BiOM Prosthesis Adapter

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Abstract

The BiOM Ankle Prosthesis Device is an advanced robotic ankle which allows people with below-the-knee amputations the ability to walk unassisted. An adjustable adapter was needed to test the BiOM Ankle Prosthesis device for research purposes. The adapter was to span from the BiOM Ankle Prosthesis device to the bent knee of an able-bodied person to allow research to be conducted on the ankle prosthesis without the need of an impaired subject. This adapter was to fit different sized users, be lightweight, comfortable, durable, safe, cost effective, and have a quick attachment for the user.

Currently, researchers have no way to accurately and quickly test the BiOM device on able-bodied users. If the BiOM device could be tested on able-bodied users, it would shorten the time the BiOM would be under research, and would provide amputees with a more reliable and realistic BiOM device.

As a result of the final design, the adapter was made to withstand a full grown adult who weighs no more than 175 pounds, is adjustable to the users leg and height, is light weight, comfortable, quick to attach to the user and has a critical factor of safety of 3.2.

Figure 1: BiOM Ankle Prosthesis Device

Requirements

Shown in Table 1 are the client expectations for the final product. The client required the product to be used by a fully grown adult, be comfortable to wear, safe, and adjustable to the user.

Table 1: Requirements

Customer Requirements	Engineering Requirements
Lightweight	Weight < 4 kg
Comfortable	The system must have 8/10 comfortability rating
Quick attachment	Entire system must attach to the user in under a minute
Height adjustable	Height range of 12 cm
Width adjustable	Width range of 14 cm
Durable	System must not fail under 2 hour testing
Affordable	Cost of system < $1,000
Safe	Factor of Safety (FS) ≥ 3
Reliable	Lifetime of approximatly 10 years in constant use

Design

Leg Support
- 2 L-Shaped supports made of carbon fiber
- 3 thermoplastic leg supports; thigh, shin, and knee supports
- Assembled using bolts

Attachment
- U-shaped attachment made of carbon fiber
- 2 flange ball bearings embedded in carbon fiber L-support
- Shoulder bolts attached L-support through bearing to U-bar support
- Spring and piston mechanism allowed rotation about knee axis

Pylon
- Upper and lower pylons made of hollow carbon fiber tubing
- Clamp attached to upper pylon to allow vertical movement of lower pylon respective to upper pylon
- Lower pylon attached to BiOM Ankle Prosthesis using BiOM adapter

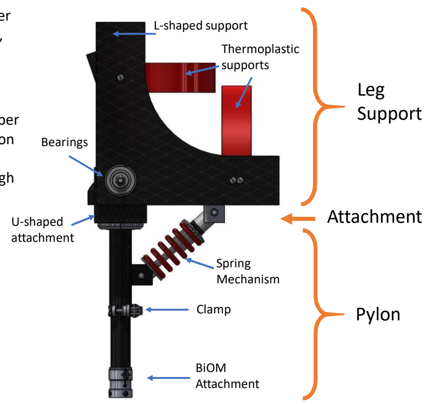

Figure 2: CAD model side view of device showing subsystems

Testing Procedures

Leg Support
1. Have 10 volunteers secure leg support without the attached pylon to their leg, see Figure 3.
2. Volunteers will stand and put their weight on their bent knee while it is resting on a table.
3. The volunteers will rate the comfort of the support from 0 to 10, 10 being very comfortable, 0 being painful.

Figure 3: Comfortability Testing

Attachment
1. Place U-bar attachment on small rigid beam in geometric center.
2. Apply downward force to sides until U-bar breaks due to bending stress, see Figure 5.
3. Calculate actual factor of safety of the component. *Note: U-Bar did not break during testing under applied load.*

Pylon
1. Stand pylon upright in extended position on top of a force sensor.
2. Extend pylon to 2 inches longer than the height of side-by-side tables
3. Place flat plate over top of pylon
4. Apply force over top of flat plate until pylon buckles/clamp slips to determine factor of safety

See Figure 4 for the force applied when the pylon clamp slipped

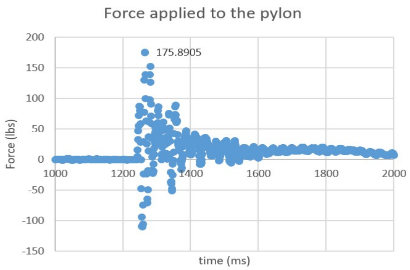

Figure 4: Testing for Force Required for Pylon Slip

Analysis

Carbon Fiber U-bar Analysis: Determine how many carbon fiber layers are need in the U-bar attachment layup using a composites analysis.
- Utilized the Promal Composites Program to solve for maximum allowed stress [1]
- $\sigma_{allow} = \frac{F \times L \times \left(l \times \frac{t_{1-ply}}{2}\right)}{w \times \left(\frac{\left(l \times t_{1-ply}\right)^3}{12}\right)}$; solve for l to determine carbon fiber layers
- A minimum of 9 layers are need for a factor of safety of 3 [2]
- Additional 3 layers were used to account for voids and delamination within the component.

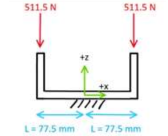

Figure 5: Simplified model of Attachment

Results

Results of the testing procedures are shown in relation to their engineering requirement and target values in Table 2.

Summary
- 2 sizes of leg support cuffs were needed
- Durability test to be completed in June 2019
- Minor slipping occurred in the pylon with weights over 175 pounds, but not a critical system failure

Table 2: Results of Testing Procedures

Requirement	Results	Target Values
Light Weight	1.7 kg	4 kg
Comfortability	8.3/10	8/10
Quick Attachment	19.11 sec	60 sec
Pylon Extension Range	13 cm	12 cm
Small/Large Calf Cuff Circumference	27 – 41.5 cm/41 – 46 cm	30 cm – 45 cm
Small/Large Thigh Cuff circumference	30 – 42.5 cm/42 – 68 cm	35 cm – 65 cm
Durable	TBD summer 2019	2 hours of continuous use
Affordable	$313.05	$1,000
Safe	Critical FS of 3.2	FS of 3

Conclusion

The system meets almost all of the customer requirements. Due to slipping of the pylon, the system is only able to support 175 pounds before the pylon slips back into its minimal range state. This is not a critical failure of the system. The leg support can secure a larger leg with circumferences of the thigh and calf of 42 – 68 cm and 41 – 46 cm respectively, with the option to switch out the larger cuffs and the attachment for smaller replacements. The system can be used for someone between 5' and 6' 2" tall based off the pylon extension range. The entire system is affordable and light weight with an attachment time of about 20 seconds and a comfort rating of about 8/10.

Future work for this project includes constructing a new leg support for smaller users using the smaller replacement parts to allow a faster and easier switch-out, and completing the durability test during the summer of 2019. A torque sensor could be applied to the knee joint axis between the pylon and the leg support to determine what torque is applied to the system. From this, a knee actuation could be implemented using motors or torque springs at the knee joints to replace the spring system.

References

[1] Liebelt, L. (1997). *Promal Software*.

[2] R. F. Gibson, *Principles of Composite Material Mechanics*, CRC Press 4th ed, 2016.

Acknowledgments

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