STRUCTURAL ANALYSIS DURING THE DESIGN OF POLYCENTRIC PROSTHETIC KNEE

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SUMMARY

The aim of this work is to find the proper dimensions of a polycentric prosthetic knee under a structural perspective. Stress analysis was performed using finite elements method (FEM) under three different load conditions, two related with the ISO Norm 10328, and a compression load equivalent to the weight of a person of 100 kg. For the most critical load condition, 5 of the 9 prosthesis components yield a safety factor less than 1, which implicated a redesign that included an increase in the diameter of the axes as well as modifications in four of the links.

INTRODUCTION

The proposed polycentric prosthetic knee with a 4 bars mechanism is composed by five links (aluminium 7075, E=71GPa, Sy=241MPa) and four axes (stainless steel 304, E=207GPa, Sy=480MPa), as shown in the Fig. 1a. After defining the dimension of the mechanism considering the proper kinematics [1, 2], and in order to guarantee the success of the design supporting the loads during the gait cycle, verification was necessary from a structural perspective. This work presents the results of the stress analysis, using FEM for several loads conditions, and the changes performed in the model of the prosthesis to guarantee load support for every component.

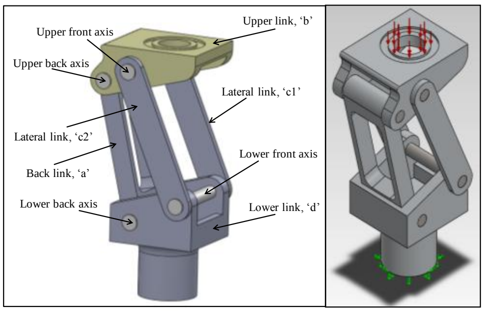

Figure 1: (a) CAD prosthetic knee model. (b) Boundary conditions for load case 3 (compression load).

METHODS

SolidWorks software was used for the 3D CAD design and finite elements stress analysis; boundary conditions on displacements and external forces were adjusted to simulate three load conditions: the first two from the structural principal test as indicated in the ISO Norm 10328 "Prosthetics – Structural testing of lower-limb prostheses – Requirements and test methods" [3], and the third condition associated with the prosthesis submitted to a compression of 1000 N applied as a pressure at the top, with a total restriction at the lower end of the device as shown in Fig. 1b. Contact without penetration was used for all connections between the prosthesis components, in all load conditions.

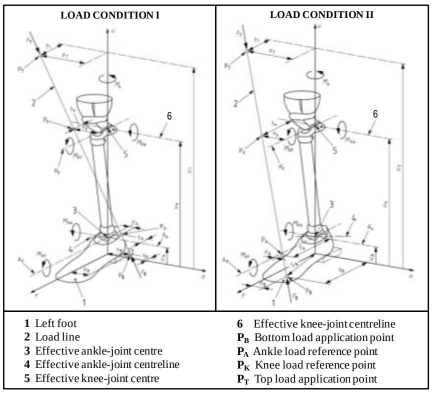

Figure 2: ISO Norm 10328, static test

Table 1: ISO Norm 10328 specification for static test.

	Load condition I	Load condition II
Load (N)	2240	2013
f_K (mm)	52	72
o_K (mm)	-50	-35
f_B (mm)	-48	129
o_B (mm)	45	-19
u_K - u_B (mm)	500	500

Fig. 3 shows the configuration of the load condition I (F = 2240 N), which is remotely placed respect to the prosthetic knee (see Fig 3c). Fig. 3a and Fig. 3b present the frontal and sagittal plane respectively, with dimensions reported in Table 1.

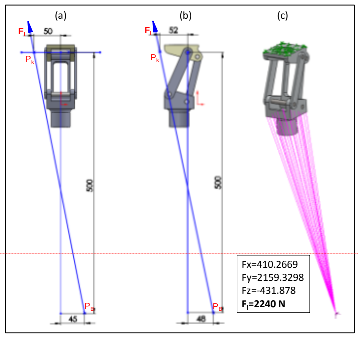

Figure 3: Configuration of the load condition I.

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All the simulations were done statically using 10 nodes tetrahedrical elements, both materials were considered lineal and isotropic. Convergence was checked for von Mises stress and deformation energy using nine different models, the proper mesh was selected considering less than 5% variations in results.

RESULTS AND DISCUSSION

Fig. 4 shows convergence for maximum von Mises stress and deformation energy for load condition I. Mesh No. 6 with 90091 elements was selected to perform the analysis.

