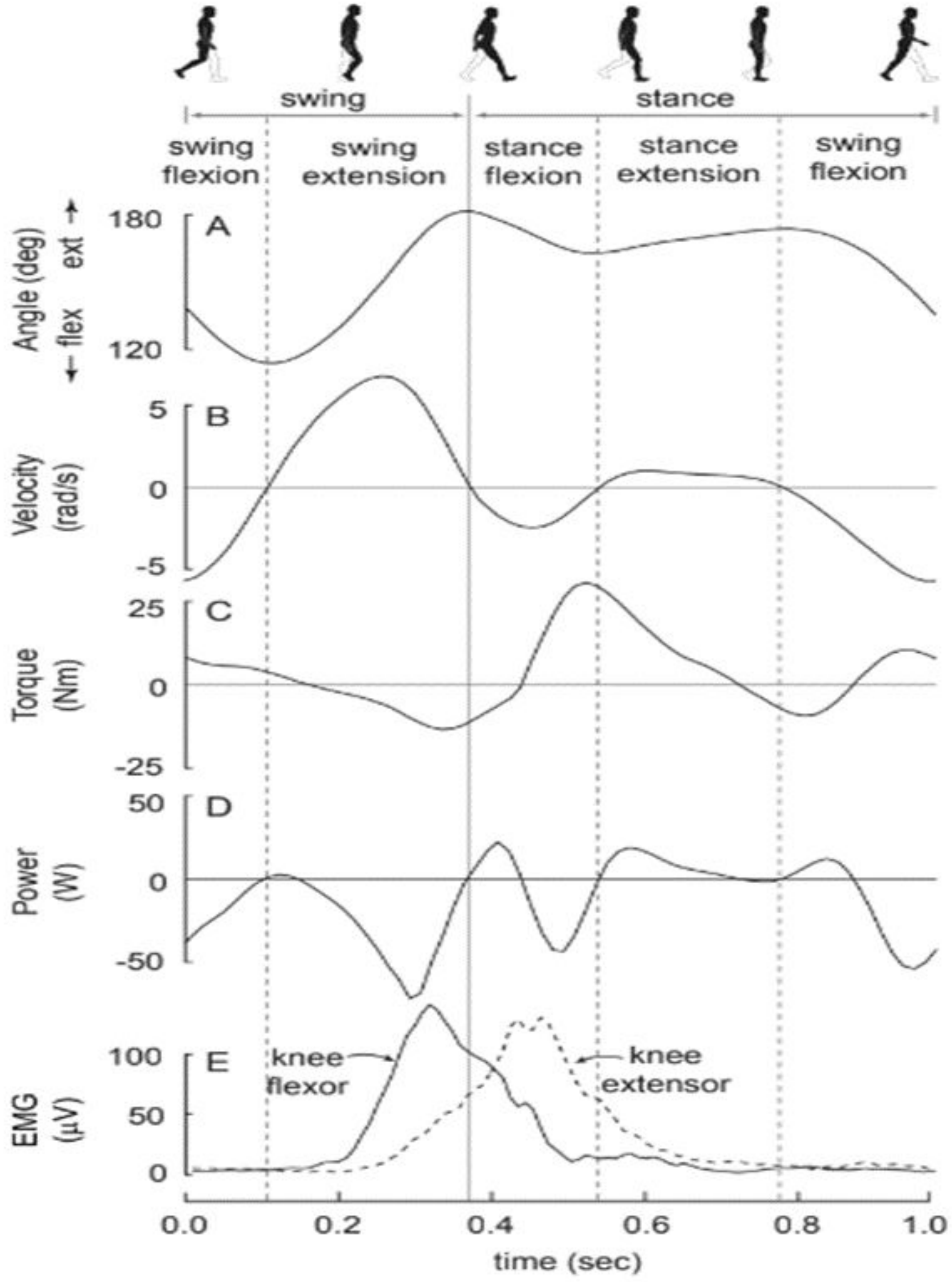
Knee Movement & Mechanics

The knee primarily performs negative work during walking.

Four main phases of knee kinematics.

Each phase delineated by a change in direction of motion:

- Stance flexion
- Stance extension
- Swing flexion
- Swing extension.



Our concepts & challenges

- Determining an effective mechanism for converting bio-mechanical power into electrical power.
- Generating enough power to charge a smartphone
- Designing a mechanism for converting the intermittent, bi-directional and time varying knee joint power into a form suitable for efficient electrical power generation.
- Optimizing the system parameters to maximize the electrical power generation.

Requirements

Design and build a knee device that can generate sufficient energy to charge a cell phone as a person walks.

1. Low cost
2. Lightweight
3. Generate a min of 2.5W to charge a cell phone
4. Non - Intrusive
5. Durability and water resistant
6. Safety

Interfaces

- A standard knee brace will be used as the main interface for our project.
- The knee brace will be mounted on the lower extremity of the leg with straps
- The energy harvester will be attached to the external side of the knee brace with screws.
- The knee brace can be worn on either leg during walking.
- The chosen knee brace is made of durable aluminium alloy, making it lightweight and comfortable for the wearer.
- The weight of the knee brace is 2.18 lbs with overall dimensions of 14.21 x 13.23 x 3.78 inches.

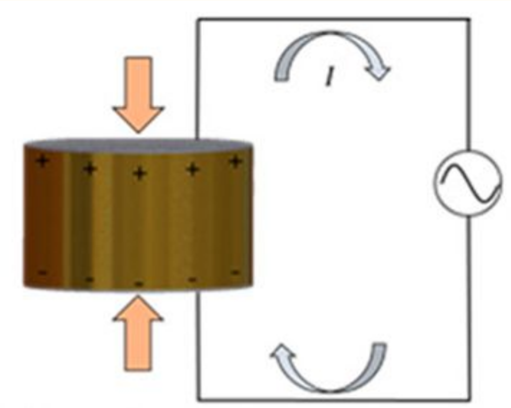
Three Energy Harvesting Solutions:

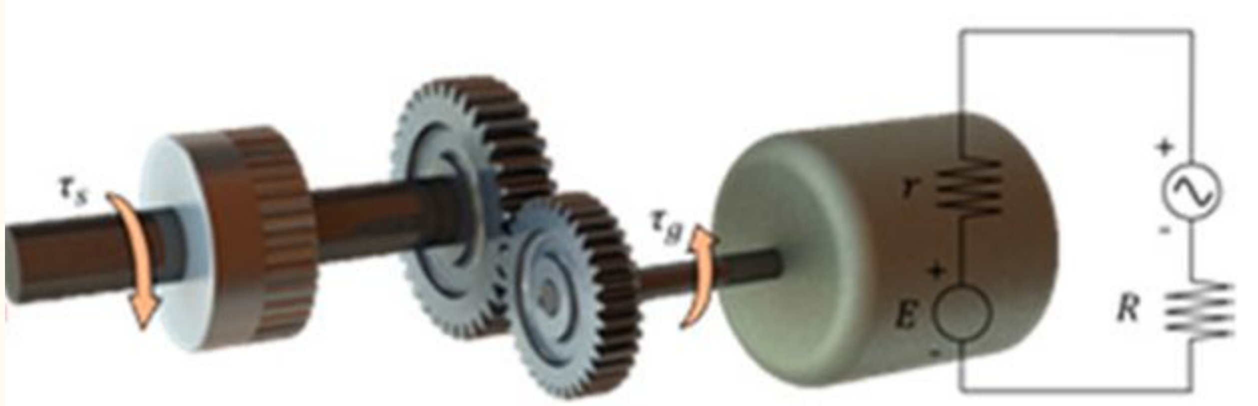
Three Alternative Solutions:

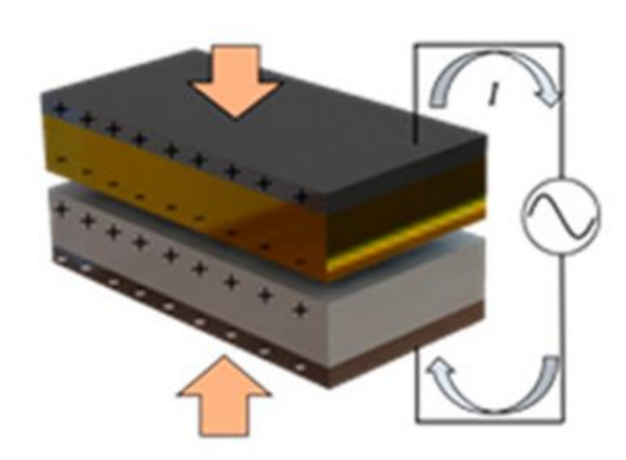
●Electromagnetic Energy Harvesting (Gear-and-Generator)

●Piezoelectric Energy Harvesting

●Triboelectric Energy Harvesting







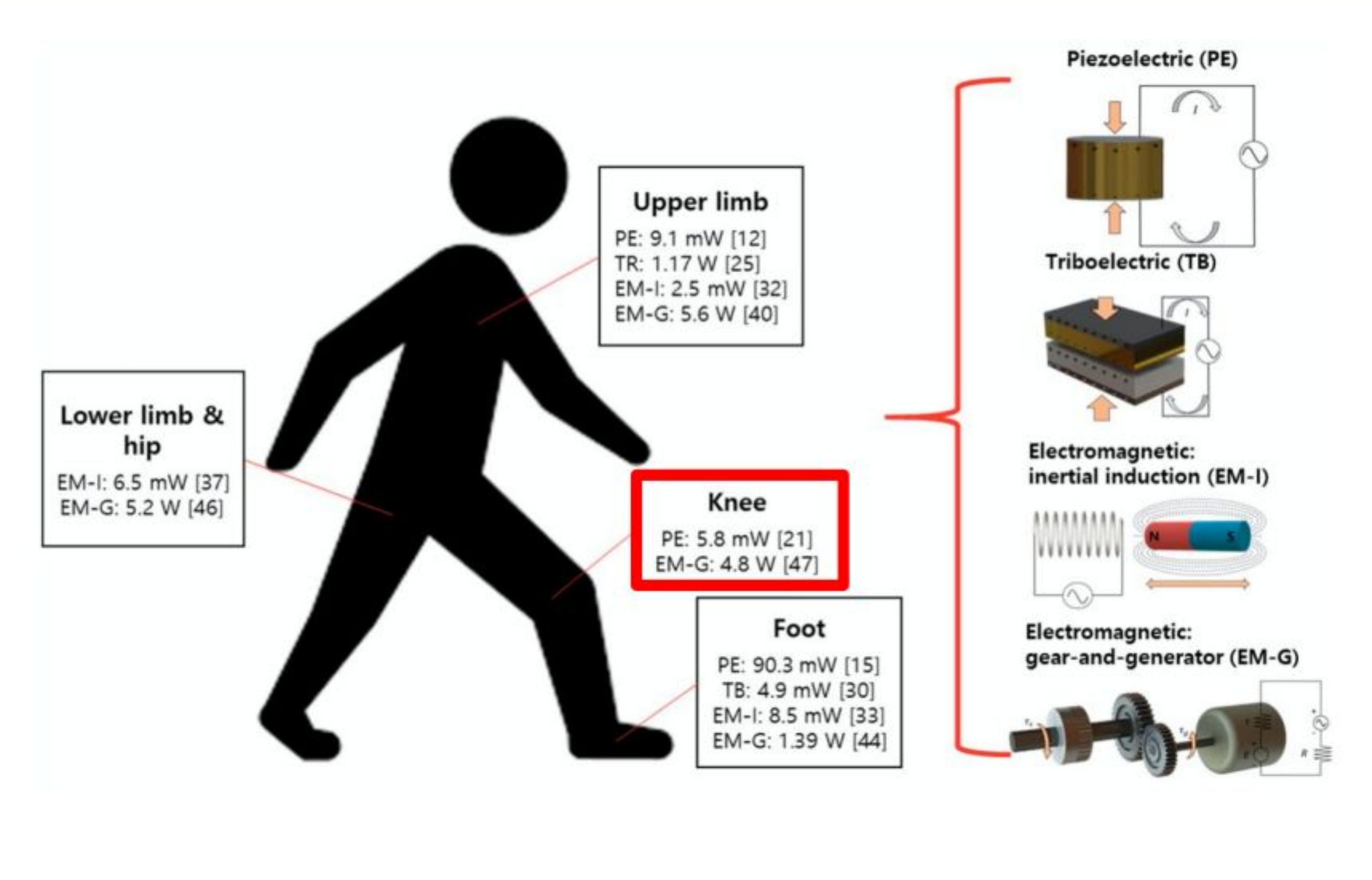
Comparison of Energy Harvesting solutions

