Design Modeling and Optimization of a Passive Lower-Limb Exoskeleton

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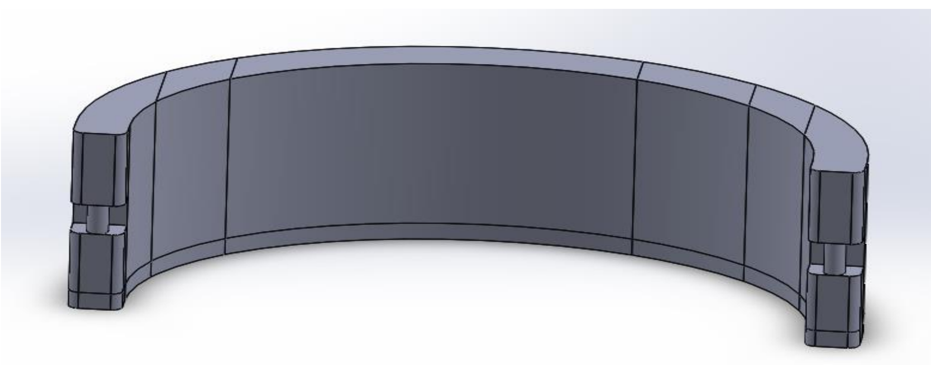
1. Introduction

Various diseases or accidents can damage a person's nervous system. Problems such as congenital diseases mean that the nervous system cannot perform at its best. In addition, due to age or the large amount of effort involved in performing an action, some kind of help is needed to be able to perform it. The use of exoskeletons is indicated for each of these situations, helping the user to perform a motor action with less difficulty.

There are several classifications of exoskeletons, however, those used for the recovery of the user's mobility are rehabilitation exoskeletons. They need to be comfortable and lightweight, which is why passive exoskeletons, i.e. without motors, are often built to reduce their weight and give the model the ability to be portable.

2. Problem Statement

This project focuses on the construction of a belt for an already designed and built exoskeleton. The shape is deemed most suitable for modeling a person's hip, and therefore the initial reference for the final geometry is an ellipse. This ellipse contains the required average waist measurements shown in the ANSUR II anthropomorphic database.

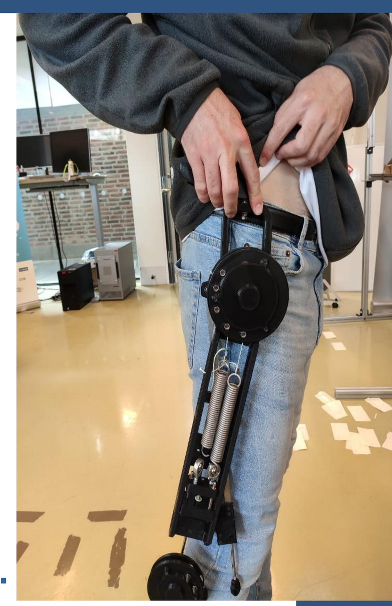


As one of the requirements of this design process is to obtain a belt shape with as less mass as possible, it is intended to use composite material for the design. The reason for this decision is that in general, these materials offer a high strength of the structure while reducing the mass of the structure, thus making the structure portable. Also, these materials cannot be designed as isotropic materials, therefore their failure cannot be estimated like these either, so the Tsai-Wu failure criterion is used to check the failure of this structure.

Material selection is one of the most influential factors in mechanical design. One of the materials studied is a composite material with a thermoplastic matrix (modified PET) and carbon fiber reinforcement, which would be produced using the manufacturing method provided by the supplier COMFIL, with the use of a heat gun and an oven for drying. An alternative for the production process is also being studied, which is 3-D printing with PLA. The results indicate that it is much cheaper to produce with PLA than with the composite material, and because the dimensions of the belt are quite critical for the design, it is decided to make a wearable prototype, produced with PLA.

Method	Price (DKK)
Comfil Method + Aluminum Mold	4260
Comfil Method + Aluminum Mold	5948.7
3D Printing (PLA)	400

3. Model Refinement



After the relevant simulations, it is decided to make changes in order to bring the model closer to reality.

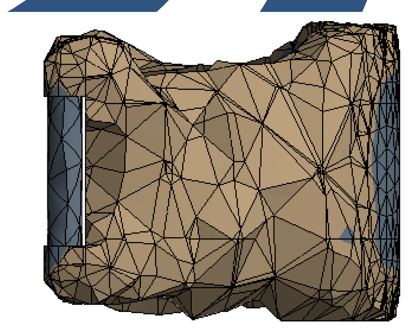
The first is the way in which the belt joins the exoskeleton, as previously this contact was on the underside of the belt, however, it was decided that it would be better on the side as shown in the figure. The reason for this change is that the contact surface between the belt and the exoskeleton was too small, which causes a high concentration of stress.

The second change is an improvement in the contact surface between the user's hip and the belt, identifying in a better way which parts are in contact.

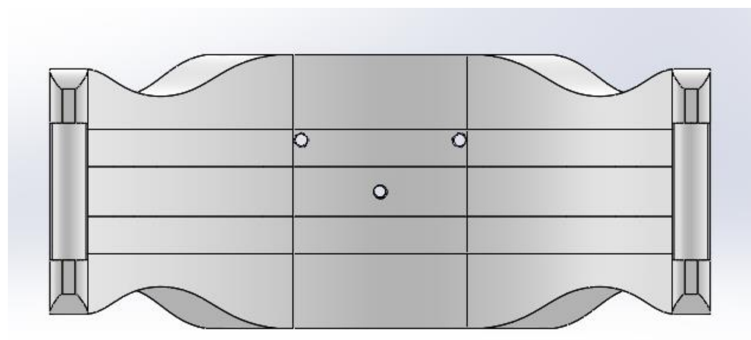
After a simulation of the interaction between a human body model and the belt, the belt did not fit snugly, so the ellipse depth dimension is changed.

4. Final Design

The topological optimization tool in Ansys is used to design the final shape. These results must be reinterpreted taking into account various mechanical considerations such as stress concentrations.



Once the figure obtained as a result of the optimization is redesigned, the following final shape is obtained.



With this final geometry, two simulations are carried out. The first one is with the Ansys ACP tool to analyze the composite material, and according to the Tsai-Wu criterion, the structure does not fail for the given static load case. As for the simulation with PLA, a maximum stress in the central hole area of 10.874 MPa is obtained, which is less than the yield strength limit of the material, being 70 MPa, i.e. it would not fail for the same load case.

5. Conclusion

To validate the model made with the PLA simulations, experiments are carried out with the belt on. Actions such as sitting or walking are carried out, and the result is very satisfactory, with the belt being comfortable and still snug around the waist.

The final design of this belt is conservative. This is due to the conservative design of the belt because of the uncertainty of the contact between the waist and the belt, and the changing direction of the acting forces. For a more accurate design, a dynamic simulation should be carried out considering the motion of the person throughout the gait cycle.

Acknowledgement

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