

ANALYSIS OF PRESSURE FORCE EFFECTS ACTING ON THE THIN TUBE NETWORK OF THE LOWER LIMB PROSTHESIS

Alina Rodica Spanu¹, Daniel Besnea¹

¹University Politehnica of Bucharest, Mechatronics and Precision Engineering Department,
313 Splaiul Independentei, Bucharest, Romania

Email: daniel.besnea@upb.ro

Abstract: Nowadays the design of lower limb prosthesis has been developed rapidly as new materials appeared and controlling methods for embedded equipment were improved. The suspension system as part of lower limb prosthesis has the most important role for fitting and maintaining a firmly contact with the stump. The paper proposed a genuine solution for the suspension system by using a network made of thin wall tubes inflated with dry air. The material the tube is made of is a biocompatible silicone rubber that has very good elastic coefficient as well as friction coefficient. The pressure force acting on the walls may provide an imposed friction force in order to assure a firmly and stable contact with the stump. The FEM analysis pointed out the values for the effort and displacement during working period. The experimental set-up consists in a mechatronic system controlled with Arduino that has to receive signals from the pressure sensor and from the force sensor too, so the dynamic balance could be established.

Keywords: Lower Limb Prosthesis, Suspension System, Pressure Force, FEM Analysis, ePTFE.

1. Introduction

During the last years many people over the world have experienced some injuries, car accidents or some other diseases, so that the lower limb prosthesis is the only solution for their normal life. For instance, only in the UK there is 7000 lower limb amputation per year [1]. There are now 45 NHS Prosthetic and Amputee Rehabilitation Centres in UK providing a service, free at the point of delivery, to those with limb deficiency from all causes. From the designing point of view, the field of lower limb prosthesis has been developed rapidly due to the improvements of new material properties, such as composite material, silicone rubber, graphite and some others. The rehabilitation process should



Figure 1: The main parts of lower limb prosthesis

be also taken into account, because it aims to analyse the walking limitations, increasing participation in daily activities and leisure time as well.

The main parts of the lower limb prosthesis assembly are (fig. 1): 1 – the socket; 2 – the suspension system; 3 – the pylon.

Very common complications that could appear often during the use of lower limb prosthesis are the volume fluctuation during day and night, the patient could lose or increase his weight, and finally there are the reasons leading to maximize or minimize the pressure over the tissue. Due to this causes, the suspension system has the main role of maintaining the firmly contact between the socket and the stump.

The main conclusion is that nowadays it is an imperative demand of new prosthetic design that has to prevent not only to accommodate the patient with all the negative effects of prosthesis wearing and moreover to afford real-time measurement and adjustment capabilities.

Regarding the new materials used for lower limb prosthesis, the expanded polytetrafluoroethylene (ePTFE) is a new material with biomedical properties obtained by stretching PTFE (polytetrafluoroethylene) which is the most common fluoropolymer identified by its lubricating capacity and existing in some particular expanded forms, especially used for some medical applications, as well as bulk, film and sheet. There are two ways of producing the ePTFE. The first one starts from a powder of PTFE and a lubricating agent is added. The deformation at high rates has conducted to

increased tensile strength. The second procedure for obtaining ePTFE is based on paper fibres or carbonate and it is less used in pharmaceutical industry.

There are some techniques used in order to improve the surface functionalization of ePTFE as the paper [2], especially antimicrobial properties, consisting in covalent or non-covalent bonding. The covalent has the goal of introducing functional groups to the surface. For instance, PTFE could be etched chemically and after few minutes the surface is modified with alkali metals. The non-covalent bonding allows the using of liquid-infused porous surfaces to fill its pores, so that the bacteria will not penetrate and the material will be more hydrophobic. Consequently, the properties obtained upon these modifications increased the efficiency against the bacteria. The ePTFE is a material widely used for biomedical applications due to its mechanical, chemical and biocompatible properties. The most important one is the strong chemical inertness that could be altered by very few aggressive techniques. The way this material may be used for application in medical devices should be chosen according to working pressure and temperature.

The paper [3] points out the advantages of obtaining new biocompatible materials by in tissue engineering grafts, so the properties of new synthetic materials are comparable with natural ones. One of the most promising solutions is the synthetic graft designed for in-situ incorporation of cells. The most essential requirements for in-situ proliferated vascular grafts (iPVG) are biocompatibility, bioactivity, and mechanical properties. The aim of the research was to study and to develop new mechanical characteristics for small diameter tubes made of iPVG comparable to ePTFE used for medical devices. Flexible polylactic acid (PLA) and soft polycaprolactone (PCL) matrix were chosen as basic materials. Textiles from biocompatible polymer fibres were studied and the results were favourable to tissue-incorporating grafts. For instance, in order to manufacture PLA tubular the PLA multifilament was used as raw material.

