Final Testing Results

Robotic Ankle Exoskeleton

Diego Avila, Emma De Korte, Tre Green

NAU NORTHERN ARIZONA UNIVERSITY

Design Requirements

Customer Requirements

- **CR1** - Lightweight
- **CR2** - Ergonomic- Human Centered Design
- **CR3** - Durable
- **CR4** - Economical or Cost Effective
- **CR5** - Low profile- nonobtrusive to daily life
- **CR6** - Have a chain to pulley system

Engineering Requirements

- **ER1** - $3,800.00 budget
- **ER2** - Range of motion should be 45 degrees in either direction (resting is 90)
- **ER3** - Weight < 1 kg per leg
- **ER4** - Cannot extrude from the body more than 10 cm
- **ER5** - Lifetime of 100,000 steps
- **ER6** - Time to take on/off (<60 s)

Testing Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed	Other Resources
Ex1 – Weight Test	CR1- Light Weight ER3- Weight<1kg	Scale Device to take photo	Space to place scale and weigh device
Ex2 – Range of Motion	CR2-Ergonomic ER2-Range of motion of 45 degreed in either direction	Level/Level App Device to take photo	Table to place device
Ex3 – Measurement Test	CR2-Ergonomic CR5-Low Profile ER4-Cannot Extrude > 10cm	Ruler/Measuring Tape Device to take photo	Flat ground to place device
Ex4-Cost Analysis	CR4-Economical/ Cost Effective ER1-Less then 1900 per leg	BOM	
Ex5- Durability Test	CR3- Durable CR6- Have a chain to pulley System ER5-Liftime of 100,000 Steps	SolidWorks & Torque Sensor	Treadmill
Ex6 – Time Test	CR2-Ergonomic ER6- Time to take on/off (<60s)	Stopwatch Device to make a video	Space to put on device

Ex1 - Weight Test

Summary:
One exoskeleton leg must weigh less than 1,000 grams. The team will utilize a scale that can withstand at least 1,500 grams, level, and timer. To complete the test, one leg will be placed on the scale for at least 30 seconds and repeated a minimum of four times to ensure the reading is accurate. The mechanical portions of the design will be isolated as the electronic components are not within the team's overall project scope.

Specific Procedural Steps:
1. Using a level, place it on the surface where testing will occur, ensure the surface is level, if not level, adjust surface until level
2. Place the scale on the leveled surface
3. Turn on scale and tare to ensure it scale reading is zero
4. Place the constructed mechanical components on the scale
5. Set a timer for 30 seconds
6. Record the weight in grams
7. Repeat steps 3-6 a total of four times

Expected: SOLIDWORKS analysis - 808.85 grams.

Measured: 793 grams

Ex2 - Range of Motion Test

Summary:
Since the exoskeleton is used to adjust the gait cycle, there needs to be at least 45 degrees in either direction on a flat walking surface. To measure the 45-degree angle, the team will use a protractor. A level will be used to ensure the ground is flat. The protractor will be placed in line with the shoulder screw parallel to the ground, then a team member will adjust the carbon fiber tubing accordingly. To ensure only the range of motion is tested, the footplate will be affixed to the ground and the carbon fiber tubing itself will be adjusted .

Specific Procedural Steps:
1. Using a level, place it on the surface where testing will occur, ensure the surface is level, if not level, adjust surface until level
2. Place the footplate on the leveled ground
3. Have one team member hold footplate to ensure the device does not leave the ground
4. Have another teammate adjust the rest of the exoskeleton until it will no longer move
5. Have the remaining teammate measure the angle using a protractor, protractor can be placed on level to ensure it is parallel to the ground
6. Record the measured angle
7. Adjust the upright in the other direction until it will no longer move
8. Repeat steps 5 and 6

Expected: SOLIDWORKS analysis - at least a 128.54-degree range of motion.

Measured: 47º Forward, 49º Backward

Ex3 - Measurement Test

Summary:

The exoskeleton needs to be close to the user's leg, it should not exceed 10 centimeters from the body. A measuring tape will be used. The measurement will be from a touch point on the calf to the outer most item on the exoskeleton. The team will measure multiple points across the leg to ensure all items do not exceed the requirement.

Specific Procedural Steps:

1. Have one teammate put on the exoskeleton
2. Using a measuring tape, measure the distance from where the exoskeleton touches the leg to the outer most protruding item
3. Record that measurement
4. Repeat steps 1 and 2 in various locations to ensure the first measurement was the largest

Expected: SOLIDWORKS analysis – 4.95 cm

Measured: 5 cm

Ex4 – Cost Analysis

Summary:
To ensure that one exoskeleton leg costs less than $1,900, the team will perform a cost analysis utilizing the bill of materials.

