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NMSBA – Twist Resist: Final Report

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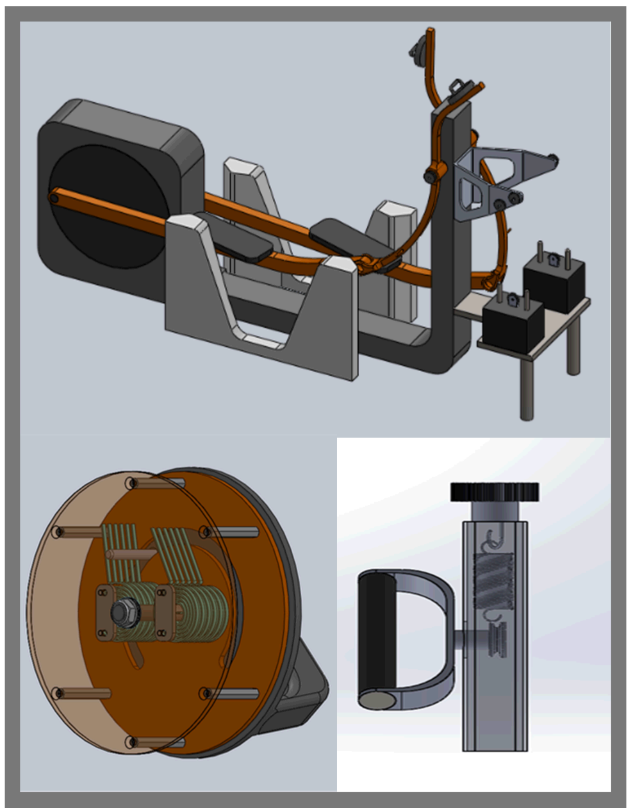
New Mexico Small Business Assistance Program

Company: Twist Resist

Project: Rotational Exercise Module



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Acknowledgements:

We would like to thank the NMSBA Program Office, and Twist Resist, for their collaboration on this project.

1 – Project Overview:

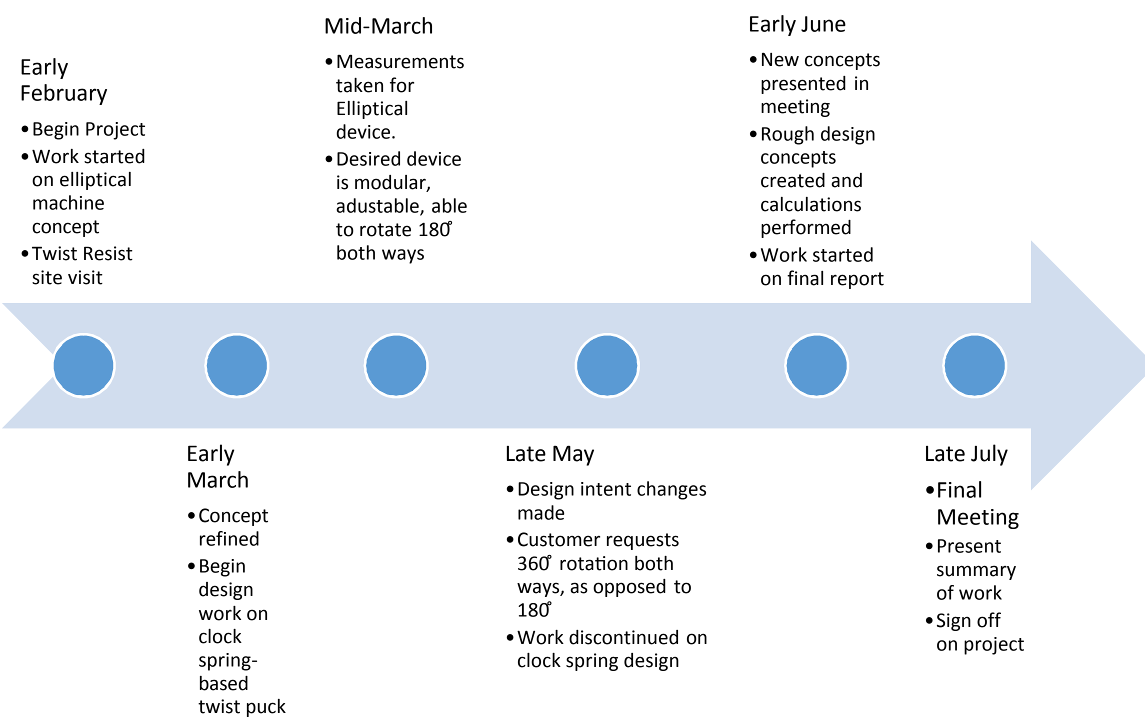
1.1 - Introduction:

This report contains a summary of the work completed to develop a modular, rotational exercise device. In the report are images, diagrams, and explanations of the efforts contributed to the project since its inception. The purpose of this document is to provide a walk-through of the progress on this project, from the initial design concepts to the final design and work done, so that the customer (Twist Resist), or individuals/firms who work on this project in the future will have a springboard of ideas/concepts to work from.