Trade study

Design Attribute		**Piezoelectric**		**Triboelectric**		**Electromagnetic**	
	Weight factor	Rating	Score	Rating	Score	Rating	Score
Assembly		3	9	3	9	2	6
Power Obtained	10	3	30	3	30	8	80
Size	5	5	25	4	20	2	10
Durability	5	3	15	3	15	5	25
Weight	5	5	25	5	25	2	10
Reliability	5	3	15	3	15	5	25
Cost	5	4	20	4	20	2	10
Total Score			**139**		**134**		**166**

Electromagnetic Gear and Generator

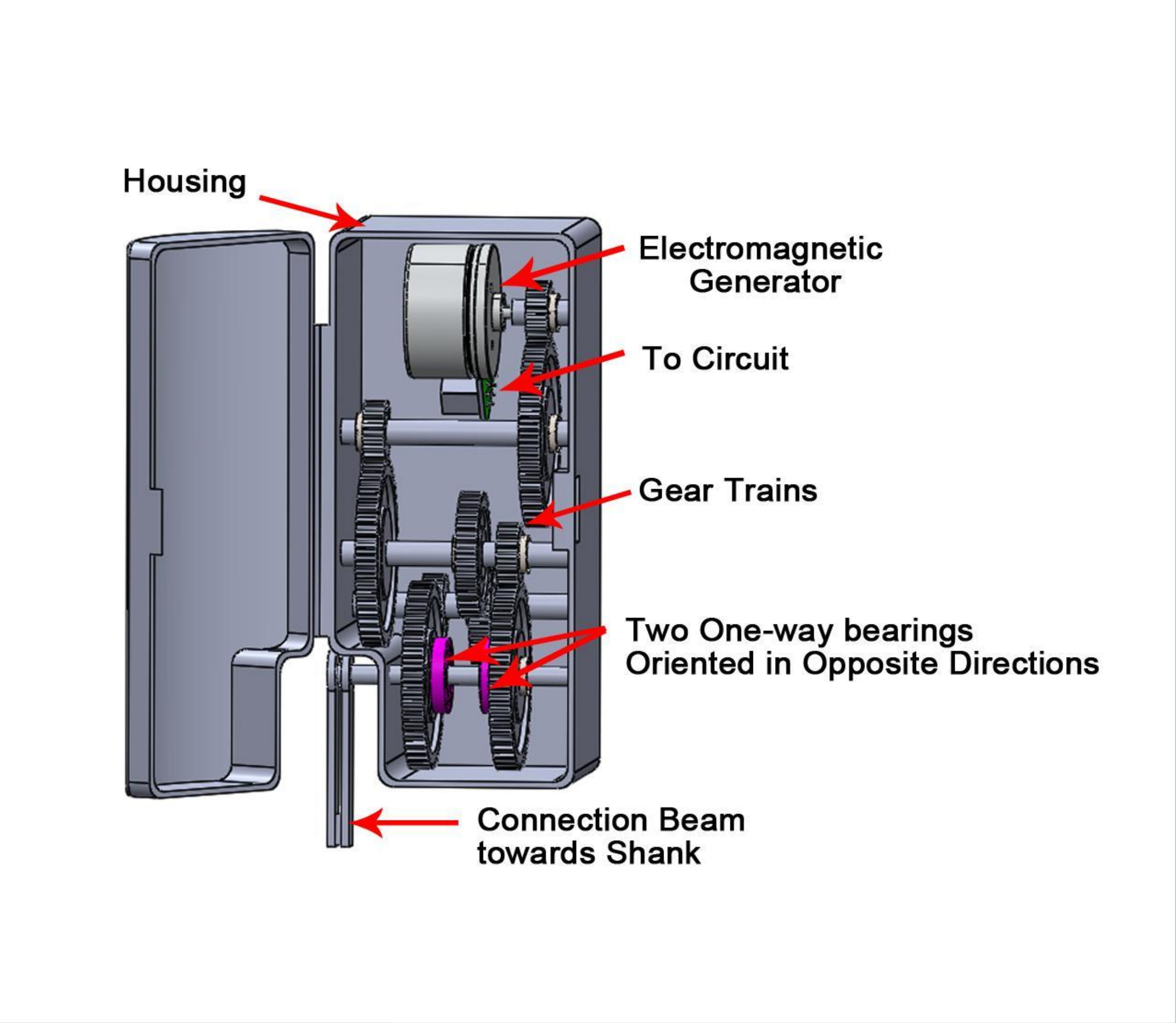
- ❑ Pros: cheap, high energy output
- ❑ Cons: Form factor, weight



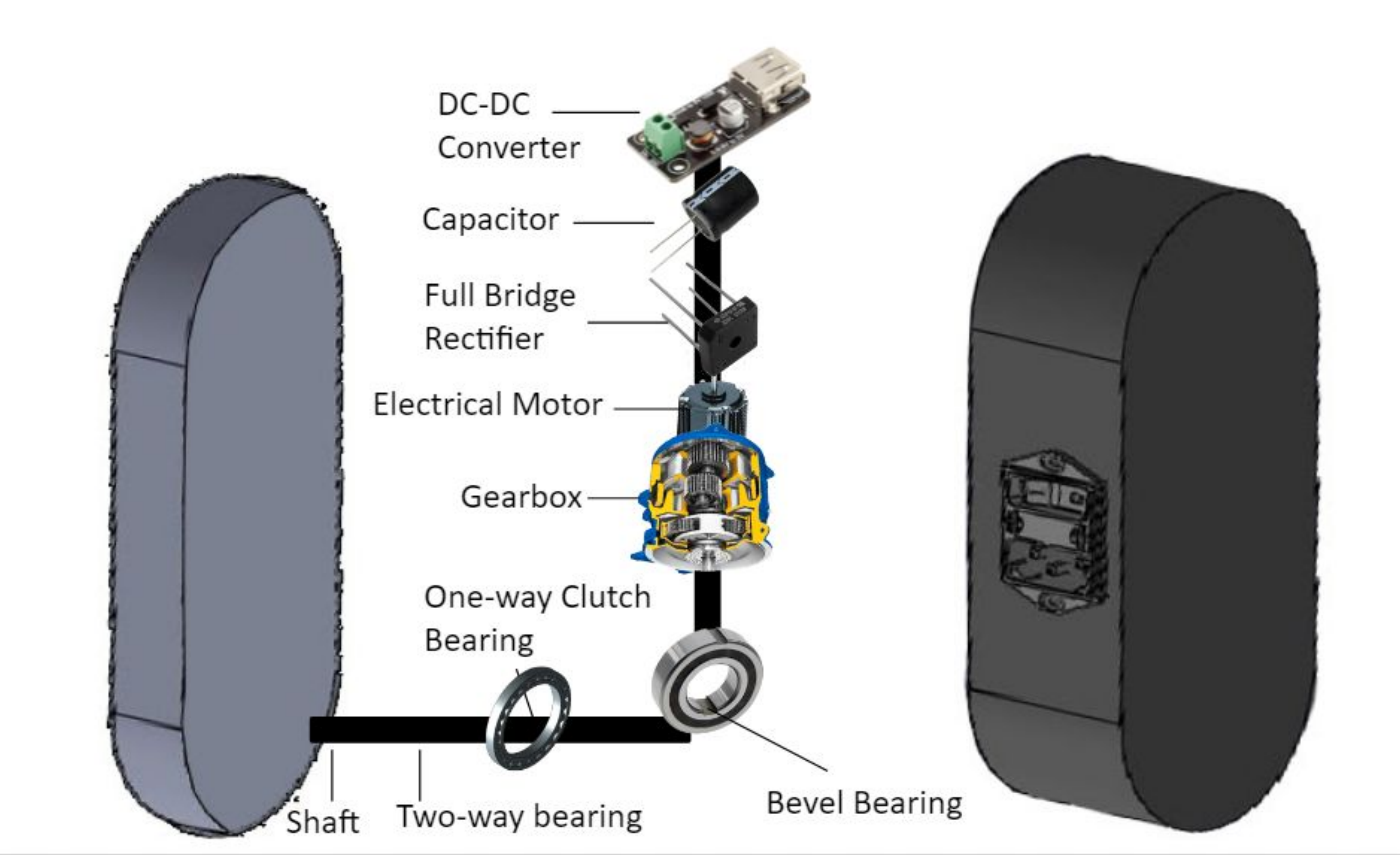
Summary of Solutions

The energy harvester consists of five major parts:

- Several gear trains (Transmission system)
- Two one-way bearings
- An electromagnetic (EM) generator to circuit
- A connection beam
- Housing



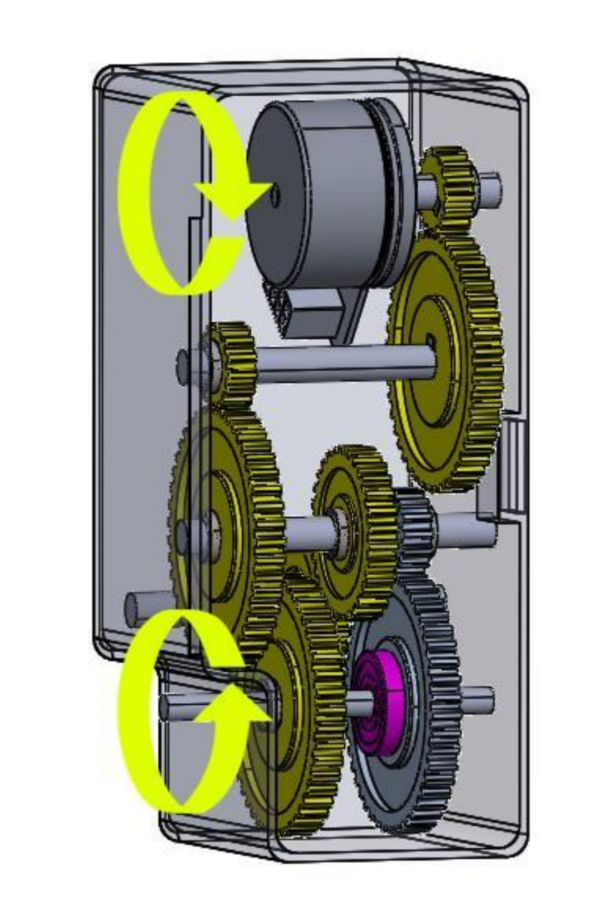
Overview of Design (Mechanical and Electrical)