The following mechanical properties were tested and the results were analysed. At first, the longitudinal and radial tension was analysed for the sample lengths 60 mm and 18.84 mm with a pre-tension of 0.5 N, so the slope of stress – strain curve was 5% elongation. The obtained value was 20.28 MPa. The radial compressive pressing and shape recovery were tested for the same sample by pressing it with a finger of 5 mm diameter having a speed of 10 mm/min. When 50% of its original diameter has been modified, the force was stopped for 10 s. The compressive resistance was defined as the required force applied in order to reduce the tube diameter with 50%. There were taken into

account the plastic deformation, the hysteretic elastic deformation and instantaneous elastic deformation. The radial strength was measured and the value was 11.83 MPa. The torsion was studied as torsion torque with the known inner diameter of the tube. The dynamic compliance testing was measured by supplying a pulsatile flow at imposed values of pressure 90 mmHg, 120 mmHg and 150 mmHg.

The paper [4] presents the main aspects regarding the influence of increased gas pressure inside the thin wall tube over the axisymmetric deformation mode during energy absorption and gas release rate.

Another problem that should be taken into account is the effect of entrapped air inside closed cellular materials. The pressure control system should be very carefully designed, due to its influence over the material structure.

The pressure into the tube was applied theoretically by using two methods. The first one was referring to Eulerian elements for the dry air, which may be considered a realistic behaviour. The main advantage of this method was that it was involving the fluid structure interaction between air and the thin wall tube. The second method have considered a constant value pressure, so the effect of the pressure waves could not be examined.

The aim of this paper is to study the effect of dry air pressure acting inside a thin wall tube. This thin wall tube is the main part of a network that is working as main part of the lower limb prosthesis, so its main role is to provide the required friction force between the patient tissue and the suspension system.

2. The FEM Method Applied for the Pressurized Thin Wall Tube

The main role of the lower limb prosthesis is to provide the stability during walking and to assure the body balance. The patient was traumatized enough, he has experienced some pains, and his life should be normal as it was before, working and leaving with perception of comfort.

The suspension system has the main role of providing the affordable contact of the lower limb prosthesis and the tissue mainly by generating the friction force. The value of this friction force should be suitable because of the following reasons. If it is slower, the slippage acts and the stability are affected. If it is greater than imposed values, the blood pressure is increasing rapidly, at first it could heart, but later some diseases could appear.

As it is mentioned in the paper [5] whether we work with the silicone gel, as material of suspension system, the variation of friction coefficient (COF) for is 0.5 to 0.9 when a normal force between 5 and 20 N is acting against a skin-like material (leather). For the same working conditions, the elastomer as

material for the suspension system has the COF between 0.4 and 0.8 and it is decreasing when the normal force is increasing. There are studies for determining the COF of the silicone rubber that has the value of 0.61.

We have design the three dimensional shape of the thin wall tube as part of pressure network by using the software CATIA V19 – the Generative Shape Design. The thin wall tube has the shape presented in fig. 2 and the width of the wall is 0.5 mm.

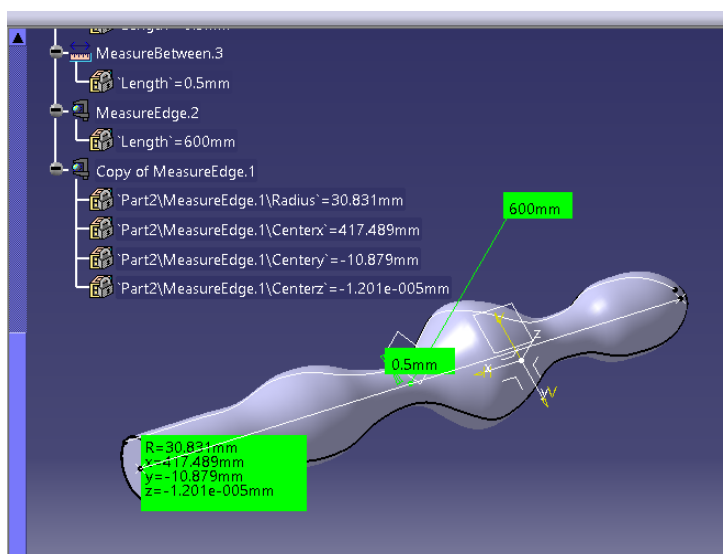


Figure 2: The designed thin wall tube

As we may infer from the Fig. 2 there are three active surface of the designed shape having three diameter values and axial distance of the external shape. The skin was assumed as an elastic bulk with Young's modulus of 20 KPa [5] and a Poisson ratio 0.5 [5]. The material we have used for manufacturing the thin wall tube was Zhermack – silicone rubber

and its elastic properties are: $E = 0.15 \text{ MPa}$ and Poisson ratio = 0.45. By designing a dry air pneumatic system, equipped with air pump, regulator and check valve we aim to provide a constant value pressure inside the thin wall tube (Fig. 2). Accordingly, the pressure force inside the thin wall tube was 30 N for the following analysis.