1.2 – Statement of Work

Sandia National Laboratories will provide design consultation and support with mechanical design of cardio exercise equipment. Deliverables will include a report documenting the work done by SNL, which may include design input, sketches, and mechanical drawings.

1.3 - Timeline:



2 – Design Concepts:

2.1- Elliptical Machine Addition

At the beginning stages of the design project, the objective was to introduce adjustable resistive rotation at the foot and hand positions of an elliptical trainer. At the foot position, a limited amount of rotation was desired in order to allow the natural rotation of the hip, knee, and ankle. At the hand position, 180 degrees of clockwise and counterclockwise rotation (360 degrees total) was desired to allow the natural rotation of the shoulder, elbow, and wrist.

The low level design concepts below were a product of this initial design effort. In Figure 1, a traditional rear drive elliptical trainer is fitted with a weighted cable and pulley system, similar to the current Twist Resist machine, in order to provide resistive rotation at the hand positons. Additionally, cam blocks (silver) mounted to the side of the elliptical act as guides for the rotation of the foot pad assembly shown in Figure 2. The foot pad assembly utilizes opposing springs for resistance and self-centering. However, there is no mechanism for resistance adjustability.

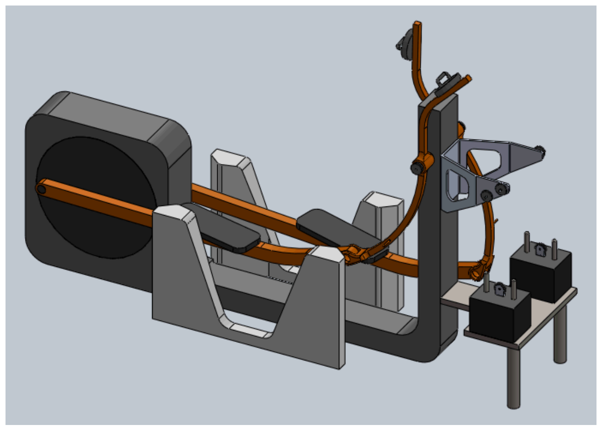


Figure 1: Initial design concept showing a weighted cable and pulley system for rotation at the hand position and a guided foot pad system for rotation at the foot position

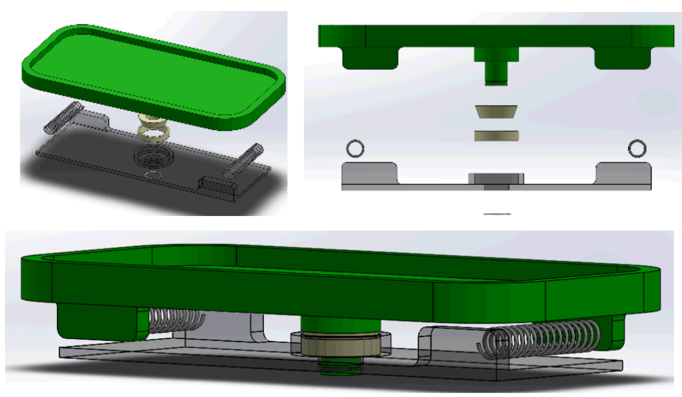


Figure 2: Foot pad assembly utilizing opposing compression springs to provide rotational resistance and self-centering; there is no current mechanism for adjustable resistance.

2.2– Twist Puck (Clock Spring System)

In response to the concepts above, focus was switched to a modular design that could function in both the hand and foot positions and also be used in applications beyond an elliptical. The resulting design consisted of a self-contained unit that houses two stacks of clock springs where one stack is engaged during clockwise rotation and the other stack is engaged during counterclockwise rotation (this unit will be referred to as the resistance puck).

In the Figures 3-6, the design is shown. The frame of the resistance puck consists of circular base plates spaced two inches apart. A shaft that is coupled to a handle or foot pad runs through the base plates and is fastened by a nut on the backside. Clock springs are mounted on studs protruding from the rear base plate. The front base plate has a circular slot that allows clearance for a cylindrical adjustment mechanism when the handle or foot pad is turned. To provide variable resistance, a selected number of clock springs can be engaged by this adjustor mechanism, which is housed in the handle and adjustable in length. The mechanism for length adjustment was not deeply explored but ideas of a telescoping mechanism with detent pins or a threaded assembly were considered.

To account for a greater weight-bearing requirement at the foot positions, the slot in the front plate was shortened (Figure 7). This was initially not an issue since the amount of necessary rotation at the foot was small. In Appendix A, basic stress and displacement simulations are provided for the front and rear base plate based on a 250-pound user.