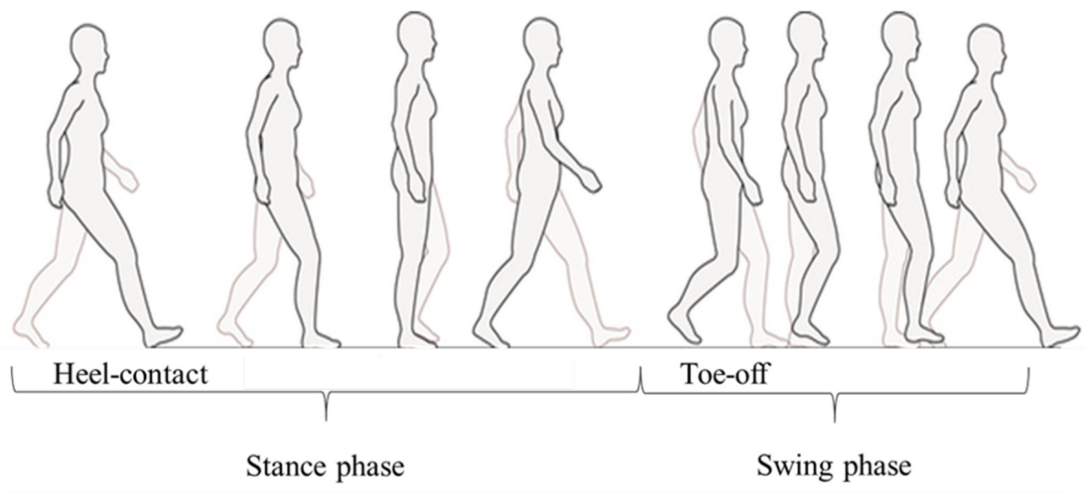


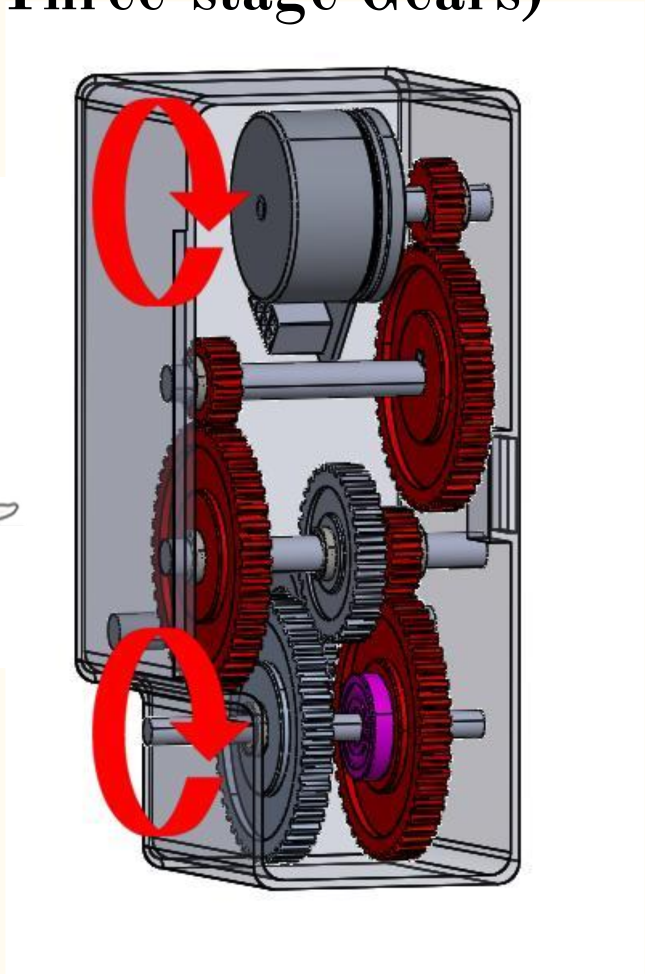
Two Transmission Phase

Transmission of Stance Phase (Four-stage Gears)

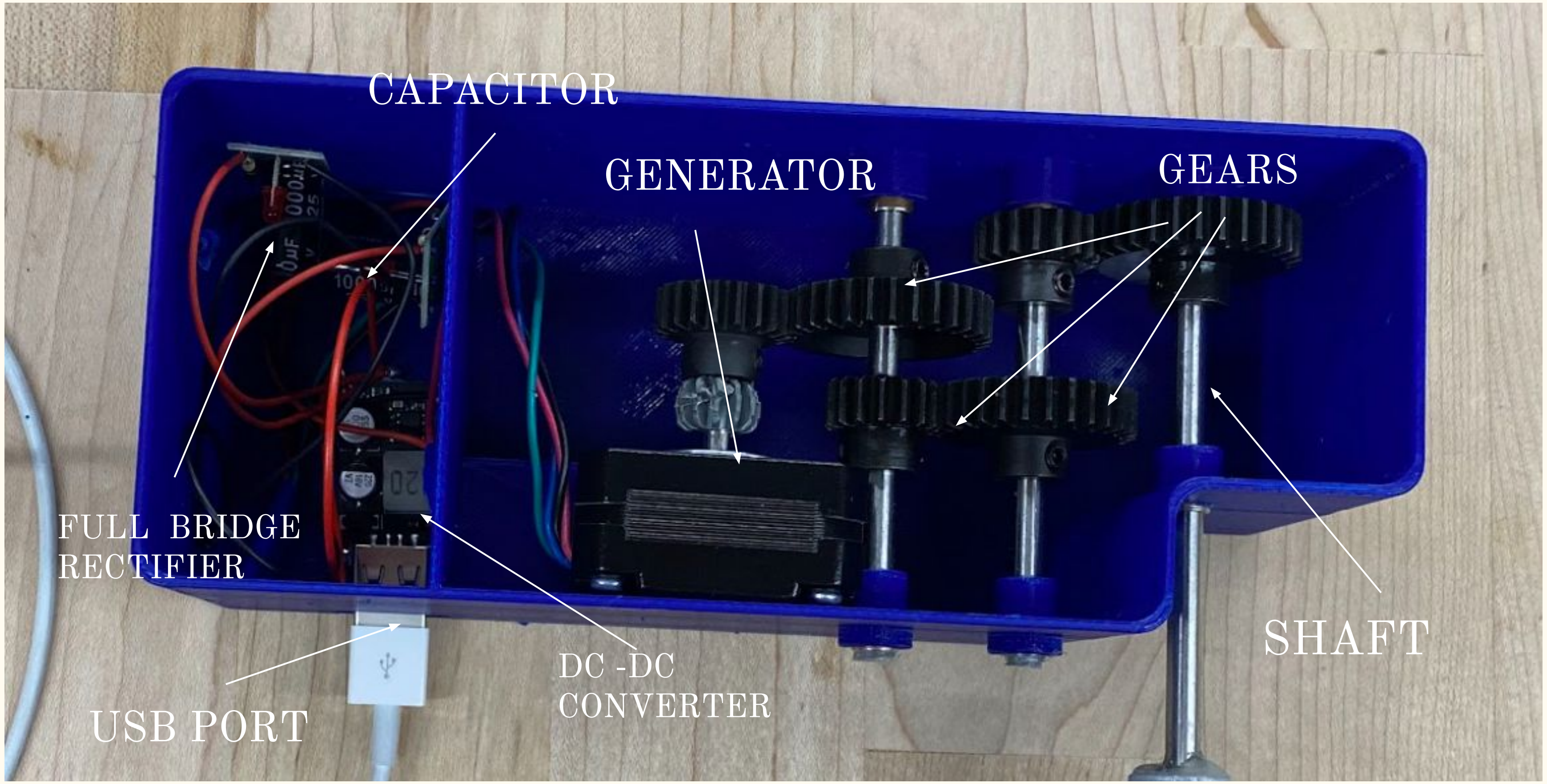
Transmission of Swing Phase (Three-stage Gears)