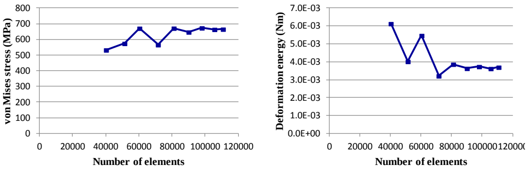

Figure 4: Convergence for maximum von Mises stress and deformation energy.

Results for von Mises maximum stress for every component for all load conditions are shown in Table 2, stress distribution for load condition I is shown in Fig 5. The maximum stress occurs at the lower end of the link ‘a’, with a value of 641.41 MPa nearby the contact area to component ‘d’, were the stress is 622.83 MPa. The most demanded axis is the upper back one, with a maximum stress of 455.07 MPa, followed by the upper front axis with a stress of 327.72 MPa. Table 2 shows that the most critical load condition is load I, where 5 of the 9 components yield a security factor (N) below 1. These results suggested the need to redesign the prosthesis.

The redesign included increasing the diameter of three axes, the two upper ones and the lower front one, from 8 mm to 10 mm, as well as the corresponding adjustment of all other components to the new diameter. Moreover it was necessary to increase in 2 mm the thickness of the back part of the component 'd', to increase in 3.5 mm the thickness of the sides of the link 'a' and reinforce the links 'c1' and 'c2' in the contact zones with the axes. Fig. 6 shows the prosthesis with the changes, and the stress distribution with a notable decrease of the maximum von Mises stress, and yielding values of security factor above 1 for all components.

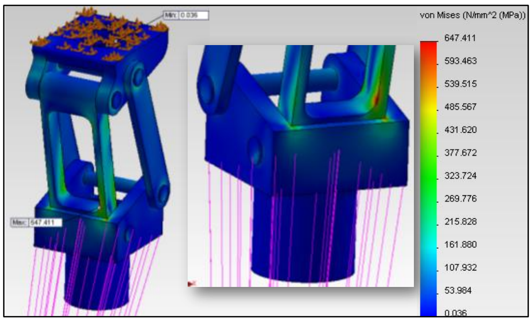

Figure 5: von Mises stress distribution at the prosthetic knee for load case 1.

CONCLUSIONS

During the detail design process of the polycentric knee prosthesis several steps are required. First, it is necessary to gauge the device to ensure kinematic stability during the gait cycle, and second, as show in this paper, structural evaluation is mandatory to guarantee the correct support of applied loads. Using FEM the proposed polycentric prosthetic knee was dimensioned under a structural perspective. The redesigned prosthesis included the change in the diameter of the axes as well as the reinforcement in critical zones of the components to obtain security factors greater than 1 when the most critical load condition of the ISO Norm for structural testing of lower-limb prostheses is applied. Future work is intended to perform mass optimization of the device, as well as manufacture and assessment tests.

Table 2: Results for all components for three load cases.

	Load condition I		Load condition II		Compression	
Components	**σmáx (MPa)**	**N**	**σmáx (MPa)**	**N**	**σmáx (MPa)**	**N**
Back link a	647.41	0.74	417.15	1.15	119.78	4.01
Upper link b	458.77	1.04	432.28	1.11	104.64	4.56
Lateral link c1	330.08	1.45	420.19	1.14	96.68	4.96
Lateral link c2	486.25	0.99	423.07	1.13	91.85	5.23
Lower link d	622.83	0.77	475.98	1.00	133.11	3.60
Upper front axis	327.72	0.74	314.84	0.77	77.91	3.09
Upper back axis	455.07	0.53	411.49	0.59	109.20	2.21
Lower front axis	240.92	1.00	309.33	0.78	46.06	5.23
Lower back axis	192.43	1.25	185.38	1.30	39.94	6.03

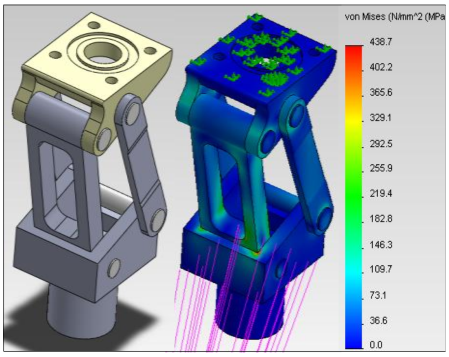

Figure 6: Redesigned polycentric prosthetic knee.

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