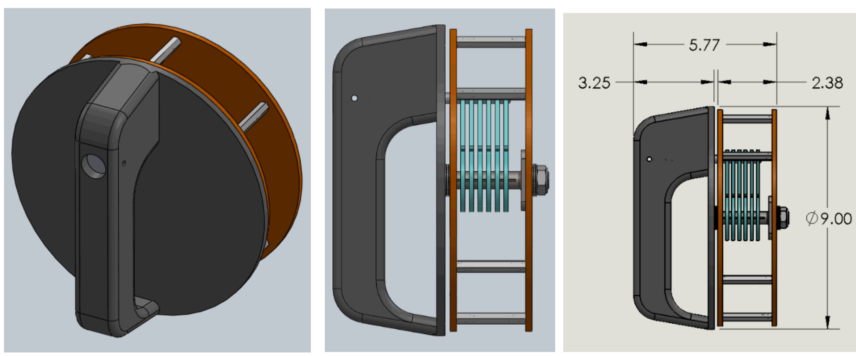


Figure 3: General views of the resistance puck (clock springs = light blue; base plates = orange)

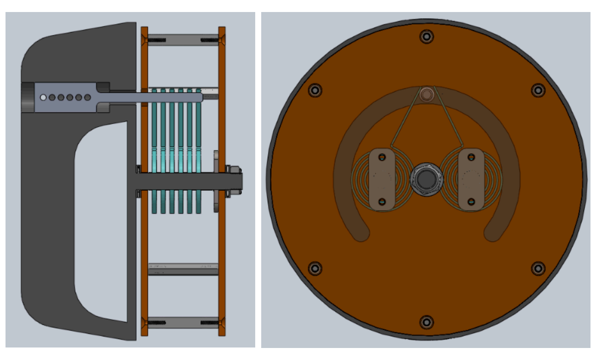


Figure 4: Section view of the resistance puck showing the adjustor mechanism (light gray) and back view of the adjustor mechanism and clock springs (light blue)

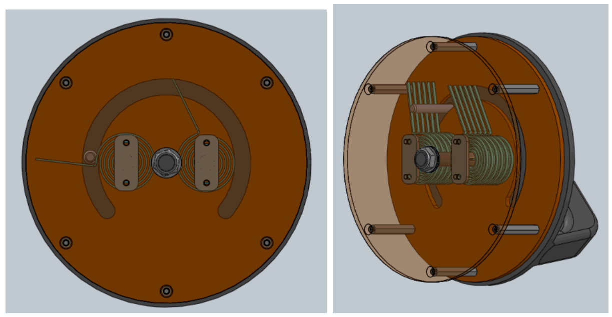


Figure 5: Back and perspective views of the resistance puck with the clock springs (light blue) engaged

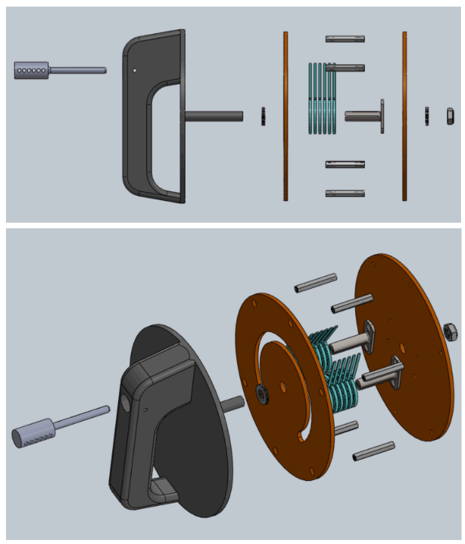


Figure 6: Exploded views of the resistance puck

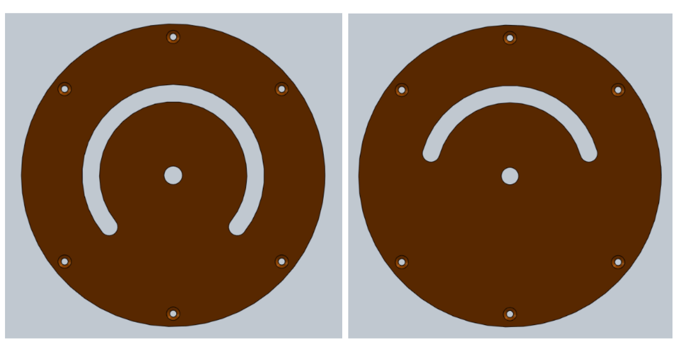


Figure 7: Front base plate for the hand position (left) versus the front base plate for the foot position (right)

After presenting the above intermediate designs, it was desired to combine the separate hand and foot units into a single unit and provide 180° of rotation in a clockwise direction and counter-clockwise direction, resulting in a total rotation of 360°. To accomplish this, the rear base plate and shaft were redesigned. The shaft was increased in diameter in order to be installed in a single shear configuration and the rear base plate became the load bearing plate versus the front base plate in earlier designs. A front ring remains so a cover can be installed around the clock spring stack assemblies. The redesigned assembly is shown in Figures 8 and 9.