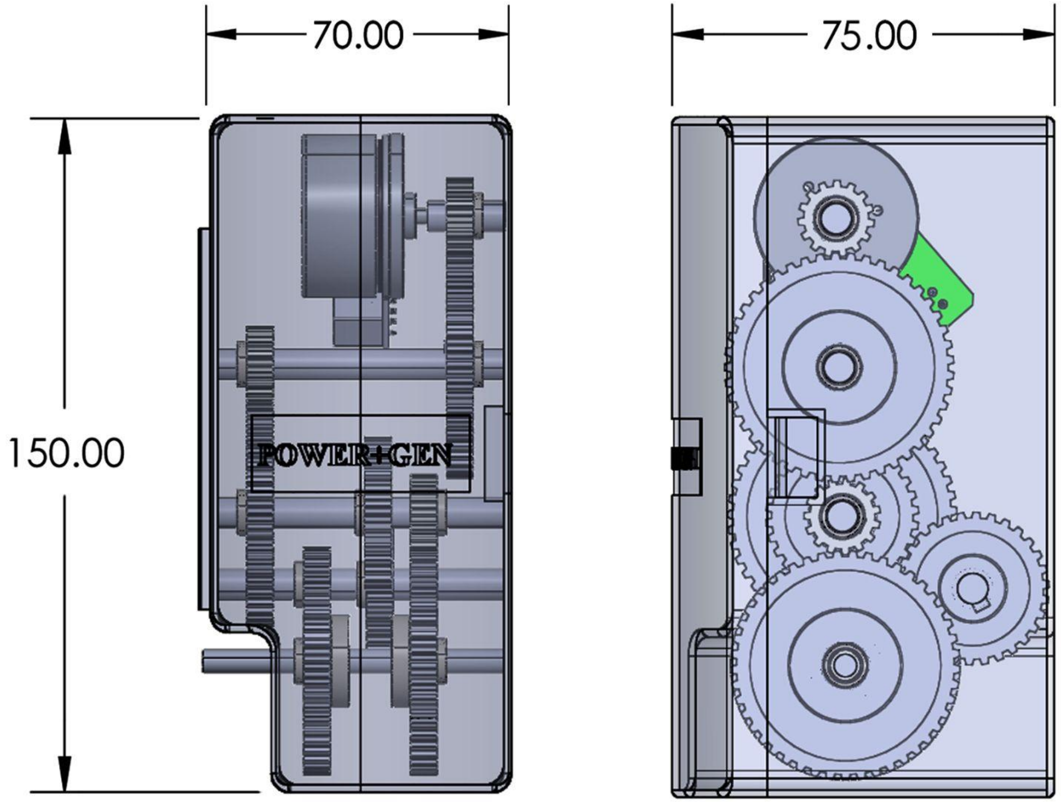


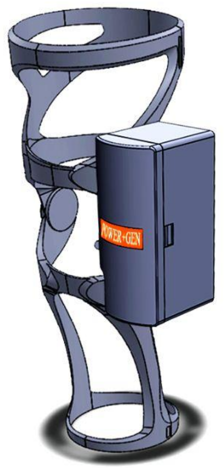


Our Solution at a glance



Initial Projection of Housing Built

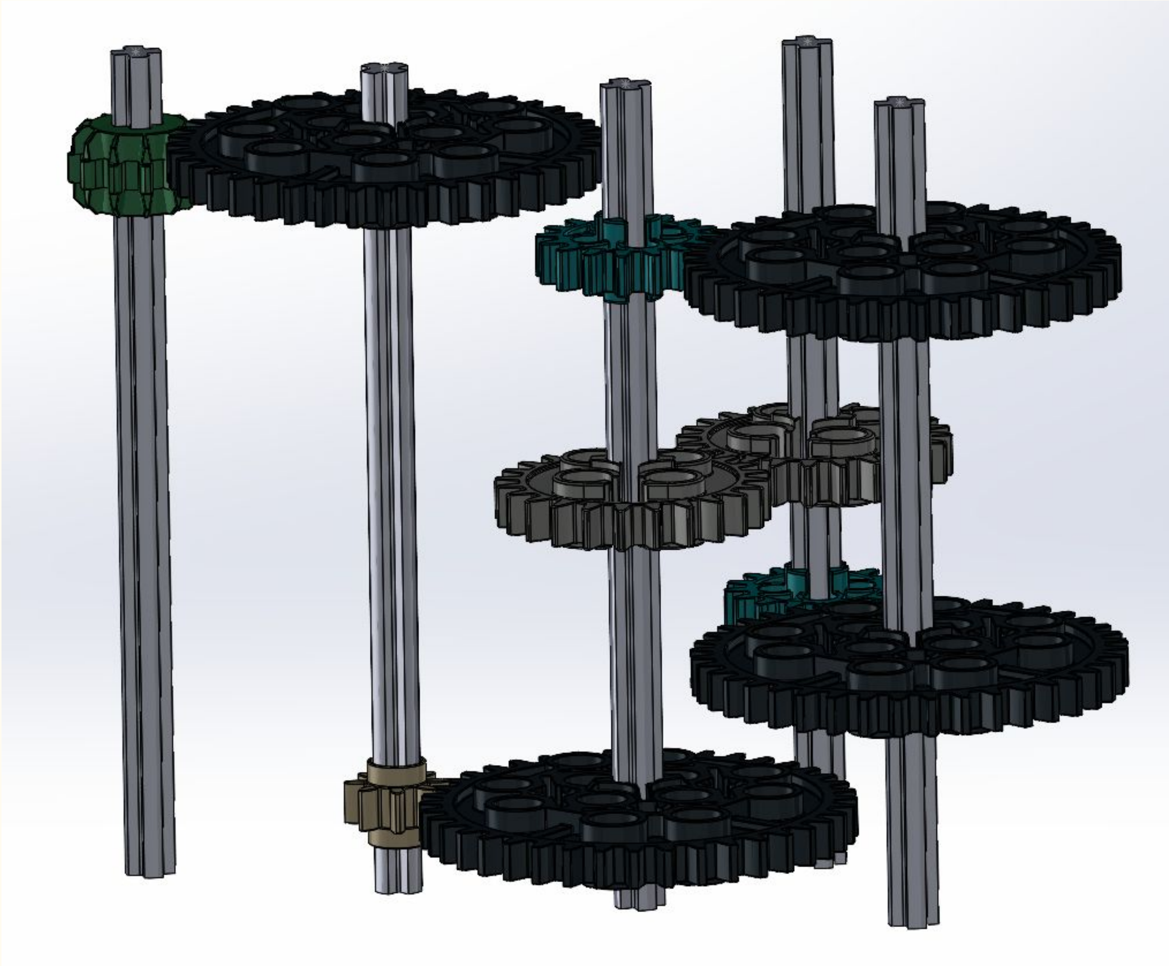




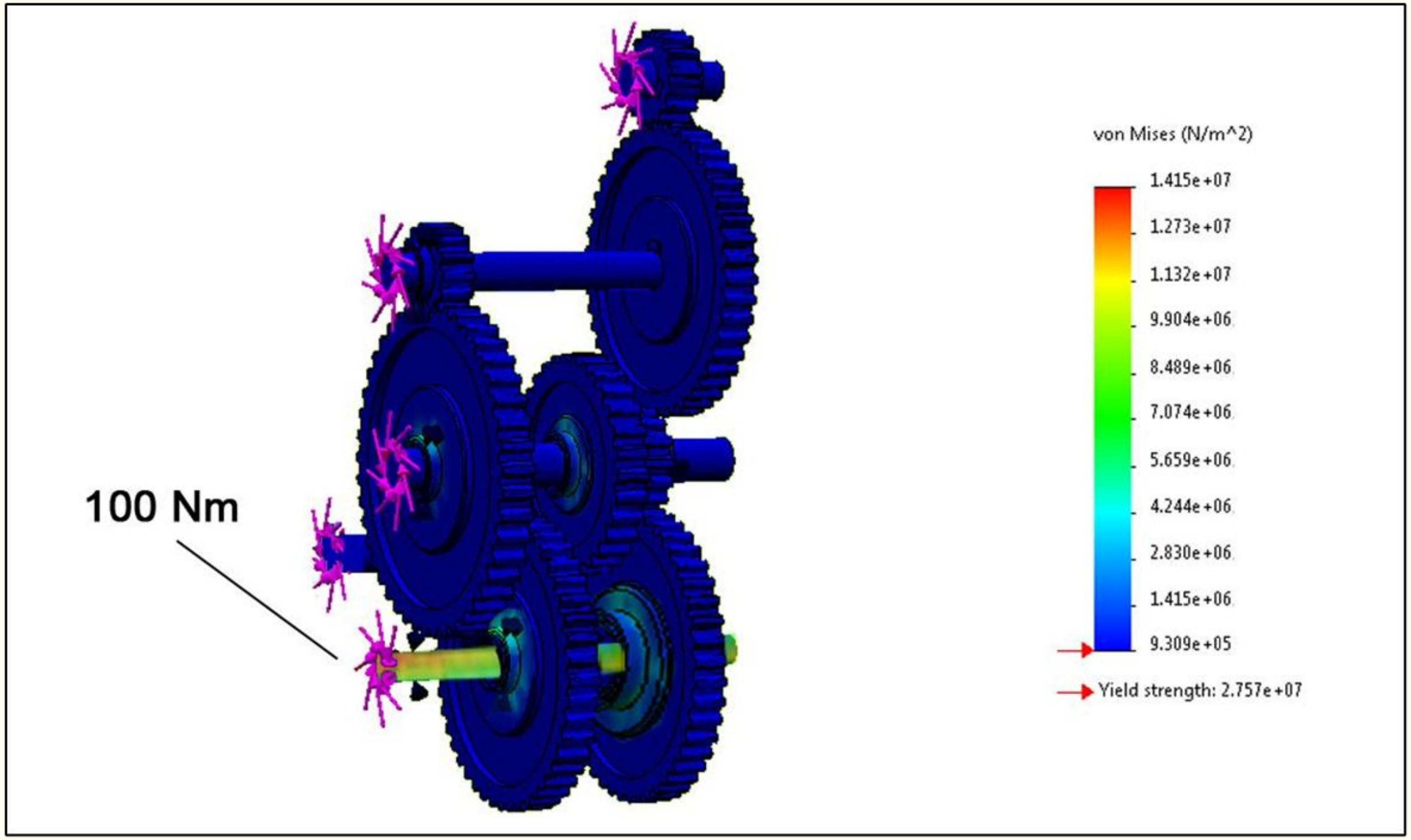
Unit: mm

Initial Gear Train CAD Model

Our model consisted of 4X 40 tooth, 2X 24 tooth, 2X 16 tooth and 1X 8 tooth gears. We also had 4 shafts of 4.7 mm diameter.



FEM Results



100 Nm
von Mises (N/m^2)
1.415e+07
1.273e+07
1.132e+07
9.904e+06
8.489e+06
7.074e+06
5.659e+06
4.244e+06
2.830e+06
1.415e+06
9.309e+05
Yield strength: 2.757e+07

Motor Specifics

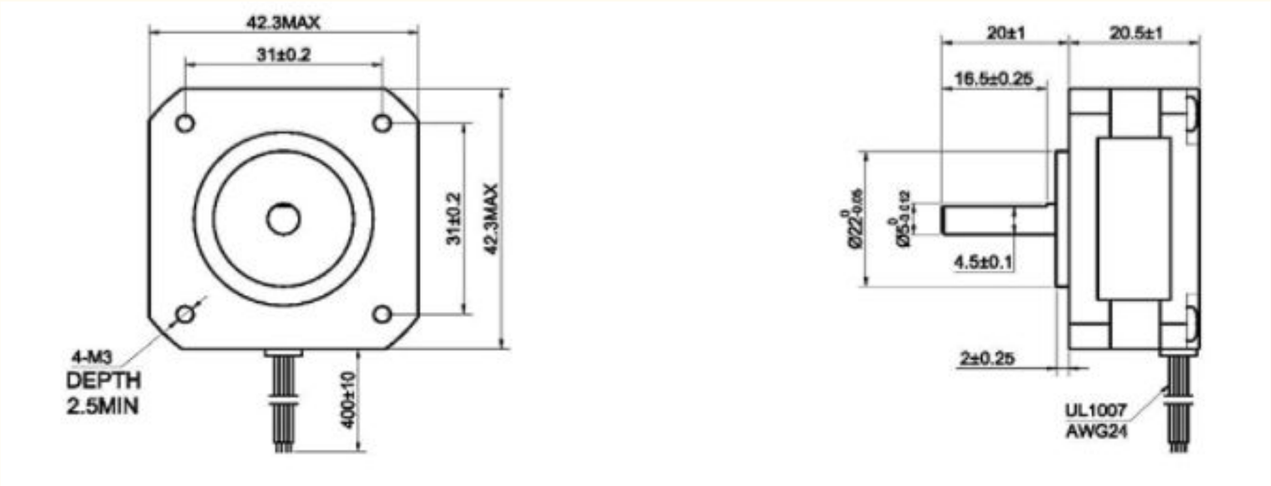
Nema 17 Bipolar Stepper Motor

1. Low torque input produces high voltage output

1. Rated current 2A per phase

1. Lightweight (140g) and small.

1. Commonly used in CNC Extruder



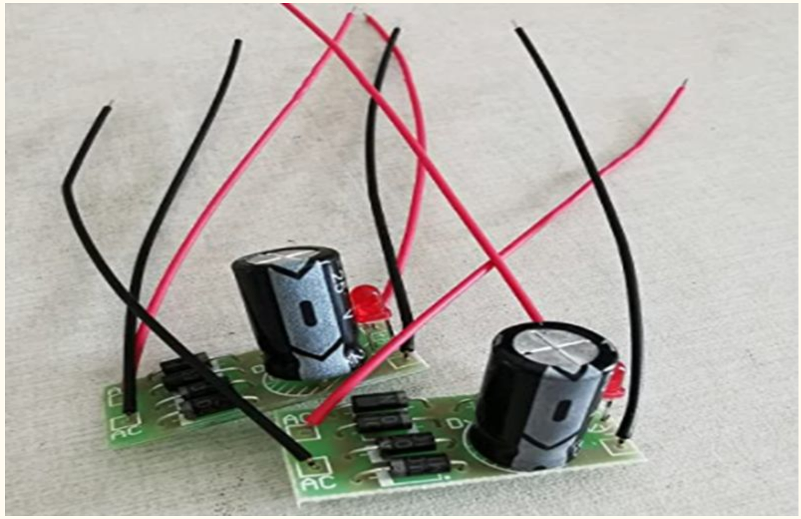
Electrical Elements

The electrical components used in our design are:

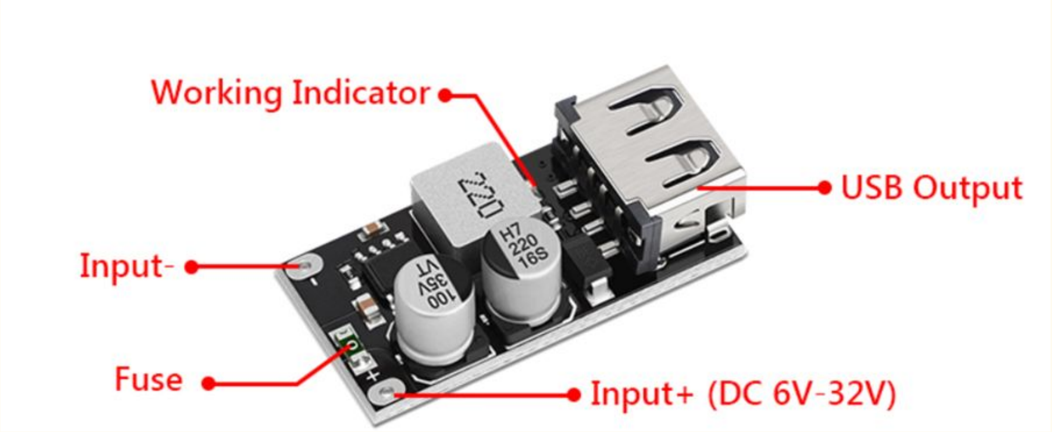
1. AC to DC power conversion module consisted of:

- Two full bridge rectifiers with AC input voltage [6V -32V]
- Two capacitors with capacitance of 25V1000UF;

