Finalized Testing Plan – 486C

Design Requirements Summary

The team has a total of 10 design requirements, 5 engineering requirements and 5 customer requirements. Two of the customer requirements are about adjustability. The design should allow for adjustable torque and zero angle. The torque adjustment will allow a wider range of users to comfortably use the design. In this design "zero angle" or "neutral angle" refers to the angle that is formed between the flat of your foot and your shin. For zero angle adjustment the client wants the design to be able to adjust where the springs apply no force to the ankle. The other three customer requirements include durability, comfort, and high torque output. The 5 engineering requirements are directly related to the customer requirements. The engineering requirements include two adjustability requirements that directly reflect the customer requirements and one requirement related to the range of motion. There is also a minimum durability requirement of 10,000 running steps and a torque requirement of 30 Nm. Each design requirement is shown in the table **Error! Reference source not found.**.

Table 1: Design Requirements

Customer Requirements	Engineering Requirements
CR 1 – Adjustable Torque	ER 1 – Adjustable torque TBD
CR 2 – Durable	ER 2 – Minimum durability of 10,000 running steps
CR 3 – Adjustable Zero Angle	ER 3 – Adjustable neutral angle +/- 20 degrees
CR 4 – Comfortable	ER 4 – Range of motion of +/- 30 degrees
CR 5 – High Torque	ER 5 – Maximum output torque of 30 Nm

Top Level Testing Summary

The team will be performing two experiments. The first experiment is the leaf spring test and using a load cell the team determine the minimum and maximum force outputs from the springs. Using the force data, the team will then calculate the torque output at different settings. Experiment 2 is the cycle test experiment. The team will take turns wearing the design and cycle it for 10,000 running steps total. This test will measure the steps taken and it will document any wear that occurs throughout the test. During this test the team will also document what leaf spring lengths are used and so if any catastrophic failure occurs the team can estimate at what torque the design failed at. By catastrophic failure the team has defined it as a failure that would prevent normal operation of the design. The main goal of experiment 2 is to fulfill engineering requirement 1.

Table 2: Test Summary Table

Experiment/Test	Relevant Drs
Exp1	ER1, ER4, ER5, CR1, CR4, CR5
Exp2	ER1, ER2, CR1, CR2, CR3, CR4

Detailed Testing Plans

Experiment 1:

<u>Purpose</u>

Experiment 1 will determine the maximum torque provided by the leaf spring to determine if the torque provided by the spring will be sufficient to meet our design requirements. This requirement was loosely set at 30 Nm but will depend on further testing that will take place after our building is complete. We do not have a great model of the mechanical loses that take place in the system so it will be important to test this engineering requirement to ensure we are providing substantial assistance as well as improving our understanding of the mechanical system. This will also cover our test for range of motion because it will allow us to see if the device allows for enough movement as to not restrict normal walking. This target was set at +/- 30 degrees.

<u>Test Summary</u>

Equipment Includes:

- Load Cell: Measure input torque to device
- Vice: To clamp the device in place while the test is performed
- Mounting Plate: To have a solid clamping point for the vice
- Angle Sensor: To measure the angle of the angle at which the maximum assistance is achieved
- Laptop: Collect the data from the load cell and angle sensor
- Arduino and Amplifier Circuit: Interface with load cell and angle sensor
- Cable and Crimps: Attach load cell to lever arm

Measurements Include:

- Angular position of the joint
- Force output to the lever arm

Calculations:

- Torque applied at the joint

$$T = F \cdot r$$

(eqn 1.)

Many of the calculations were done in the design process to build a mathematical model of the so we have a good baseline of the test should tell us how close we are to reaching the theoretical torque output. This will be done by collecting the last data points gathered at the maximum deflection and showing that it either meets the engineering requirement or not.

Procedure:

(Similar tests have been conducted previously so I will source pictures of the setup, from a previous ME495L assignment, to show the intended use of these components)

Equipment Preparation:

The first step of this experiment is to calibrate our load cell to the range of 50 Nm. This will be done using the laptop, Arduino, and supporting circuitry to collect force outputs as calibrated weights are attached. A picture of the equipment in this configuration is shown below.