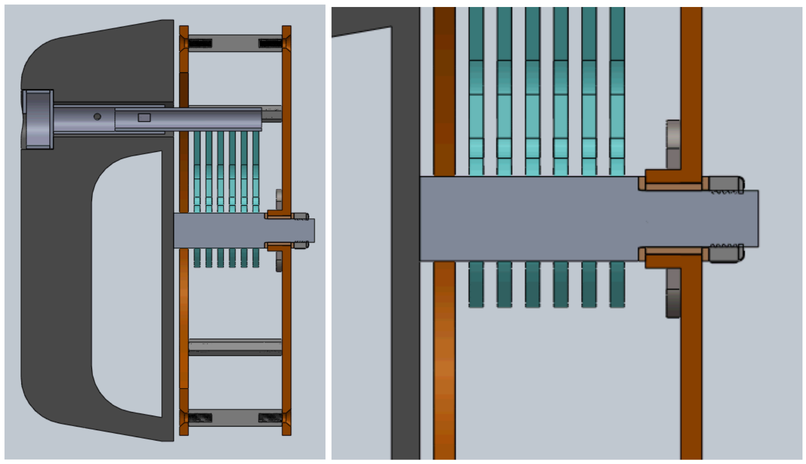


Figure 8: Section view of the resistance puck showing the redesigned shaft and bearing assembly

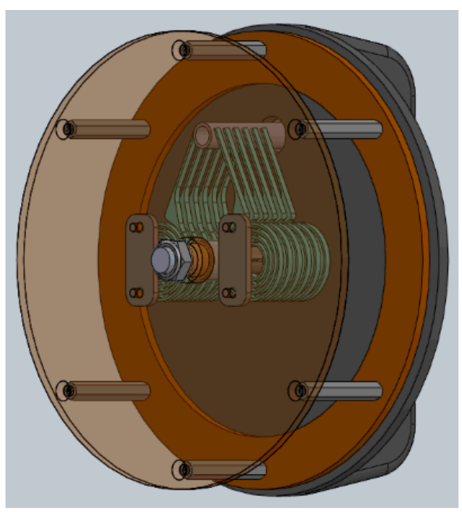


Figure 9: Perspective view of the resistance puck showing the new front plate that allows 180° of clockwise and counter-clockwise rotation

2.3– Two-way Screw Mechanism

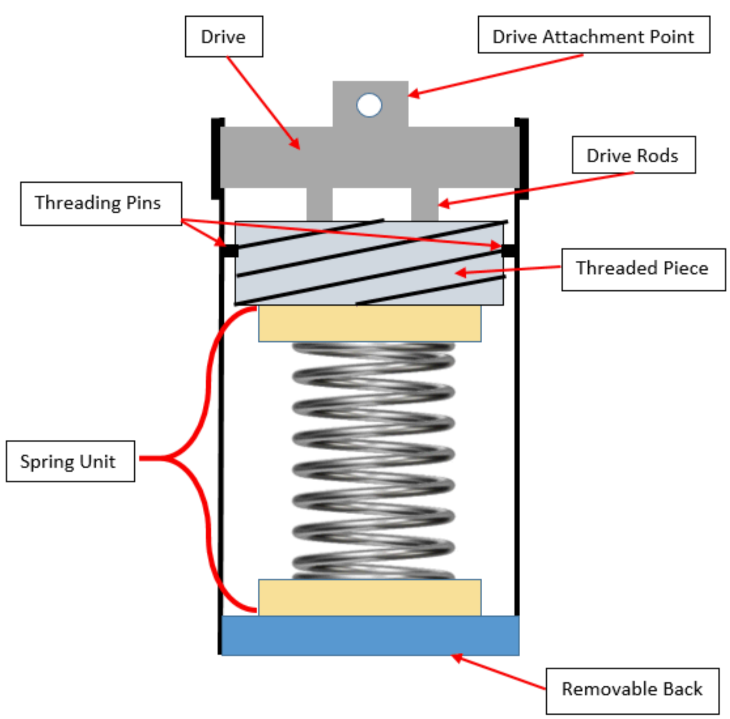
After some meetings and discussion, design efforts on the clock spring puck were discontinued, due to customer request to have the system rotate 360° in both directions, for 720° of total rotation. Due to the design of the puck, this was not possible, leading efforts to explore new design concepts. Due to the need for a major design overhaul late in the project, time was focused on developing several concept ideas for consideration by the customer, as a detailed final design on a single concept was not achievable. Sections 2.3-2.4 of the report will explain the work completed on these concepts.

The first of the new concept designs is a two-way screw mechanism (pictured below). In this system, drive rods rotate a threaded screw piece which compress a spring. This threaded piece slides up and down the drive rods as it moves up and down, meaning the user's hand can stay at the same height throughout the rotation. The threaded piece (see diagram) will be threaded in such a way that, from the very top of the threads, it can be rotated either way yet still compress the spring. In order to achieve this, the threads will have to go opposite directions on this piece.

Although this piece will feature complex geometry, it may be possible to get this system to work.

The major advantage of this type of design is that springs are easily interchangeable, allowing resistances to be easily changed. In addition, there could be some sort of pre-compression of the spring, allowing even more adjustability.

The major drawback of this setup is the threaded piece, which will be a custom part and will have a complex thread profile. This part will either need to be machined to high precision or



possibly injection molded with high-strength plastic (although use of plastic may result in a wear item that needs replacing).