1. Dc – Dc Converter with an input voltage of DC 6V -32V

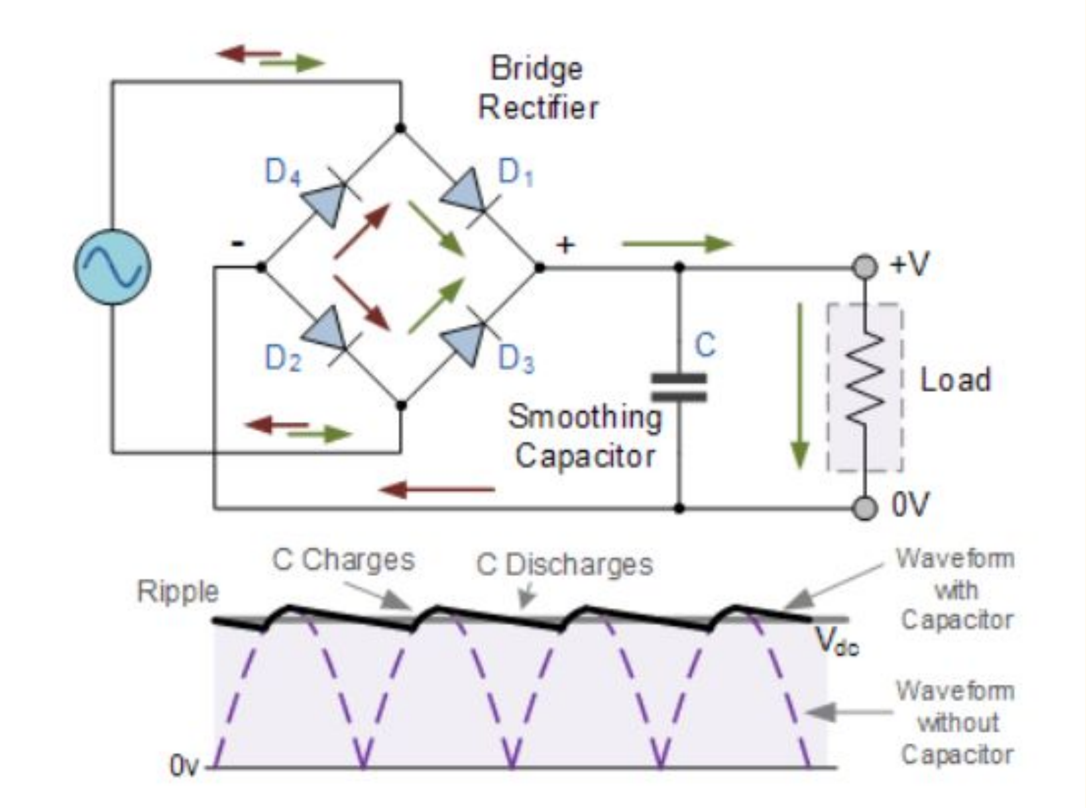


Power module



DC - DC converter with usb port

Circuitry



- Two phase brushless DC motor (acting as generator) outputs a highly sinusoidal waveform which requires rectifying and smoothing in order to charge a phone

- Full bridge rectifier used to convert AC waveform to DC by flipping negative parts of waveform

- Capacitors are to used to smoothen the output voltage

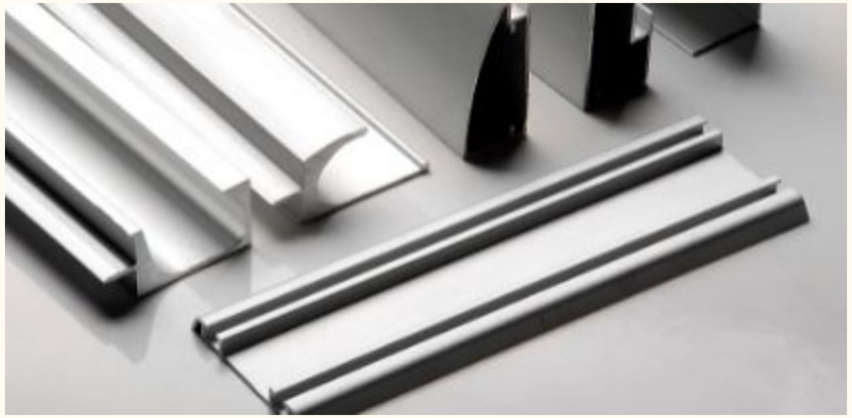
- A DC -DC convertor is used to step down the DC output to a suitable voltage of 5V

Electronic Component	Function	Picture
Full Bridge Rectifier	Converts sinusoidal signal outputted from motor to partial DC voltage signal	
Capacitor	Charges and discharges according to partially DC voltage signal to smoothen out DC signal	
DC-to-DC converter	To stabilize the voltage output by the motor	
Battery	To store the power generated by the stepper motor	
Insulation	Helps to prevent circuits from shorting	
Cables	Connects all the components together	

Manufacturing Parts and Procurement

Aluminum:

- ❏ relatively expensive
- ❏ lighter than steel
- ❏ durable



PLA:

- ❏ cheaper than metal
- ❏ speeds up redesign process
- ❏ solid structural rigidity for a plastic material
- ❏ Availability

Knee Brace

- ❑ Off-the-shelf knee brace
- ❑ Easily Modifiable
- ❑ Components are mountable to the existing features of the knee brace

Housing Design and Iteration

First iteration

- just used to fit and test a working gear mechanism
- Protrusion on side to drill hinge
- we realized it was too small to fit generator

Second iteration

- Larger to fit generator
- design included holes for the shaft so that we can assemble the gears

Third iteration

- added platform for the motor

Fourth iteration

- minor changes to adjust motor position and reduced dimensions
- Added hole in wall to run wires through
- Eliminated mount for the hinge

Final Housing Design (Fifth iteration) (Blue)

- Size comparison between final design (fifth iteration) and third iteration

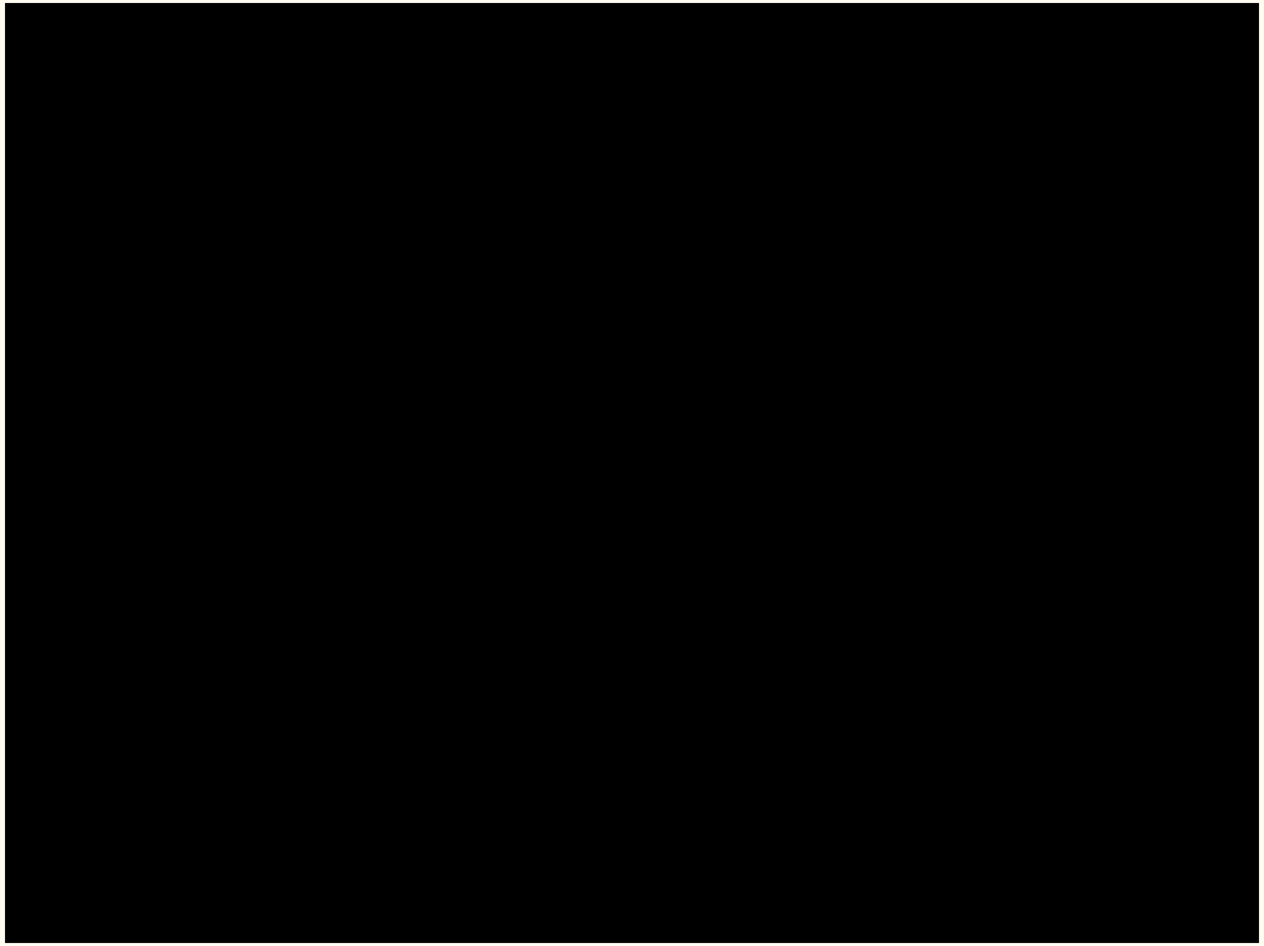
Assembly & Testing

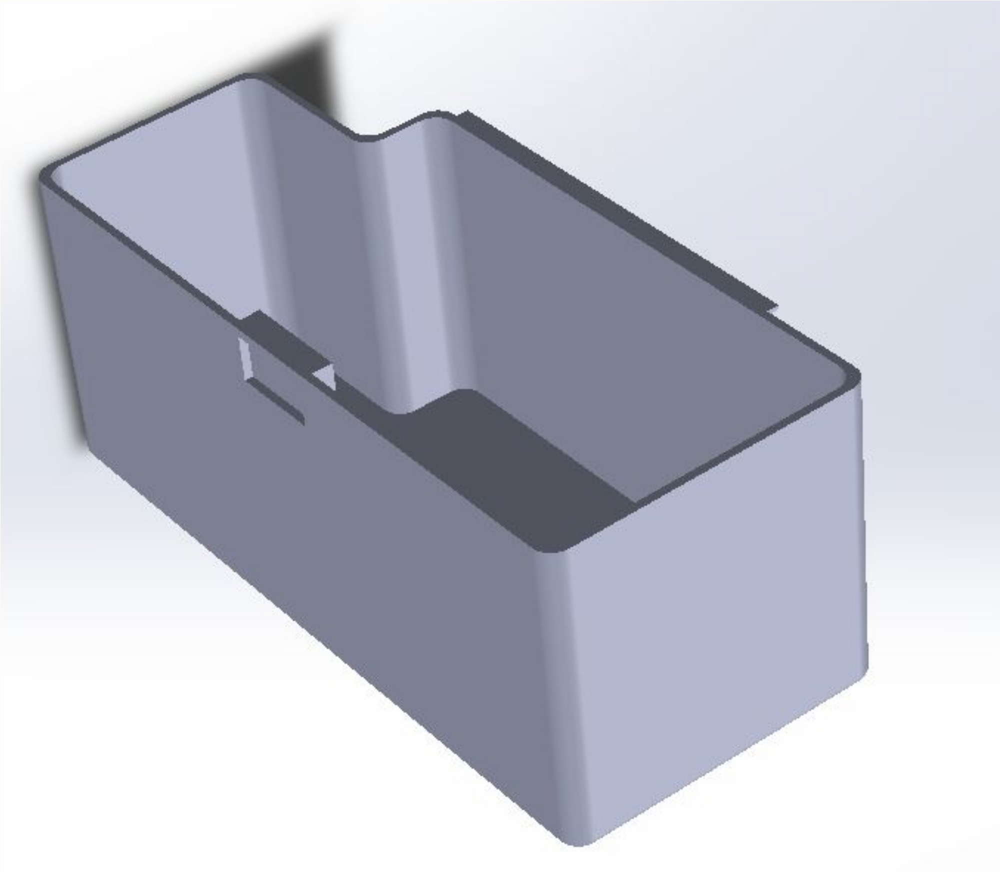
Iterations and Final Parts with modifications in conceptual design

Issues and Obstacles

- Ordered parts not delivered.
- Reduced time for assembling and testing.
- Due to design alterations and time restraints, the prototype did not certain meet the design criteria
- As a group, we projected that it would take approximately three weeks to assemble our design and one week for testing.
- However, due to unforeseen circumstances, the project schedule had to be adjusted and requirements constrained.