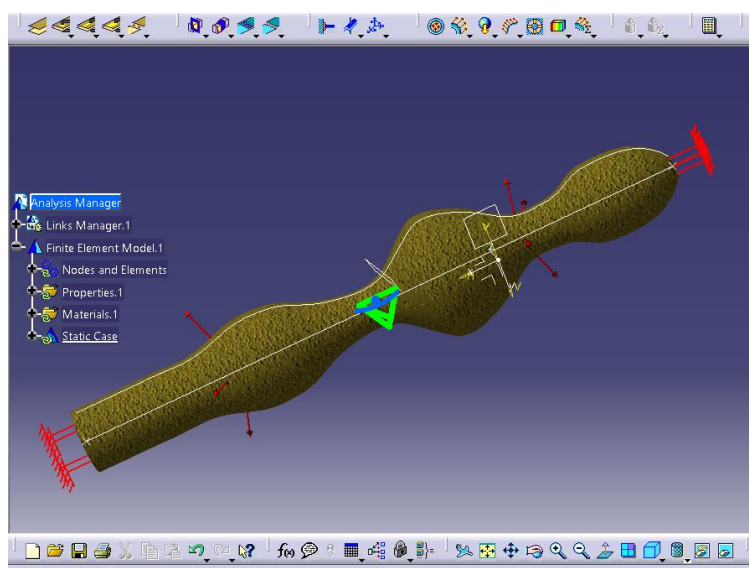


Figure 3: The forces acting on the internal surface

Taking into account all the numerical values specified before, we have made the static analysis by using CATIA V19 – Generative Structural Analysis. The results are presented in Fig. 4 for the Von Misses Stress and in the Fig. 5 for the displacements acting on the external surface especially due to the material

elasticity. As we may observe the values for the displacements are inside the imposed limits due to the clinical conditions. Regarding the safety conditions we have to mention that the Zhermack material is biocompatible and widely used for medical devices providing a very good elasticity.