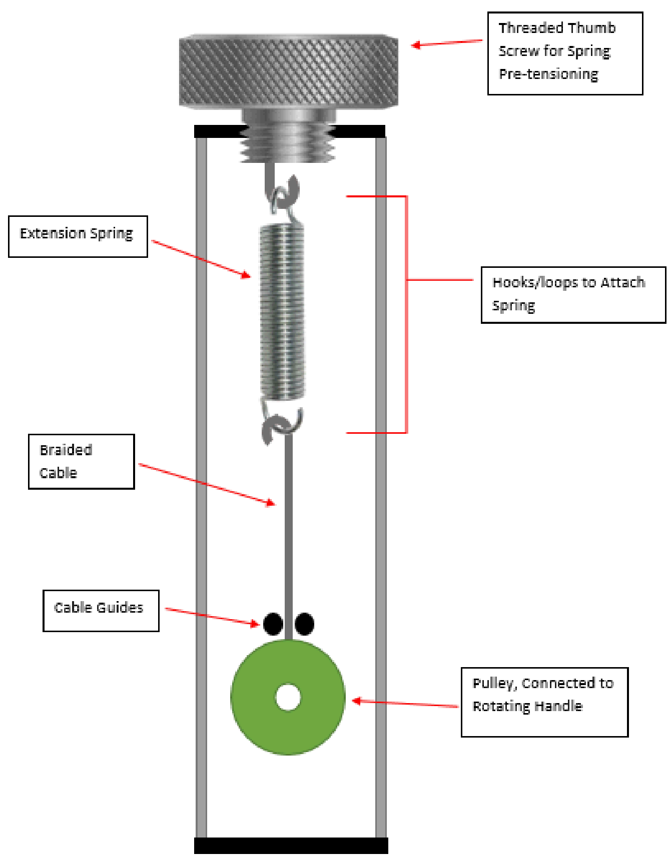
2.4 – Pulley-Spring Mechanism

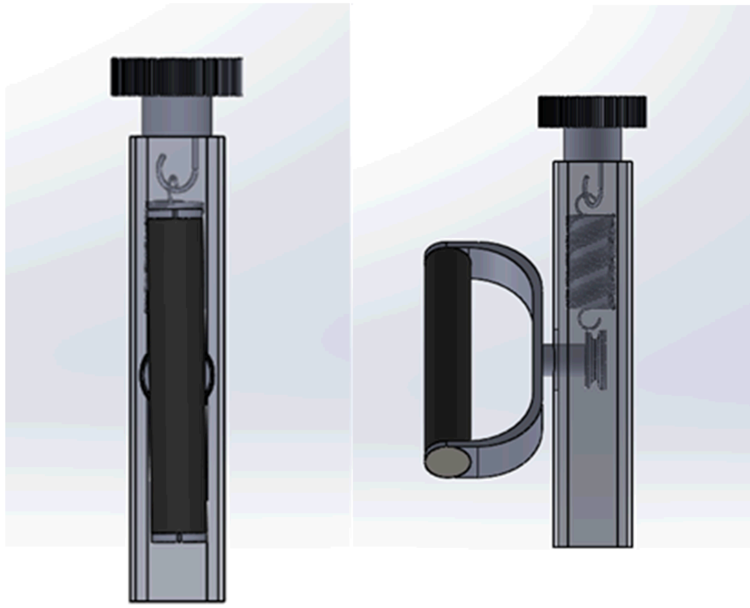
Another option for 360° rotation in both directions is a pulley-based mechanism with an extension spring. In this system, the user rotates a handle or some kind of attachment which is attached to a drive rod. This rod rotates a pulley, which is attached to a cable. This cable, when wrapped around the pulley, causes the device's spring to extend.

To modify the resistance of the device, a threaded thumb screw is connected to the extension spring. The user can unthread this screw to pre-extend the spring and increase the resistance.

A positive aspect of this design is its relative simplicity. It is likely that it can be prototyped mostly with off the shelf parts. In addition, the final product will have a fairly small amount of moving parts, increasing reliability.

One thing to note is with this mechanism, the total amount of rotation will be a little shy of 360° both ways, due to the use of a pulley with only one track.





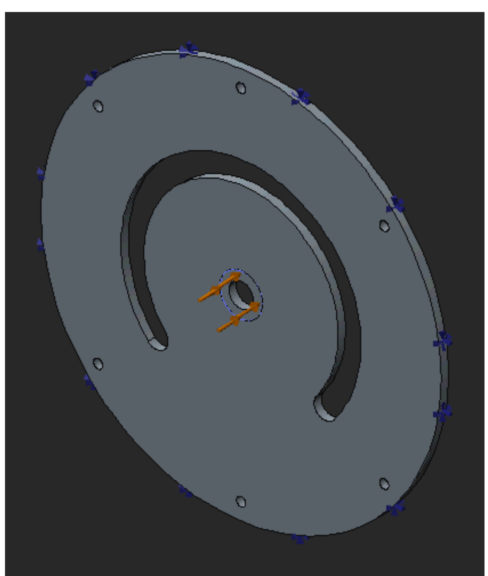
3 – Conclusion:

Throughout the course of the project, ideas and concepts have changedgreatly, eliminating the ability to provide one refined final design with this batch of funding. However, the completed design work and the concepts created should provide a starting point for further work on this project, hopefully leading to a working prototype with a minimal additional effort.