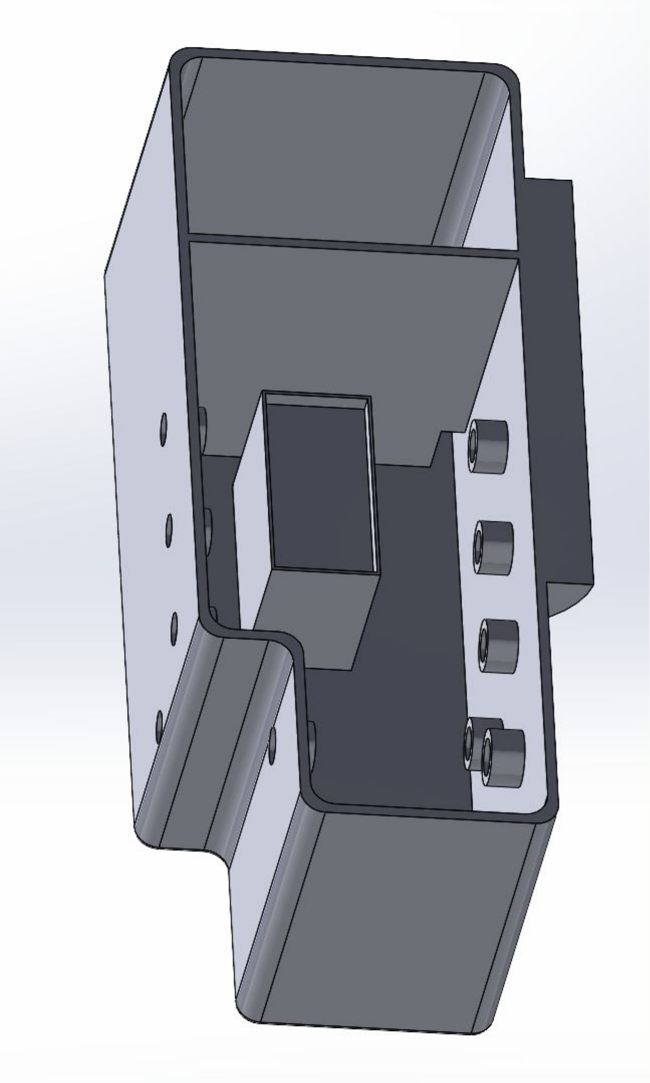
Housing and Prototype Lego Gear System





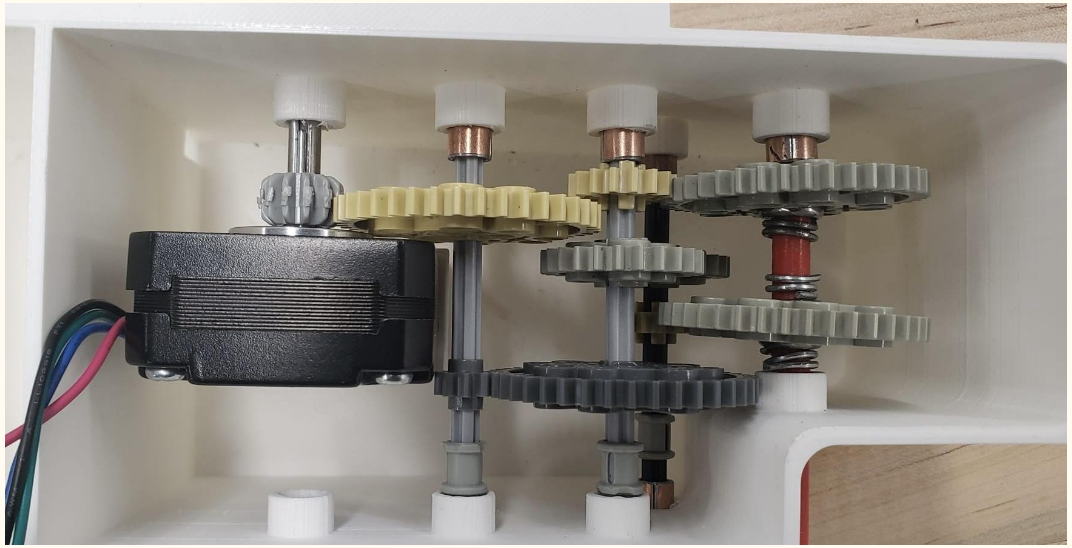
Initial Housing CAD Model with lego gear train

- Our model has extruded cylinders to secure the shaft in place.
- An elevated platform is also included to align the motor with the gears.
- A partition is created so that the electrical components could be stored.

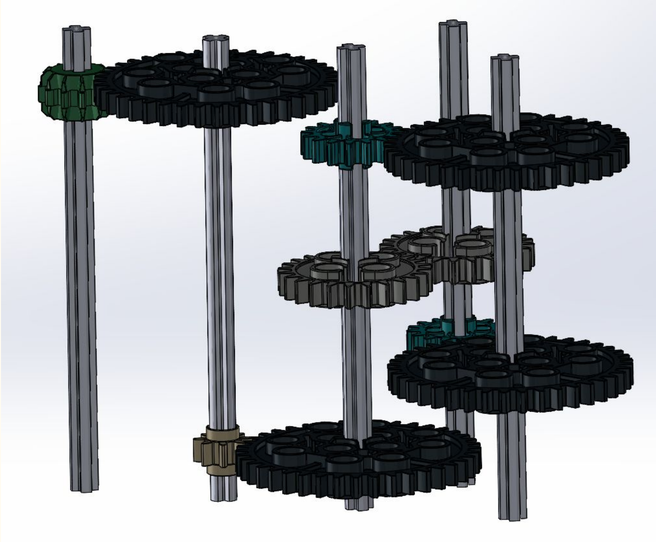


Obstacles with the LEGO gears

Since our design uses two clutch bearing to maximize the efficiency of energy generation when walking, it will be mounted between two of the 40 tooth gear in our new design.



However, after inserting our one way bearings to the 2 gears on the right, instead of hindering motion, it started to slip due to high torque from the knee.

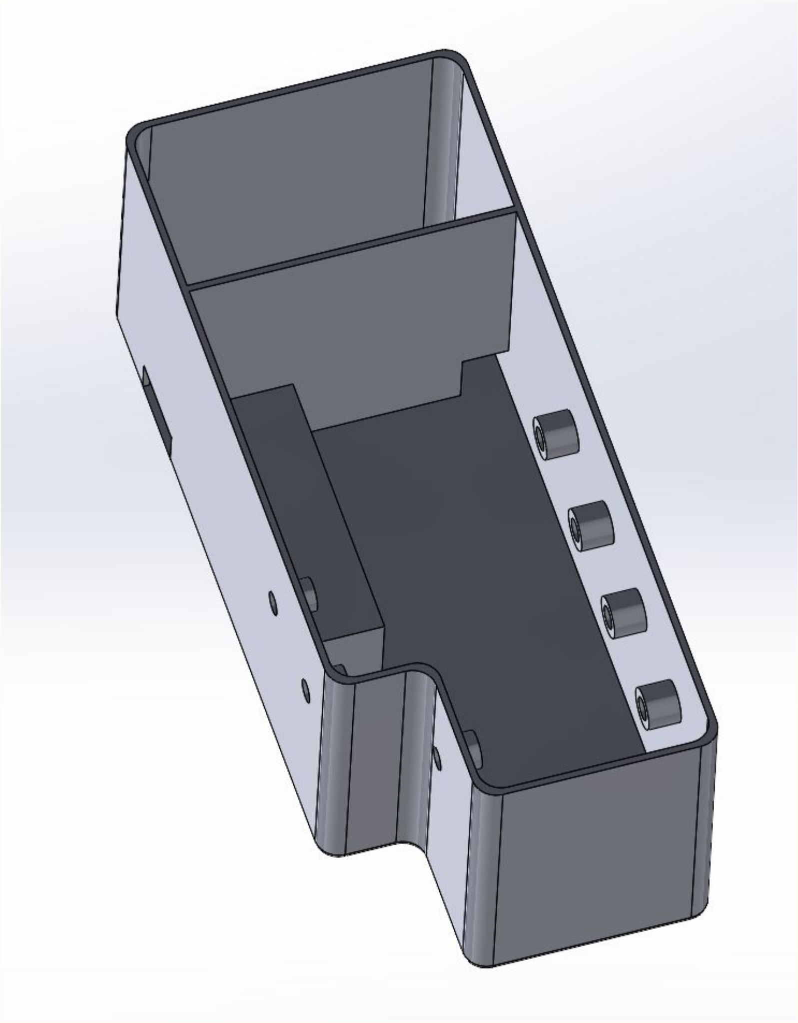


Final Housing CAD Model

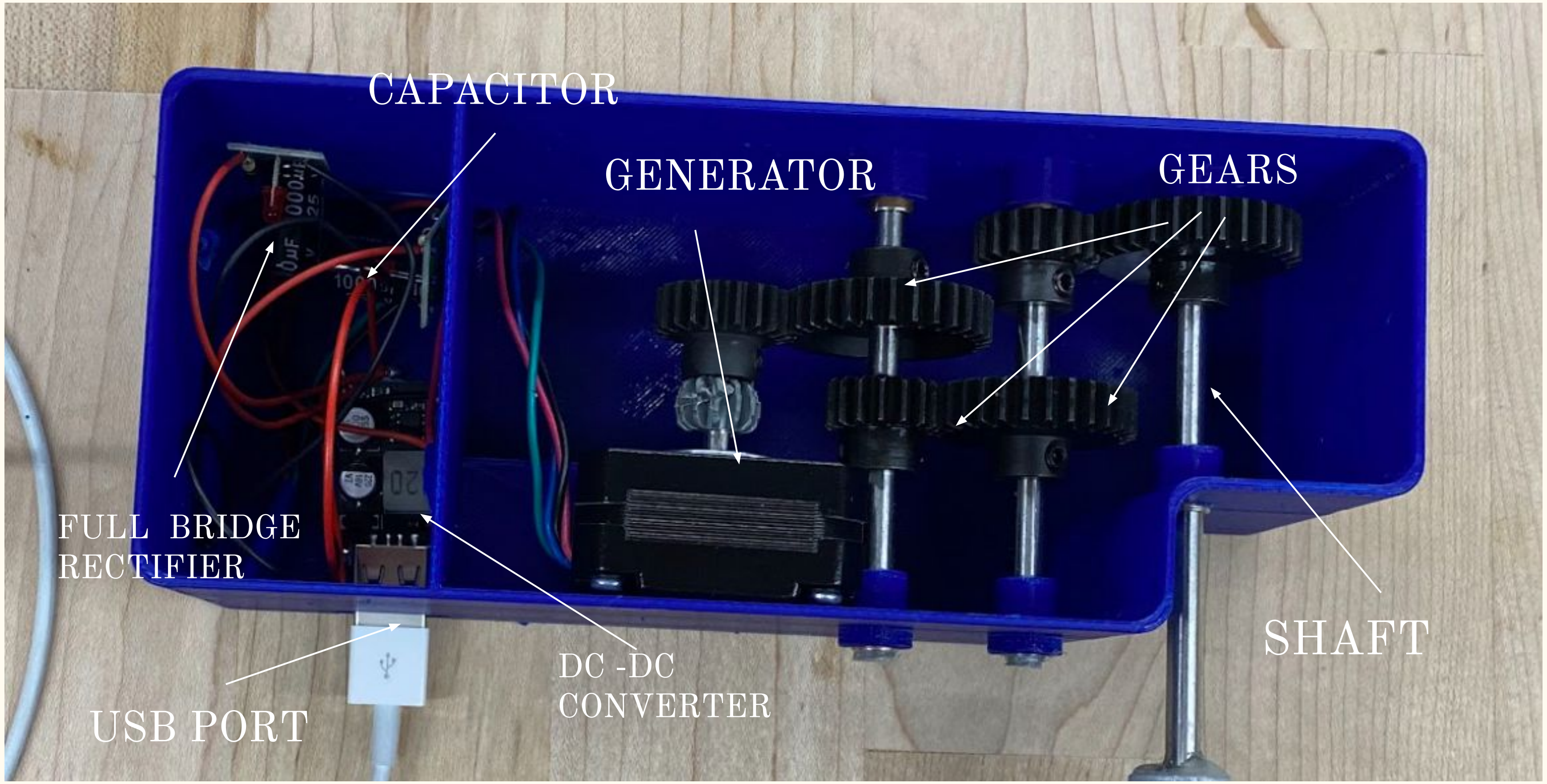
- This design is has minor changes to adjust motor position and reduced dimensions