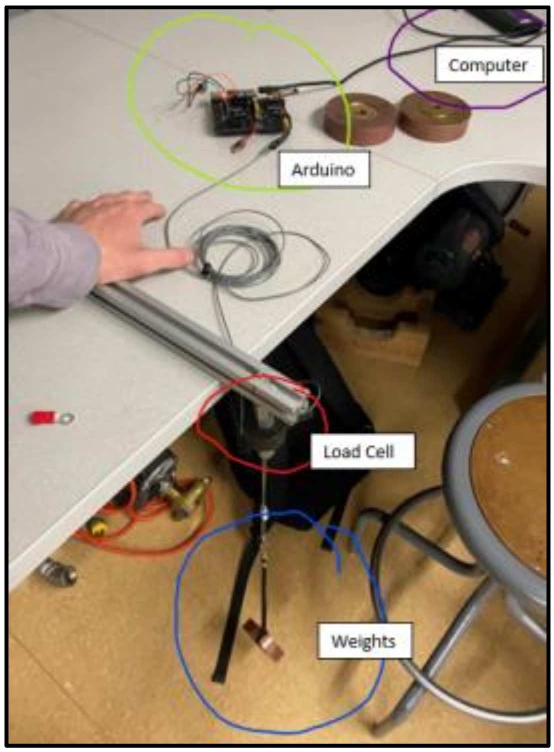

Figure 1: Load Cell Calibration

Experiment Setup:

The next step will consist of mounting the device to the vice using the mounting block and attaching the load cell to the marked lever arm. This can be seen in the figure below.

Figure 2: Experimental Setup the

Data Collection:

This step involves connecting the laptop to start the trial and pulling the load cell until the device reaches full deflection. This step will be repeated a minimum of three times at both the minimum and maximum adjustment points. The data collection interface can be seen below in figure 3.

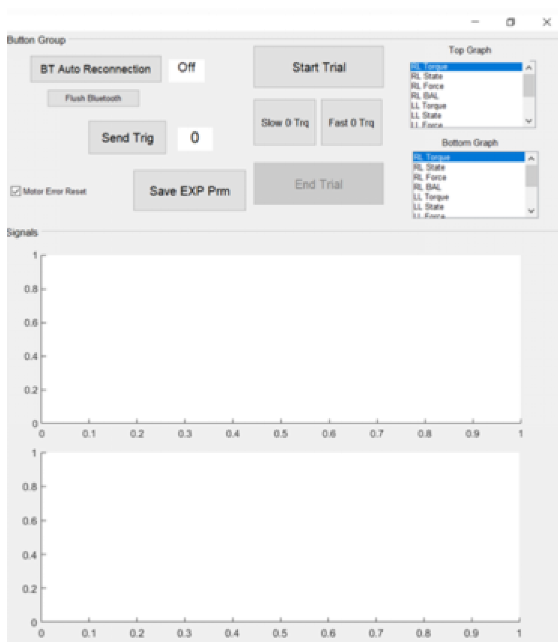

Figure 3: Data Collection GUI

Results:

We are looking for results that agree with our mathematical model and the engineering requirements set by our client. This includes the min and max angles of the spring deflection (+/- 30 degrees). A maximum torque output of 30 Nm. The minimum torque did not have a requirement because it is unknown what a good range is yet. The client just instructed us to have some level of adjustability. This will be tested later by our researchers and can be easily adjusted in the design. This value will be noted in the experimental results.

We have a MATLAB script that can generate plots of the expected outputs at different adjustment points. The plot below shows the results from the adjustment being set to the maximum output.