APPENDIX

A) Clock Spring Puck Finite Element Analysis (FEA) Results

In the figures below, simple static FEA methods are applied to the hand and foot front base plates for the initial intermediate designs. Further, the same methods are applied to the rear



base plate for the revised 360° intermediate design. To simulate a standard pushing load on the front hand base plate, a 50 pound load is applied at the center bearing surface and the outside face of the base plate is fixed. Additionally, to simulate a worst case scenario a 250 pound load, equivalent to a 250 pound individual standing on one foot, is applied at the center bearing surface of the front foot base plate and the rear 360° base plate and the outside faces are fixed. To determine safety factors (SF), common 6061-T6 aluminum with a yield strength of 40 ksi was used.

Figure A1: 50 pound load (orange) and fixed constraint (blue) applied to the front hand base plate

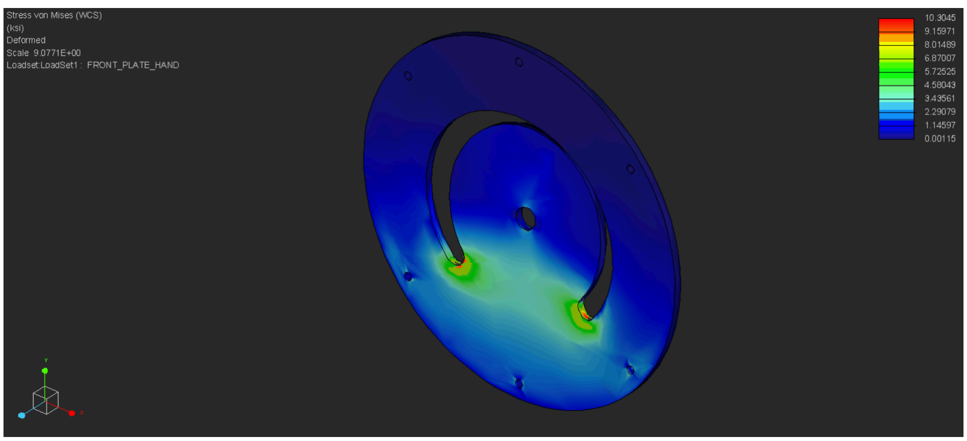


Figure A2: Deformed image showing the stress distribution in the front hand base plate under the applied load (maximum stress = 10.3 ksi; SF = 3.9)

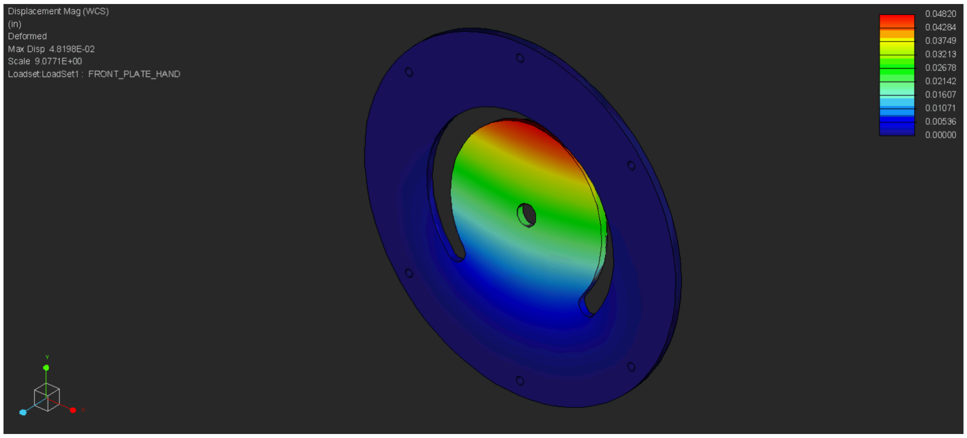


Figure A3: Deformed image showing the displacement in the front hand base plate under the applied load (maximum displacement = 0.048”)