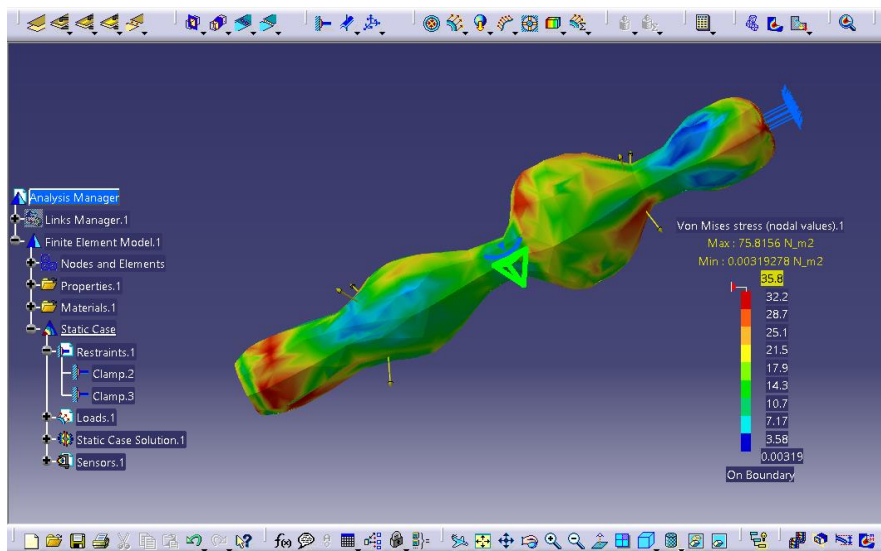


Figure 4: The Von Mises stress applied to the

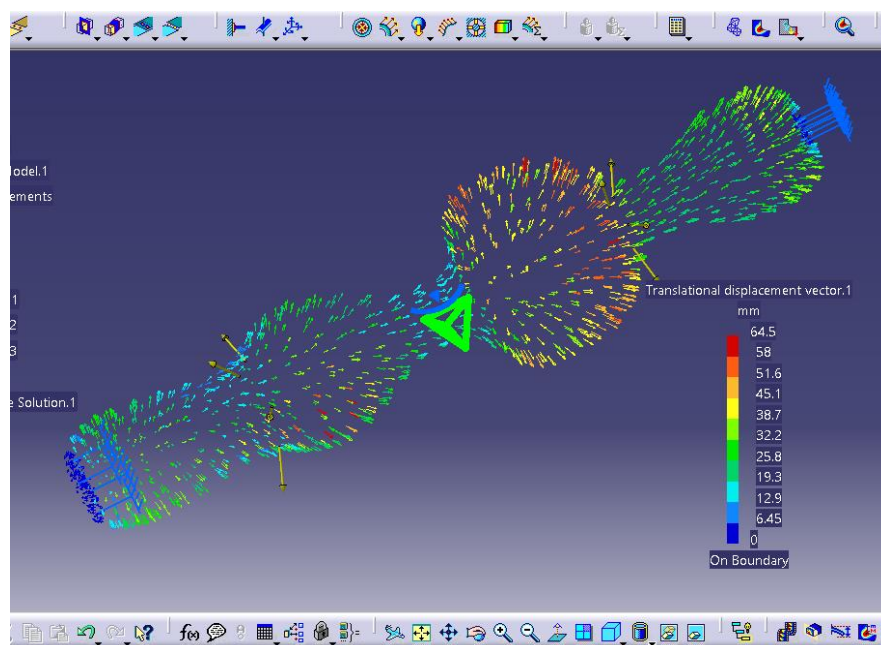


Figure 5: The displacement result as static analysis

In order to compute the efforts and the displacements of the inflated thin wall tube, it has been used the mechanical properties specified for the material named Zhermack, which was implemented as new user material in the library.

As we may infer from fig.5 the displacements are bigger enough compared with a classic material, such as rubber for instance.

3. The Experimental Set-up

At first, for the experimental set-up we have manufactured the thin wall tube made of new material Zhermack by using the Fused Deposition Material (FDM) procedure. The aim of the experimental set-up was to analyse the effect of pressure acting against the walls of the tube 1 (Fig. 6,

7). The dry air pressure is provided by the air pump 2. The pressure value is controlled with Arduino microcontroller 3 and a sensor pressure 4. Due to the mechanical properties of silicone rubber material named Zhermack, such as elastic coefficient and friction coefficient, the compression force is acting when the surface contact with the solid wall 5 is established. The force sensor may control the variation of this friction force during the process. These values of the force have to be limited due to their influence over the patient skin.

An important feature of the experimental set-up is about the way we have to assure the contact along the normal direction of the active external surface of the tube by controlling the accurate displacement of the mobile assembly on which the thin wall tube was assembled.

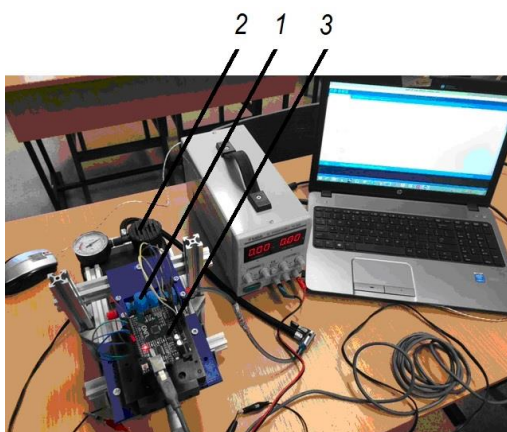


Figure 6: The experimental set-up.

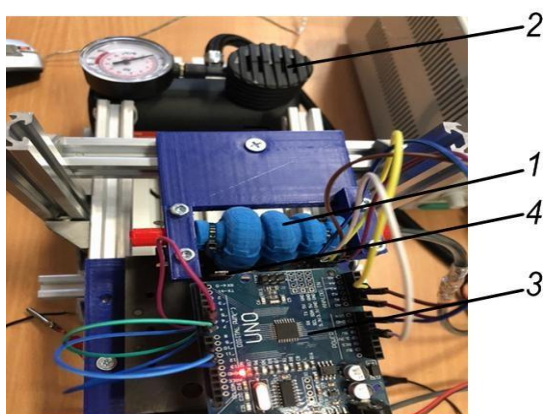


Figure 7: The detailed view of the thin wall tube

The results obtained after the experimental set-up have approved the improved elasticity of the thin wall, so that the required force could act on the external contact surface.

As future work we aim to reduce the wall thickness and to study the dependence of material elasticity as function of surface contact dimensions. Meantime, we aim to improve the solution for accurate displacement of the tube in order to be in contact with the fixed force sensor.

4. Conclusions

The paper aims to point out the influence of pressure force and of the mechanical properties of the material the thin wall tube was manufactured. The material is a silicone rubber named Zhermach, is biocompatible and has very good properties, especially the elastic coefficient.

Due to the pressure existing inside the tube, a friction force will act on the surface contact with the stump. The results computed using the FEM analysis proved the utility of this solution. The experimental set-up was designed as mechatronic system controlled with Arduino and comprising pressure sensor and force sensor.

Acknowledgements

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