- Added hole in wall to run wires through

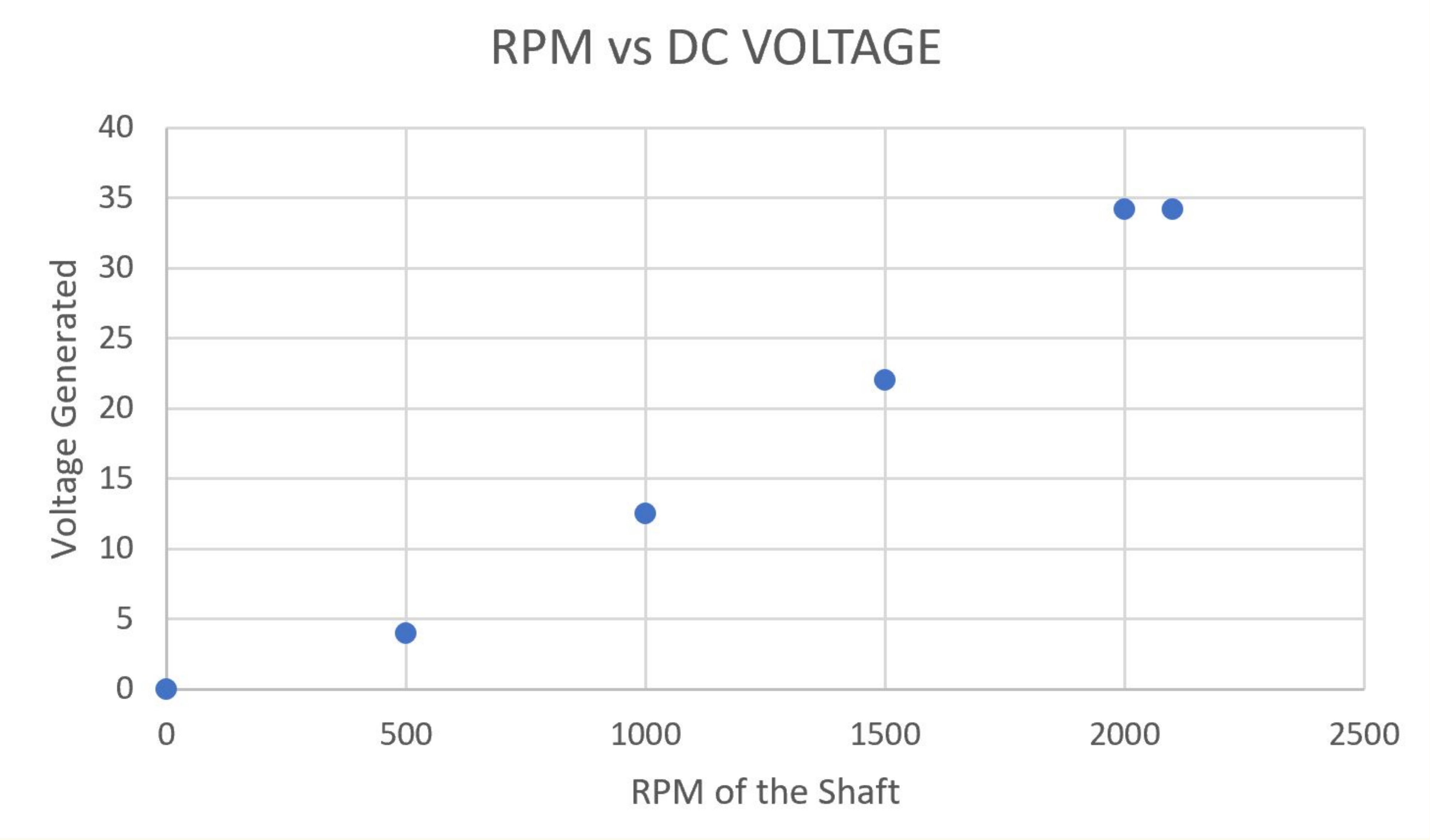
- Final Dimension: 180 mm X 74 mm X 63 mm



Updated Design



TOTAL VOLTAGE GENERATED BY METAL GEARS



Testing

Test	Procedure	Cost	Time
Ergonomics	Test comfortability of the brace with the generator mounted to see if the design is efficient	N/A	8 hrs
Power Output	The velocity of the wearer on a treadmill and the power generated as a result would be measured and evaluated by hooking up a multimeter to the output	N/A	3-5 hrs

Safety and Durability	The device would be dropped from a knee height to observe its endurance against high impacts. Also, the device would be subject to a stream of water to observe it’s water resistive capabilities.	May be high if certain parts fail to pass the test	Less than 1 hr
Low Weight	Worn during activities like squatting, running and crouching to see if it performs any negative mechanical work and would be compared to reference	N/A	3-4hrs

ERGONOMICS

- Design weighs about 350 grams and is attached to the metal support with the straps from the knee brace to keep it steady
- Looks bulky but since it doesn’t weigh much, wearer gets used to the feeling and doesn’t hamper their natural movement
- Does not hinder natural flexibility

Comfortability Test

Test 1: Wear the knee brace by itself for about 8 hours

Test 2: Wear the brace with the generator for about 8 hours

Test 3: Within those hours, let the wearers walk, jog and run as they do normally and get an overall experience rating

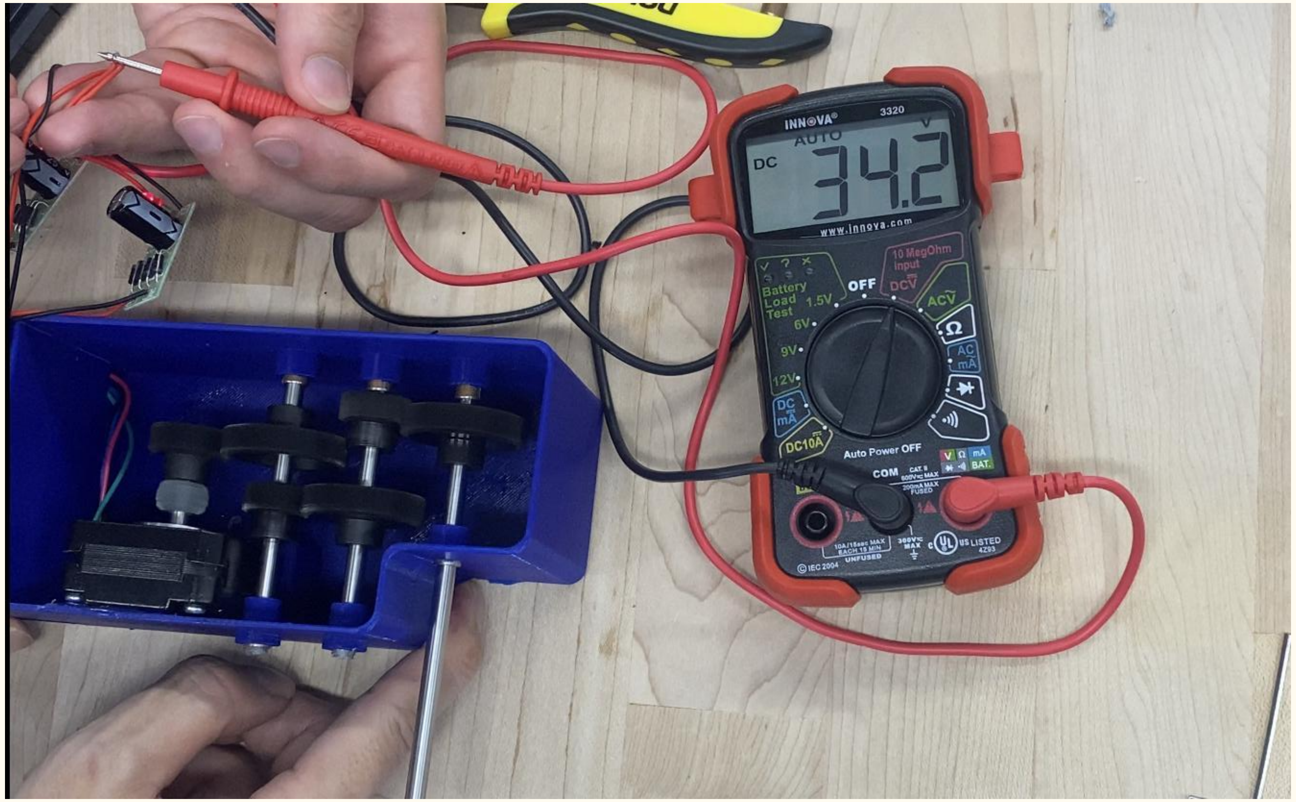
Test 4: Rate the experience from a scale of 1-10

CONCLUSION: After testing the comfortability within our group with a sample size of 5, the overall score for comfortability was 7.9/10.

POWER OUTPUT REQUIREMENT

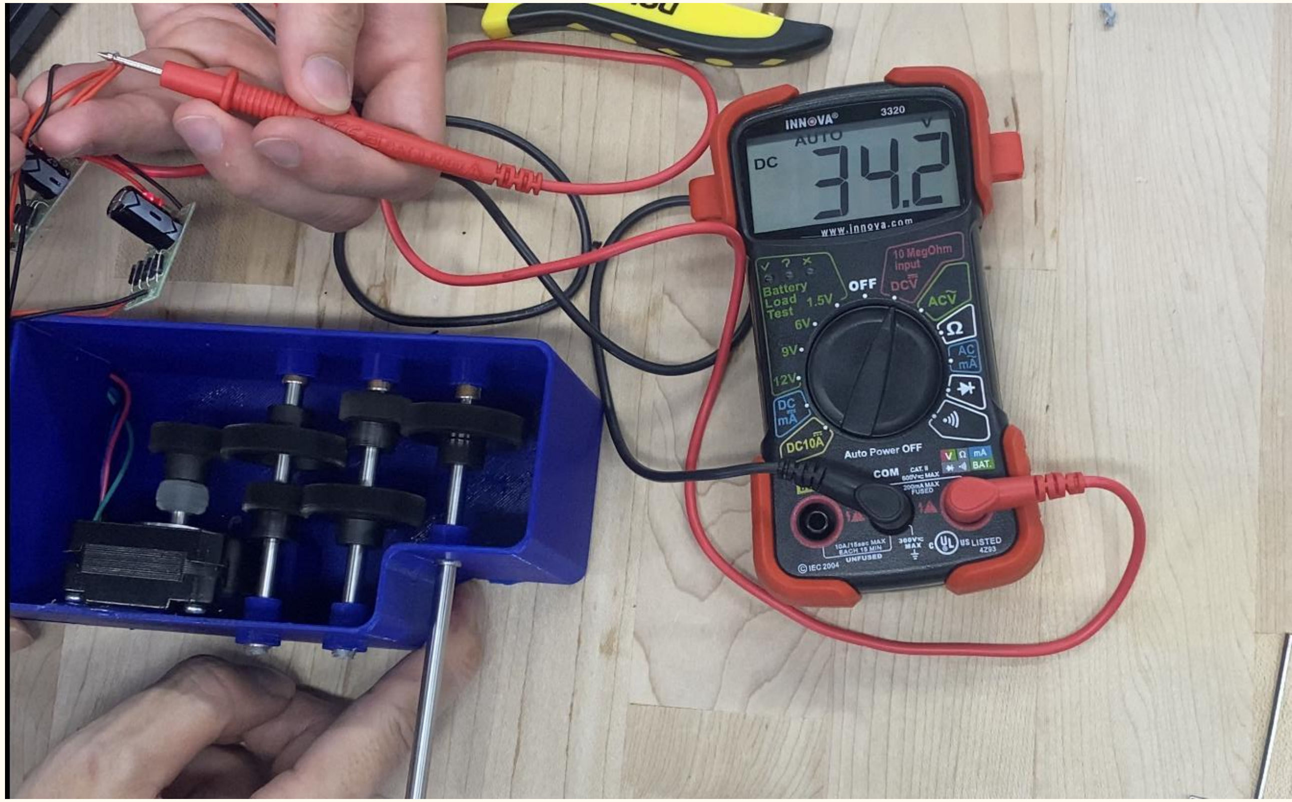
- The minimum voltage and current required to charge an iphone is 5 volts and 500 mA. Any current less than 500 mA is undetected by the phone itself.