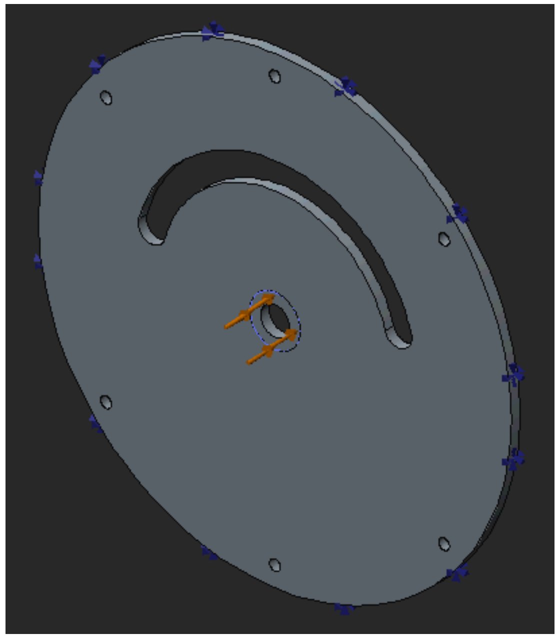


Figure A4: 250 pound load (orange) and

fixed constraint (blue) applied to the

front foot base plate

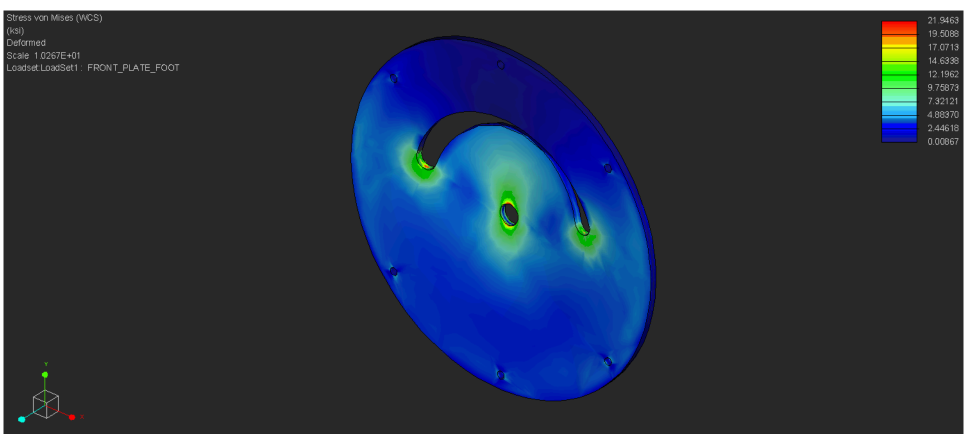


Figure A5: Deformed image showing the stress distribution in the front foot

base plate under the applied load (maximum stress = 21.9 ksi; SF = 1.8)

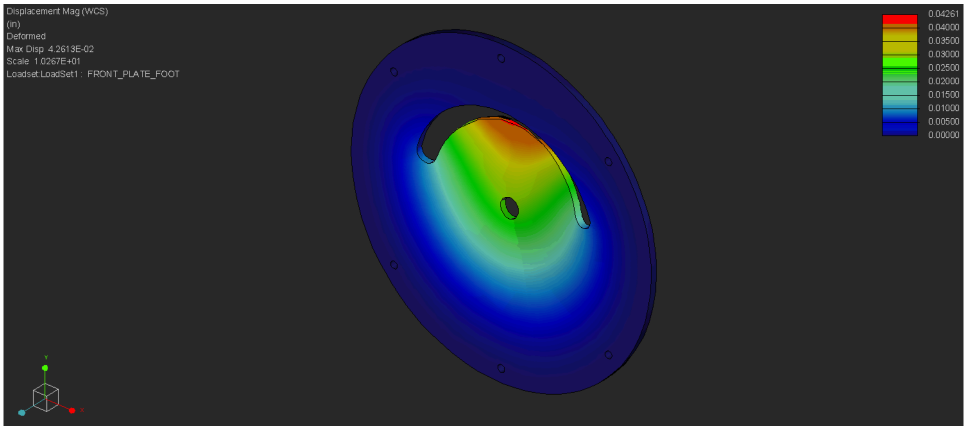


Figure A6: Deformed image showing the displacement in the front foot base plate under the applied load (maximum displacement = 0.043”)

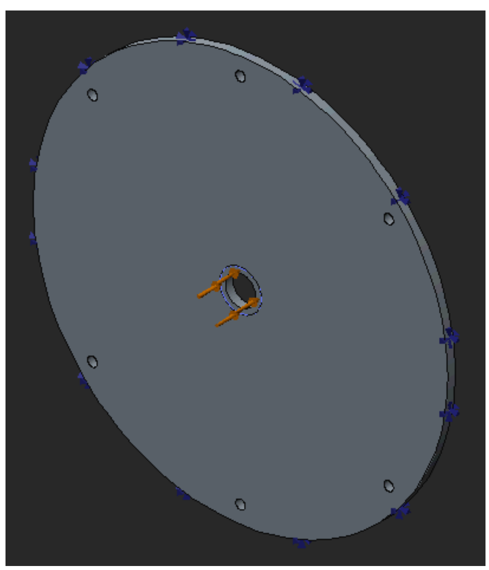


Figure A7: 250 pound load (orange) and fixed constraint (blue) applied to the 360° rear base plate

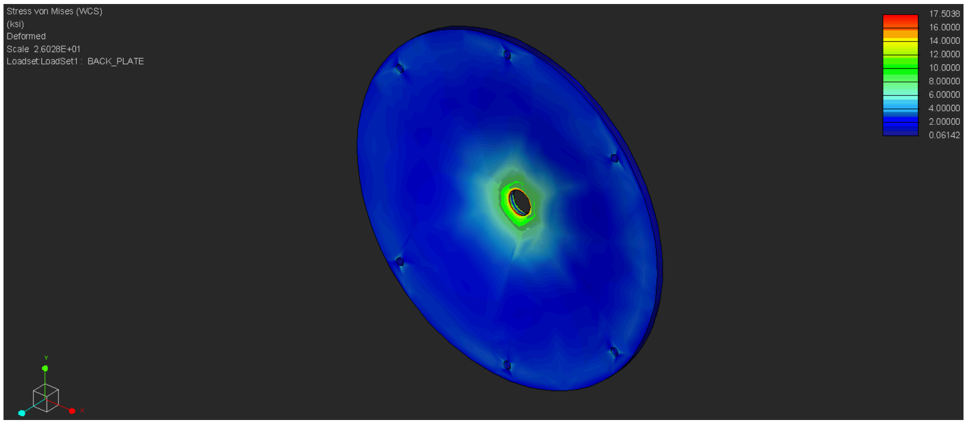


Figure A8: Deformed image showing the stress distribution in the 360° rear base plate under the applied load (maximum stress = 17.5 ksi; SF = 2.3)