Anticipated: Based on current purchases, the entire budget was used, therefore it is anticipated that the cost of one leg will be within the $1,900 cost.

Results: $1786.57 per leg

Current Bill of Materials								
Part	Number in Category	Manufactor/Source	Quantity Per Unit	Cost Per Unit	Quantity Needed	Cost per Unit needed	Quantity purchased	Item Number
Footplate	1	Provided by Lerner	1	-	1		Provided	
Torque Sensors	2	Provided by Lerner	1	-	1		Provided	
M2 Assorment of Screws + Nuts	3	Amazon	562	$9.98	6	0.1	1	
Chain (1ft, 05B, 8mm Pitch)	4	McMaster-Carr	1	$9.00	1	9	2	6027k91
M3 X 35	5	Amazon	2	$2.00	2	2	1	
Stainless Steel Ball bearing 5mm	6	Mcmaster-Carr	1	$9.20	4	36.8	4	7804k138
Stainless Steel Shoulder Screw	7	Mcmaster-Carr	1	$6.31	1	6.31	2	91273A392
Steel Hex Nuts	8	Mcmaster-Carr	100	$4.76	2	0.1	1	90592A095
Steel Cable 2mm diameter + Clamps	9	Amazon	1	$12	1	12	1	
PLA Material	10	Amazon	1000 Grams	$18	Grams	1.94	1	
800cc Onyx Filament Spool	11	MarkForged	800 Cm^3	$190	Volume-25 Cm^3	5.93	1	F-MF-0001
50cc Carbon Fiber CFF Spool	12	MarkForged	1	$150			1	CF-BA-50
M5 x 0.80 mm Thread, 35mm Long	13	McMaster-Carr	10	$10.36	2	2	1	90116A267
Motor	14	Maxon	1	$715.13	1	715.13	Provided	
Gearbox	15	Maxon	1	$294.65	1	294.65	Provided	370782
Bracket	16	Protolabs	1	479.11	1	479.11		
Rod + manufacturing	17	Hawley Design	1	221.5	11 inch	221.5		
Total	1786.57							

Ex5 - Durability Test

Summary:

To test the durability of the exoskeleton, a treadmill will be used, and the user will put on the exoskeleton and walk on it for 10 minutes. The NAU Biomechatronics lab is preforming this test specifically and no other information was provided about the test to be preformed.

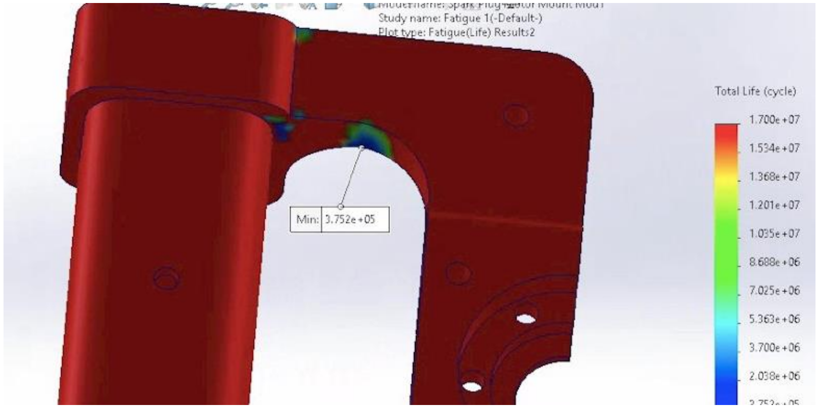
Specific Procedural Steps:

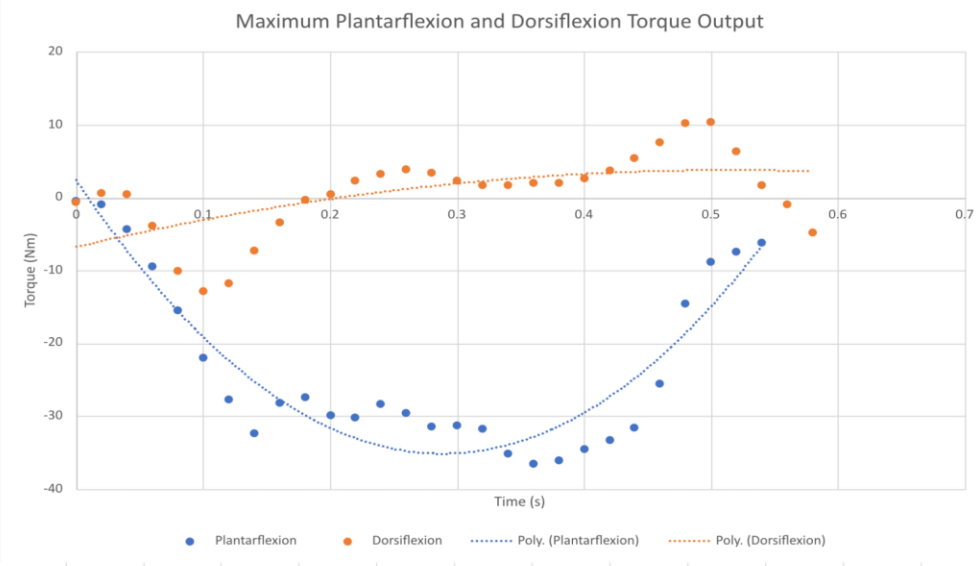
1. Prep the treadmill and make sure all settings are set to the correct values
2. Have the user put on the fully assembled exoskeleton leg with both mechanical and electrical components
3. Double check that exoskeleton turns on and functions
4. Have user step onto treadmill and prepare to begin testing
5. Set a timer for 10 minutes and have the user walk on the treadmill at comfortable walking speed for the user
6. After the test, record Torque data from the device
7. Then using Measured Torque do a fatigue analysis within SolidWorks

Anticipated: It is anticipated that the exoskeleton leg will withstand the 100,000 steps during the walk test with minor deformations based on previous SOLIDWORKS analysis.

Results:375,000 Cycles

With the walk test only being 10 minutes, this will not be a full test to determine if the leg can withstand the minimum of 100,000 steps. Therefore, in addition to the walk test, the team will preform a fatigue test on the device utilizing the fatigue analysis feature within SOILDWORKS. The software will be used to determine how many cycles the device can go through and to make an educated determination if it satisfies the customer requirement.





Ex6 - Time Test

Summary:
The user of the exoskeleton should be able to remove and put on one exoskeleton leg in less than 60 seconds while sitting. To perform the test a stopwatch will be used, each team member will place on the exoskeleton and be timed three times. The average of each group will be averaged for an overall time. Most users of this device will have varying limitations; therefore, the team will try their best to simulate these limitations such as; restricting use of the knee.

Specific Procedural Steps:
1. With one teammate holding the stopwatch, have another prep to put on exoskeleton
2. Once all members are ready, hit start on the stopwatch while the person puts on the leg
3. Stop the timer when all straps and additional items are put on and ready to be used
4. Record the time
5. Have the user repeat steps 2-4 an additional two times
6. Repeat steps 1-5 for all teammates to get a total of 12 times

Measured:
Trial 1: 22 s
Trial 2: 18 s
Trial 3: 20 s
Average of 20 seconds

Customer/Engineering Requirement Summary

Customer Requirements	CR met? (✓ or X)	Client Acceptable (✓ or X)
CR1-LightWeight	✓	✓
CR2-Ergonomical-Human Centered Design	✓	✓
CR3-Durable	✓	✓
CR4-Economical or Cost Effective	✓	✓
CR5-Low Profile-Nonobtrusive to daily life	✓	✓
CR6- Have a Chain to Pulley system	✓	✓

Engineering Requirement Summary

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER met? (√ or X)	Client Acceptable (√ or X)
ER1-Low cost	$3,800	+$10	$1786.57	√	√
ER2- Range of Motion	± 45°	≥±45°	-47° Forward 49° Backward	√	√
ER3-Weight	<1kg	+ 5 g	793 g	√	√
ER4-Dimesnions	Extrude < 10cm	+ 5 mm	Max Protrusion 5cm	√	√
ER5- Lifetime	100,000 Steps	- 100 steps	375,000 10^7 Steps	√	√
ER6- User Friendly	Time to take on/off < 60s	+5 s	20 s	√	√

Product Demonstration

QFD

		1	2	3	4	5
1	Decrease Weight					
2	Increase Durability	-				
3	Decrease Timing	0	-			
4	Decrease Cost of Each Leg	+	-	+		
5	Decrease Protrusion From Body	++	0	0	0	

			Technical Requirements				
	Customer Needs	Customer Weights	Decrease Weight	Increase Durability	Descrease Timing	Decrease Cost of Each Leg	Decrease Protrusion from Body
1	Lightweight	3	5	3	3	3	3
2	Easy to take on and off	4	3	1	5	3	3
3	Durable	4	2	5	1	2	1
4	Cost Effective	5	4	4	1	5	1
5	Small in size, close to body	3	5	2	3	2	5
	Technical Requirement Units		kg	steps	min	dollars	cm
	Technical Requirement Targets		<1	100,000	<1	<2000	<10
	Absolute Technical Importance		19	15	13	15	13
	Relative Technical Importance		1	2	3	2	3

Any Questions?