Design of an Adjustable Prosthetic Foot

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Objectives

This poster details the design and analysis of an adjustable prosthetic foot. In the prosthesis, the ankle and toe joints adjust rotationally using **gas springs** to change the orientation of the foot. This allows for a variety of shoes, with heel heights up to **5 inches**, to be worn by amputees. Pugh's 'Total Design' [1] was initially used for concept generation and selection, where gas springs were decided as the best design. The overall product was developed further, and **steel**, **aluminium** and **titanium** were defined as the materials required. A complex Computer-Aided Design model was created using **SOLIDWORKS** [2], and then used for further testing through **ANSYS Workbench** [3] for Finite Element Analysis (FEA). These tests were used to generate numerous stress and deflection plots for the prosthesis under a load of **2000 N**, which is the force on the foot of an 80 kg person whilst running.

ANSYS - Finite Element Analysis

FEA was completed on ANSYS [3] to determine the deflections and stresses within the design if an 80 kg person was to use the prosthesis. Analysis was done on four foot orientations at heel-strike, toe-off and with an even load, which imitated typical force patterns during a step.

All deformation plots were minimal and the design required little adjustments to counter-act any deflections. Figure 4 shows an example of these plots.

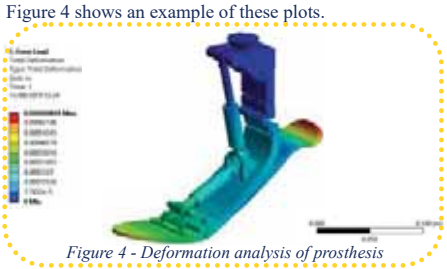

Figure 4 - Deformation analysis of prosthesis

Stress analysis was performed for the same set-ups and the results were more significant. An iterative design process was used with the SOLIDWORKS [2] design to reduce areas of stress concentration where possible. This concluded with stress values well within the yield stress of the materials used. A safety factor of 1.5 was also always included to account for any inaccuracies. Figures 5 and 6 detail stress plots from analysis, where warm colours indicate higher stress levels.

Figure 5 - Stress analysis of prosthesis

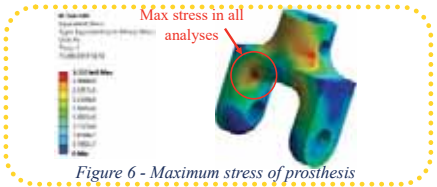

Figure 6 - Maximum stress of prosthesis

Mesh quality was an important aspect of the FEA. Quality was measured using all ANSYS mesh tools (aspect ratio, number of elements etc). Within the realms of the license limit, the mesh of the prosthesis was refined in areas of stress concentration. Figure 7 shows a finer mesh in areas such as the gas springs, hinges and heel.

Figure 7 - Refined mesh

SOLIDWORKS

A 39-part assembly was created on SOLIDWORKS [2] to replicate the exact design of the prosthetic foot. In the assembly, the pistons within the gas springs could move to show the full adjustability of the prosthesis. Figure 1 details key parts of the design.

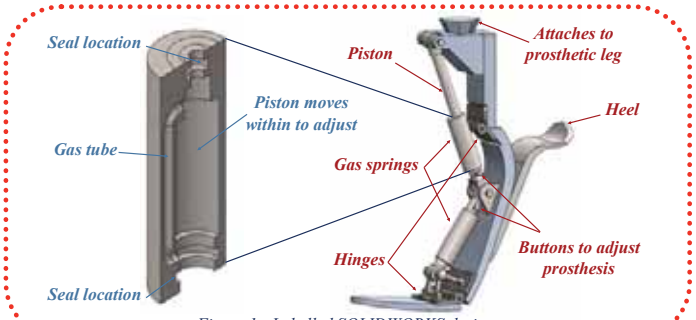

Figure 1 - Labelled SOLIDWORKS design

Figure 2 - Prosthesis in flat foot orientation

Figure 3 - Prosthesis in 5-inch heel orientation

Figures 2 and 3 show the final design in its extreme orientations. Some design features are highlighted below:

- The heel was designed with a larger arc than most prosthetic feet to ensure a line of good contact was made with the shoe regardless of heel height.
- The load acting on the prosthesis was even on each side so both hinges were made symmetrical.
- A triangular attachment was created for the hinge at the toe joint to allow extension of the toe section of the prosthesis. This mimics the typical arrangement of a digger arm and its hydraulics.
- In the joint where both gas springs meet, a complex design was created to ensure their centres of mass aligned, helping the user balance.
- Volume of the prosthesis was kept to a minimum to reduce the overall weight. The final mass was 838.53 g.

Conclusion

A precise and accurate design was created on SOLIDWORKS, where a variety of tools and features of the software were used. The ANSYS FEA results showed deflections to be minimal and stresses were always below the yield strength of that material (including a safety factor of 1.5). Analysis was done using a load of up to 2000 N, where 1000 N was the expected load for an 80 kg person walking. Fatigue analysis was also done on the design including fatigue modification factors, and the estimated lifespan of the prosthetic foot's materials were 87 years. Therefore the design was profoundly successful and is in a position to be further developed towards manufacture.

References

[1] S. Pugh, Total Design, Addison Wesley, 1991.

[2] DASSAULT SYSTEMS, SOLIDWORKS, DASSAULT SYSTEMS, 2018.

[3] ANSYS, Workbench 17.1, ANSYS, 2016.