ANALYSIS OF THE NETWORK CELL DEFORMATION USED FOR THE SUSPENSION OF LOWER LIMB PROSTHESIS

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Abstract - The paper aims to analyses the advantages of a new suspension system used for lower limb prosthesis that is comprising a network of dry air inflated cells. The cells have thin walls and are made of elastic material. The cells are grouped into two categories, even and uneven, so they are working alternatively for inflation and deflation phases. When a cell is inflated, the pressure acting inside produces a normal force. The external shape of the cell is deformed as result of this action. The deformations conduct to normal and shear stress inside the suspension system.

Keywords: Lower limb prosthesis, Suspension, Inflated cells, Deformation, Normal and shear stress.

1. Introduction

During the last years, many people experienced some trauma, car accidents, injuries, effects of circulatory diseases and diabetes, so that the only solution was the lower limb amputation and the wearing of prostheses to continue their normal life. The traumatic injury patients are active and dynamic persons in comparison with the vascular afflicted people, their rehabilitation period should be shortened and with maximum results. They aim to pass through this psychological and clinical traumatized period as well as possible and they are experienced all sorts of treatments.

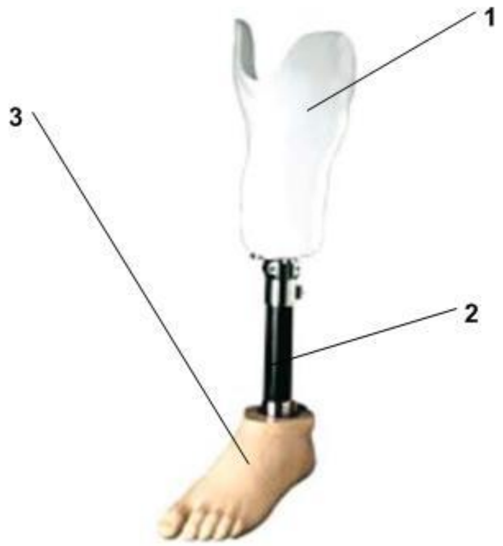

Figure 1: The main parts of lower limb prosthesis assembly [4]

The main parts of the lower limb prosthesis are (figure 1) [4]: the socket and cup assembly that surrounds the residual limb 1, the device 2 that has to make the connection and position adjustment with the artificial foot 3.

The successful rehabilitation depends on the way the secure and comfortable linkage between the residual limb and the prosthesis is assured. The most important factor of this aspect is the interface with appropriate load transmission, low friction forces and a reduced relative movement inside the cup conducting to efficient movement control. Whether these aspects are neglected, discomfort, irritation, skin damage will occur, the gait and posture of amputee will be influenced.

Moreover, there are objective factors which could influence the lower limb prosthesis wearing, such as changes in body weight, volume variation of residual limb during day and night, or during daily activities, hence making consistently well-fitting is a challenging activity adapted to the shape of individual residuum for each patient. Consequently, many amputees are hindered by permanently managing the fitting with the application of supplementary socks, pads, or some other solutions. The design of the suspension system, as main part of the lower limb prosthesis, is the best idea for avoiding all the above presented aspects.

The suspension has the liner used for the interface with the stump, and the stress induce by some modifications, volume variation, short leg-off times, external variable shape, may conduct to changes in pressure fluctuation acting directly on the skin.

The simplest solutions for improving these disadvantages are the material the socket is made of, such as elastomer, silicone rubber, polyethylene foams such as Pelite and Plastezote, the Duraform[3] which is using the selective laser sintering procedure, and the reduced liner thickness, meaning in fact some other disadvantages implying the stability during gait and posture. Even we may choose one of these improvements, the main problem remains – interface pressures and shear stresses during ambulation. The pressure distribution along the entire contact surface generates normal force, so nearby shear force acting simultaneously are the main criteria used for optimizing the design process, which has to minimize the effects of skin damage and discomfort.

The paper aims to introduce a new solution for the suspension system, by using a network of dry air inflated cells following an imposed working cycle, as the pressure inside generates a normal force whose magnitude depends on surface and material – skin friction coefficient (COF) and it must assure the permanently contact. It is very important to control the deformation of the external shape of the cell during the working period, so that the normal force and shear force variation could be minimized.

2. The Dry Air Inflated Cell Network

The suspension system is comprising a network of inflated dry air cells, whose pression values has to be very well controlled. The cells are grouped into two categories, named even and uneven, and they are distributed over the internal surface of the cup, being in contact with the stump. The working cycle is referring to an inflation period, a constant pressure period and finally a deflation one. Because of permanently contact providing, the inflation period as well as the deflation one, are alternatively switched for even and uneven cells.