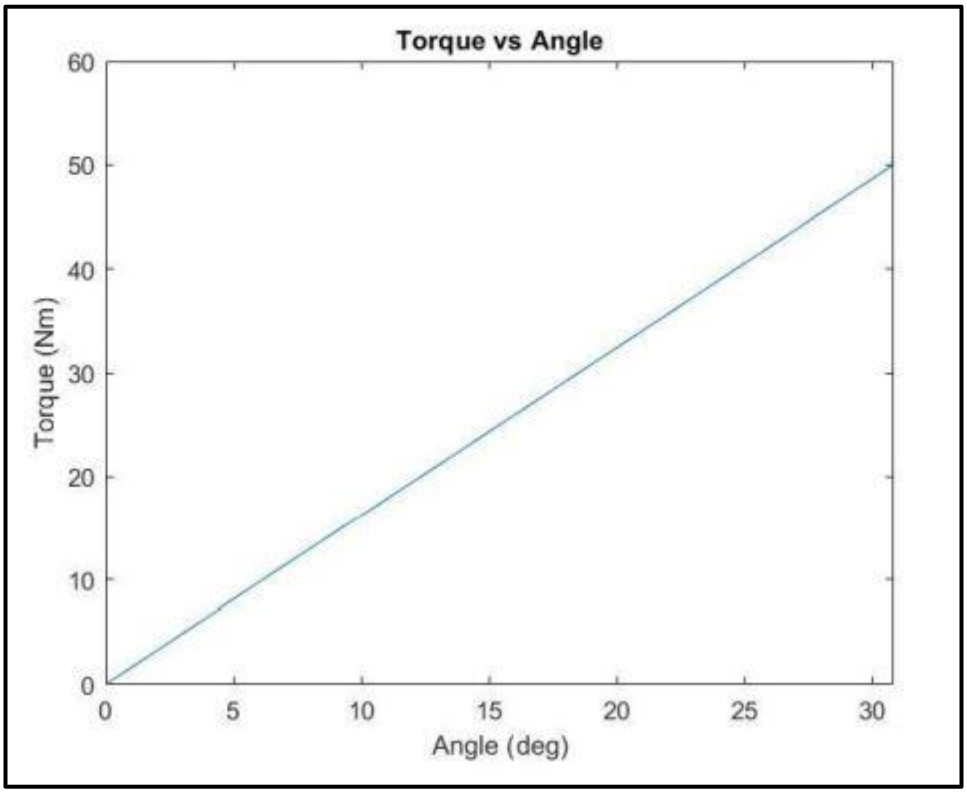

Figure 4: Torque vs Angle

This plot was generated using the equations

$$T = \frac{L^3}{3rEI\delta}$$

(eqn 2)

$$T = \frac{r}{\Delta\delta} \cdot \frac{180}{\pi}$$

(eqn 3)

Equation 2 was used to find the force output at a given deflection input in mm and equation 3 was used to convert that deflection distance from mm to degrees in our system.

Conclusion:

This experiment covers a lot of our engineering requirements in one set of data collection in a way that provides accurate and meaningful results. We have confidence that the system will meet the engineering requirements based on our system model but still expect there will be deviations and inefficiencies. Testing will inform future researchers on the work that is required by them as well as future engineers of improvements that need to be made.

Experiment 2:

Purpose

Experiment 2 will test the durability of the design and it will measure if engineering requirement 2 has been met. The design should take a minimum of 10,000 running steps according to engineering requirements. The team has FEA models of the design under static loads and the results have indicated that the system will meet the design requirements. However, this experiment will test the system under dynamic loads and confirm that the design will meet the requirements under real world conditions. This experiment will also allow the team to test the adjustable torque and adjustable neutral angle however during this test these systems will only be tested for quantitative information. The team was not given a required torque setting for the durability test so the team will split the testing into 3 parts. Each of the 3 team members will wear the AFO and adjust the torque so that it provides a comfortable level assistance. The goal is to have each team member test a different torque setting throughout the 10,000 steps.

Test Summary

Equipment Includes:

- Fully assembled design: Needed to test the durability
- Spring scale: Used to measure the springs effective length during testing
- Step counter (Apple Watch): Used to measure the steps taken
- Phone: To visually document the wear
- Laptop: To record data and experiment notes
- Hand tools: To adjust the neutral angle
- Volunteers: 3 different people to wear the design and test the different torque adjustments, this will be the team
- Adequate level space

Measurements Include

- Number of steps taken
- Leaf spring length

Procedure

Equipment Preparation

Before testing begins the team will print out and tape a scale to the assembly so that we can easily read the effective length of the spring during the experiment, the scale is from 75mm to 39mm. While this measurement can be used to calculate the torque, it will only be used for reference later.

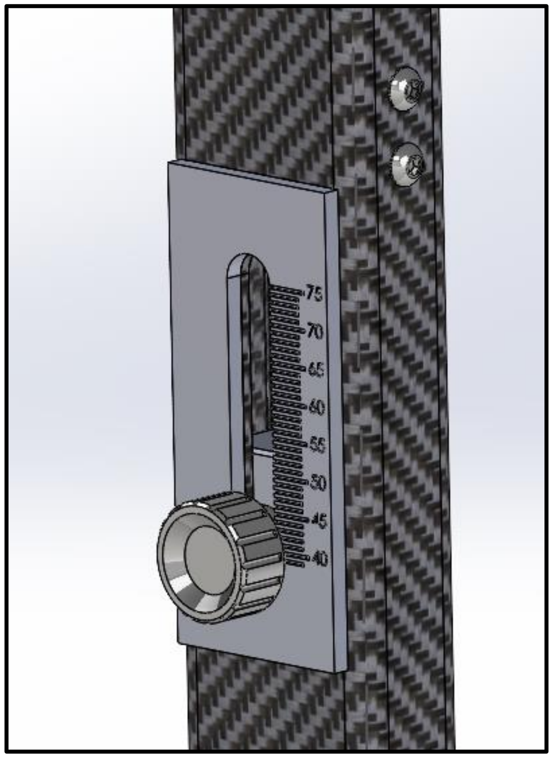

Figure 5: Leaf spring readout scale

Experiment Setup

After the scale has been attached to the assembly the team will then wear and test the device. The team plans to have the following testing order.