- This means that our minimum power output needs to be at least 2.5W (Power = VI)



MAX POWER OUTPUT

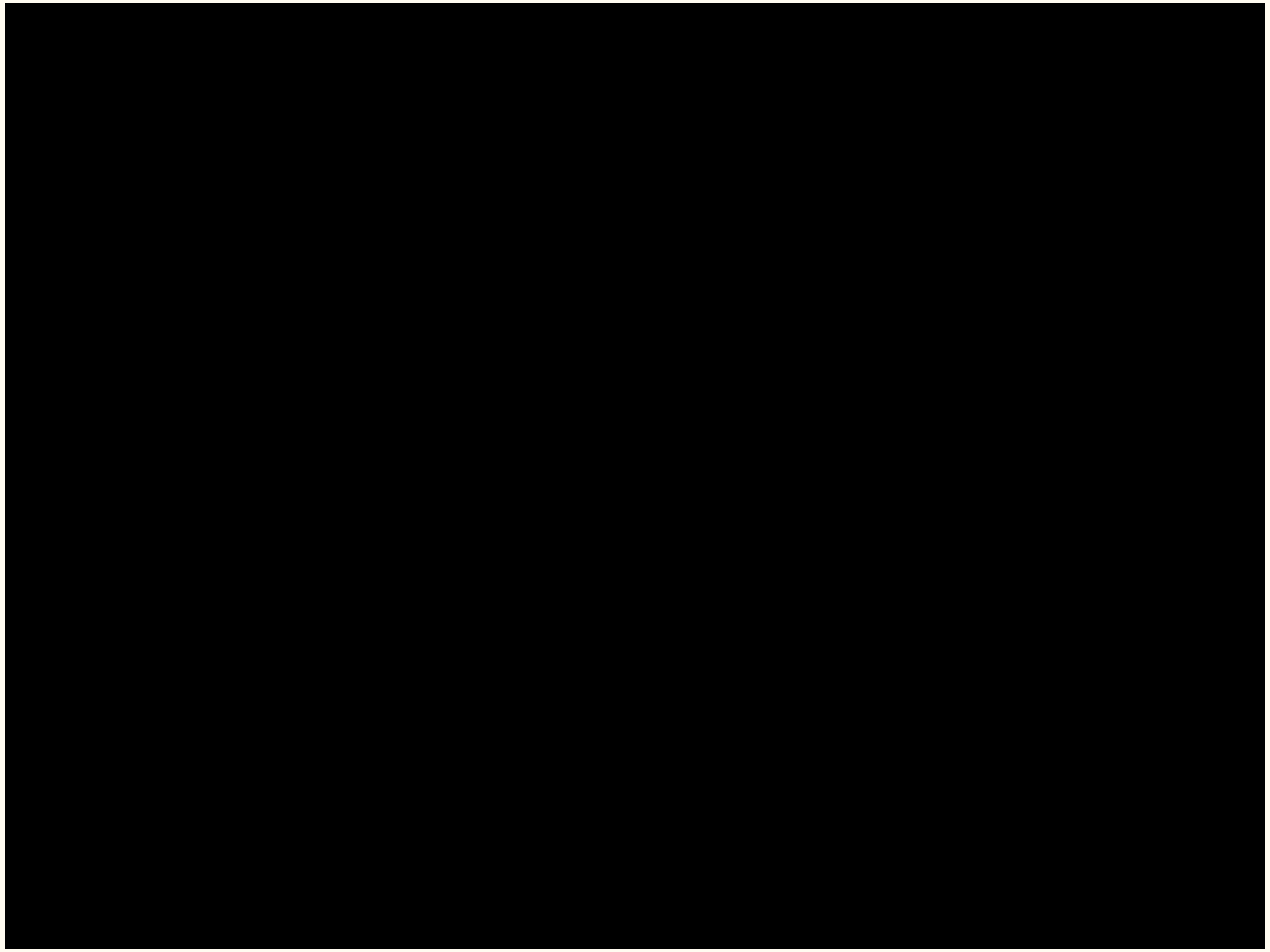
- used a drill to simulate rotation of shaft
- rpm for the drill was 400 and gear ratio was 1:5, the motor at about 2000 rpm was generating a max 34.2 Volts and 1.4 A
- power output using drill was 48 Watts, after all the losses through friction, gears and full bridge rectifier (which is max 80% efficient).
- We would use this number to estimate power outputs at lower RPMs (knee rotation)



POWER OUTPUT FOR OUR FINAL DESIGN

- Shaft slid on 1-way bearing so didn’t work as a 1-way bearing. Hypothesized this was because the weak shaft bent and caused resistance beyond limit of the 1-way bearing
- necessitated replacing the 1:60 plastic gear train with aluminum shafts and steel gears with a new ratio of only 1:5 and no 1-way bearings
- power gen is only in one direction and produces ~5Wwhen cranked by hand which is enough to charge a cell phone.
- We estimate that by using knee rotation of ~30 rpm we would get about 2W if harvesting from one direction or 4W if we utilize both directions with one-way bearings

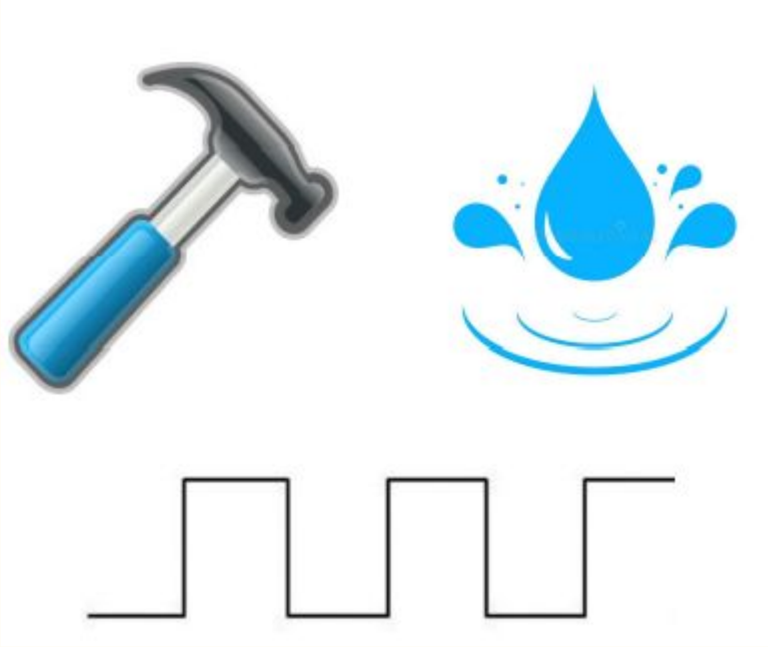
PRODUCT DEMONSTRATION



SAFETY AND DURABILITY

- The motors and gears are held inside a strong housing box with fillet edges to reduce the stress and eliminate sharp corners to avoid accidents.

- The gears are also placed securely inside a cylinder extruded from the walls of the housing so it is fixed in place and does not fall off if dropped from a certain height.



Cost Requirement

- Total cost of materials and testing cannot exceed $500

Cost Analysis

- We met our budget requirements, with $95 to spare!

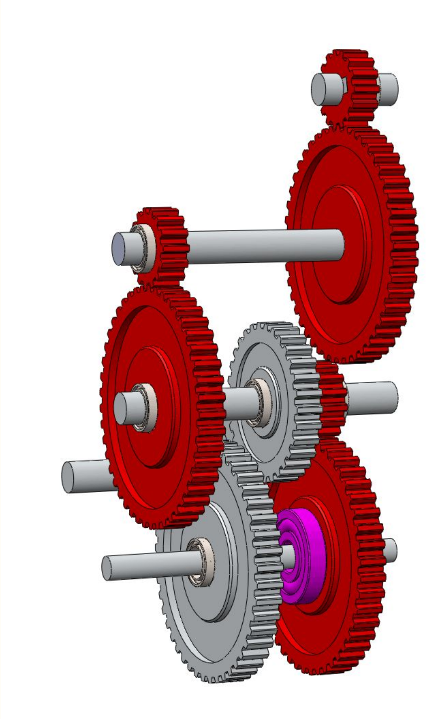
Items	Amount	Price
Knee brace	1	$69.99
Gears	10	$20.00
Capacitor	2	$0.50
Bridge rectifier	2	$0.40
One- way bearing	2	$15.00
DC-DC converter	1	$9.39
DC brushless motor	1	$74.99
Stainless shaft	5	$10.00
	Estimate total cost	$404.17

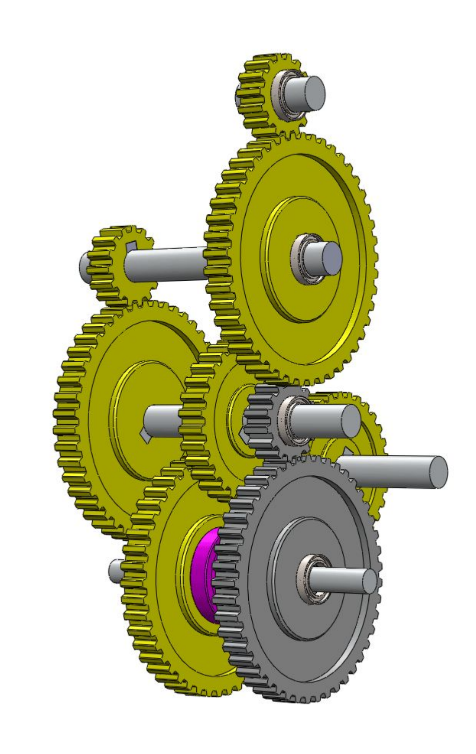
What did we learn?

- How to take a project from a concept to implementation and testing
- Think creatively within a budget
- How to work as a team
- 3D printing
- Hands-on manufacturing
- Troubleshooting issues
- Electrical circuit building
- Soldering and wire trimming skills

FUTURE IMPROVEMENTS

- Increase the total gear ratio to efficiently convert the high torque at the knee into high speed for the generator.
- Place stronger one-way bearings into the bottom gears so that the system can harvest more energy from both the swing and stance phases in gait cycles.
- Use the plastic-metal compound gears to keep the strength & wear resistance, and reduce the product weight.





How would we turn this into a commercial product?

- Troubleshoot power generation issues and resolve them by carefully testing for power output
- Make any necessary changes to the design and remanufacture a final working prototype
- Pitch our concept to multiple Venture Capital (VC) firms to obtain more capital
- Use the capital to create many more identical prototype devices
- Obtain user feedback from beta testing and make necessary design changes
- Advertise the product on social media and internet
- Make the parts mass production ready
- Create custom PCB boards for the electrical circuits
- Find a manufacturing facility and an associated distribution center
- Sell the product on the market!

Thank You!

seniordesign473.wixsite.com/group5