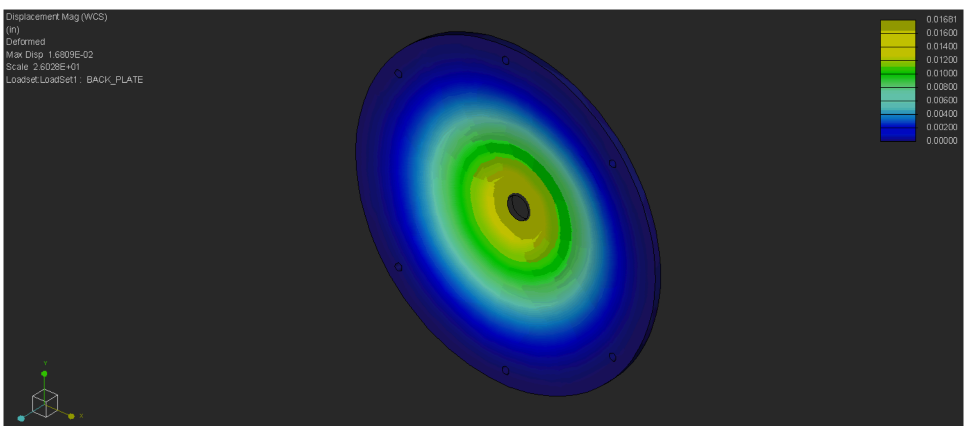


Figure A9: Deformed image showing the displacement in the 360° rear base plate under the applied load (maximum displacement = 0.016”)

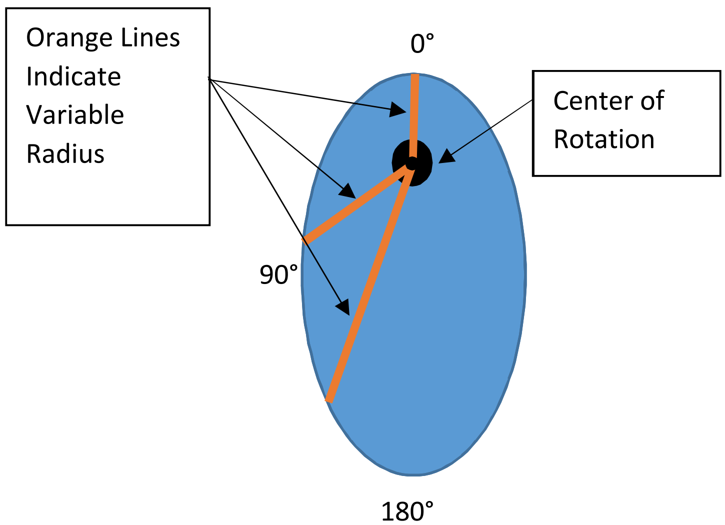
B) Correcting Spring Force to be Constant

Because of their inherent nature, springs provide a resistance which varies constantly as they extend or compress. This increase is linear and can be measured by the formula F=K*X where F= force, k=spring constant, and x=distance extended. In an exercise machine, this change in force is not ideal.

In order to combat this variance in force, a system such as a variable-radius pulley (for extension springs) or a variable radius cam-based system (with compression springs) can be utilized. In order for this to be effective, the radius of the pulley must increase linearly with the degree of rotation. By varying the radius of the pulley/cam, the mechanical advantage the user has over the spring will increase as they make the rotation, cancelling out the increase in force created by the spring.

With a system such as this, the user will be able to set and maintain a constant resistance from the beginning of the rotation, making the system function comparably to weight stacks in conventional exercise equipment.

An example of how this could be achieved is shown in the image below:



In order for this variable radius pulley/cam design to work, four conditions must be met:

1. The maximum amount of rotation cannot exceed 180° in either direction.
2. The radius of the pulley/cam must increase linearly from the 0° point to the 180° point (see picture).
3. The pulley/cam needs to be symmetrical across the vertical plane (left and right sides must be the same).
4. The design must include a stop or other way to prevent the user from executing more than 180° of rotation in any given direction.

Pros/Cons:

- Pro: This design would make the device much more effective and seamless to use

- Con: To completely correct spring force increase, the pulley/cam radius at the end of the 180° rotation will be many times the radius at the beginning. This could be difficult to execute within a small, modular package.
- Con: A variable radius pulley/cam such as this is, without a doubt, a custom part. This could prove to be cost-prohibitive.