1. Adrian
2. Samuel
3. Jacob

The order is chosen so that the chosen torque setting increases from the previous tester. Each team member will wear the AFO and adjust the spring until it provides a comfortable amount of assistance. The team will record the leaf spring length using the scale and then the team member will wear the step counter. Photos of the assembly will be taken at the halfway point and at the end of each segment of the test. So, the first set of photos will be taken at 1,670 steps and the second set at 3,340 steps, and so on. A list of these steps is provided below. Each team member is going to test the AFO for approximately 3,340 steps, after which the next team member will repeat the above steps to complete the test.

1. Equip the AFO
2. Adjust the torque until it provides a comfortable amount of assistance
3. Record the spring length used
4. Run approximately 1,670 steps
5. Take photos of the assembly and document wear
6. Run another 1670 steps for a total of 3,340 steps
7. Take photos of the assembly and document wear
8. Remove AFO and the next person repeats the above steps

Data Collection

For this experiment all data collection will be recorded on a laptop or phone. The data will be collected from the spring scale, step counter, and phone.

Results

The team expects the AFO to experience some wear throughout the test, but it is expected that the AFO will not experience any catastrophic failure that would prevent it from operating normally. It is hoped that the design will function normally at the end of the 10,000 steps. The team will be collecting spring length measurements, but it is for reference unless catastrophic failure occurs. If failure does occur the team will be able to estimate what torque the components failed at, otherwise, the spring length data will only be for reference. The spring length measurements should ideally range from the higher torque settings to the lower torque settings.

Conclusion

Experiment 2 tests one of the more important engineering requirements that the client gave the team. By testing the design to 10,000 steps the team can test the designs durability and the team can get hands-on feedback by using the neutral angle and torque adjustments. The team aims to test the design with 3 different volunteers and as a result test the different torque settings. By the end of this experiment the team will be able to confirm if the design meets engineering requirements 1 and 2. This experiment will also verify the current FEA models and possibly improve future models.

Specification Sheet Preparation

Customer Requirements

Table 3: Customer Requirements Summary

Customer Requirement	CR Met? (Y/N)	Client Acceptable (Y/N)
CR 1 – Adjustable Torque		
CR 2 – Durable		
CR 3 – Adjustable Zero Angle		
CR 4 – Comfortable		
CR 5 – High Torque		

Engineering Requirements

Table 4: Engineering Requirements Summary

Engineering Requirement	Target	Tolerance	Measured/ Calculated Value	ER Met? (Y/N)	Client Acceptable (Y/N)
Change Spring Constant/Length	TBD through testing	TBD through testing	5 – 20 Nm		
High Fatigue Life	10,000 steps	0 steps	14,000 Steps		
Clutch-able Power Train	+/- 30 degrees	+/- 3 degrees	30 degrees		
Optimal Range of Motion	+/- 30 degrees	+/- 5 degrees	31 degrees		
Stiff Springs and Housing	30 Nm	+ 10 Nm / -10 Nm	20 Nm		

QFD

House of Quality (HoQ)						
		Engineering Requirements				
Customer Requirement	**Weight**	Lasts 10,000 running steps ↑	Adjustable Neutral Angle	Range of Motion of +/- 30 degrees	Maximum output torque of 30 Nm	Adjustable torque *
1. Adjustable Torque	5					
2. Durable	5	9			3	
3. Adjustable Zero Angle	4		9	3		
4. Comfortable	3	3	3	9		9
5. High Torque	3				9	9
Engineering Requirement Units		#	N/A	N/A	ft-lb	ft-lb
Absolute Technical Importance (ATI)		54	45	39	42	54
Relative Technical Importance (RTI)		2	3	4	6	1
Target ER values		10,000	+/-10° adjustment	+/- 30 degrees	30 Nm	TBD
Tolerances of ERs		10,000 Minimum	+/-10% min	+/- 5 degrees	+ 10 Nm / - 5 Nm	TBD
Testing Procedure (TP#)		2	3	1	1	1

To meet the requirements, the customer, it is important for the engineering requirements to directly achieve each goal. Having the device achieve 10,000 steps directly relates to making the product durable enough to handle the working load it would undergo with a client.

In order to achieve the adjustable toque customer requirement, the team has decided to implement a slider block that can change the active length of the leaf springs. This also can affect how comfortable the clients experience is. If too forceful, it could be difficult for the user to walk with comfort. We will see how much the torque changes when testing.

The team has implemented a neutral angle adjuster to achieve the customer requirement of an adjustable angle adjuster. We want to achieve a range of 10 degrees of adjustment.

The goal of a high torque has been set to 30 Nm. We hope to achieve this at the highest torque adjustment and will be tested using the force pull test explained above in experiment 1.

The comfort of the device is affected by the durability, neutral angle adjuster, and range of motion. All of which have been mentioned above