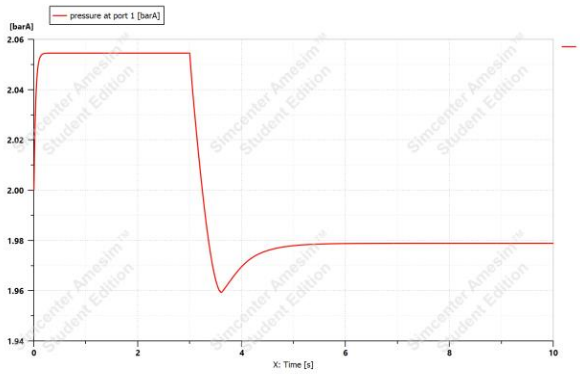

Figure 2: The pressure variation during the working cycle of inflation [5]

The pressure variation (figure 2) across the working period of cell inflation was established in the paper [5].

While the pressure, whose variation is presented in figure 2, is acting on the internal surface of the cell, the lateral surface has a deformation that could be computed with the following mathematical relation [3]:

$$\Delta R = \frac{N \cdot R^2 + \frac{F \cdot \nu \cdot R \cdot L}{2}}{t \cdot E} \quad (1)$$

ΔR- the external shape deformation of the cell when the pressure p is acting inside; N – normal pressure force; R – the radius of the cylinder; F – the shear stress transferred to the lateral surface of the cell; ν – Poisson coefficient; L – the length of the cell; E – the elasticity modulus; t – the thickness of the cell material.

We have to verify the following condition referring to the stresses that do not exceeds the material strength S_y = 20 MPa:

$$S_y > F + \frac{N \cdot R}{t} \quad (2)$$

3. The experimental Set-up

As the theoretical approach has pointed up before, we are interested to study experimentally the way we may control the deformation of the external shape when the dry air pressure is acting on normal direction inside. The cell is made of an elastic material, whose elasticity modulus should be approximatively equal to the elasticity modulus of the skin. The figure 3 presents two cells with the supply pipe and the discharge pipe with the following components: 1 – connection pipe between the cells; 2 – cell made of an elastic material; 3 – the supply pipe for both connected cells; 4 – discharge pipe.

The set of two cells presented in figure 4 are used for the even network. The discharge pipe has the main role of improving the humidity level inside the cup, otherwise the contact with the skin will be influenced, will be a wet one, so the friction coefficient will be lower.

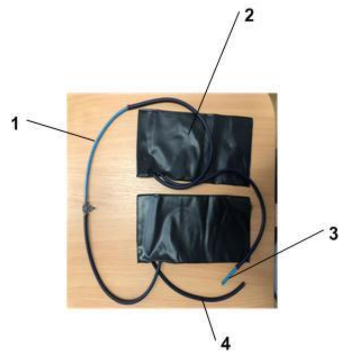

Figure 3: Two cells of the even network and their pipe connections

The cells were placed inside the cup on the entire lateral surface, so the proposed suspension system provides the fitting with the stump. Our goal is to verify the deformation of the external shape of the cell when it is working as part of suspension, so we have used a distance encoder. This encoder is grounded based on the lower limb prosthesis support, as we may establish a zero point for starting the measuring process. In the figure 4 it is pointed out the intermediate level of cell deformation when the encoder active head is measuring its displacement after the contact surface is established.

The figure 4 comprises: 1 – the conical head of the encoder; 2 – the inflated cell; 3 – the supply pipe; 4 – the system for grounding the encoder.

As we may observe, at first the cell deformation in the middle area, at the beginning of the working period.

In the figure 5 there are presented: 1 – the encoder active head; 2 – the supply pipe; 3 – the grounding system for the encoder; 4 – the inflated cell working with maximum pressure value.

Whether we make a comparison between the two figures 4 and 5 mentioned above, the main conclusion is referring to the magnitude of the contact area and the shape of the external surface of the cell. This value is the most important parameter for establishing the normal force acting on the skin.

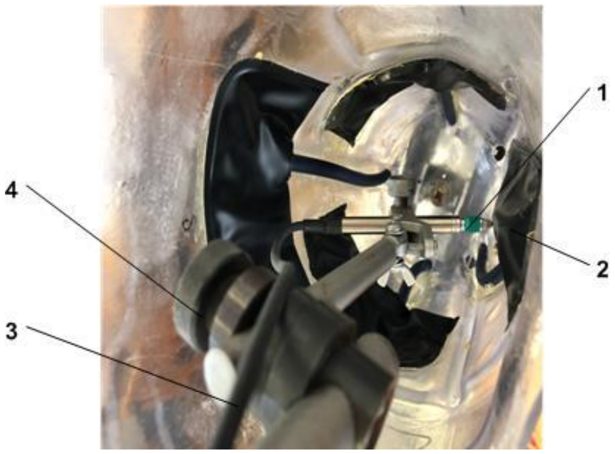

Figure 4: The intermediate level of deformation for the inflated cell

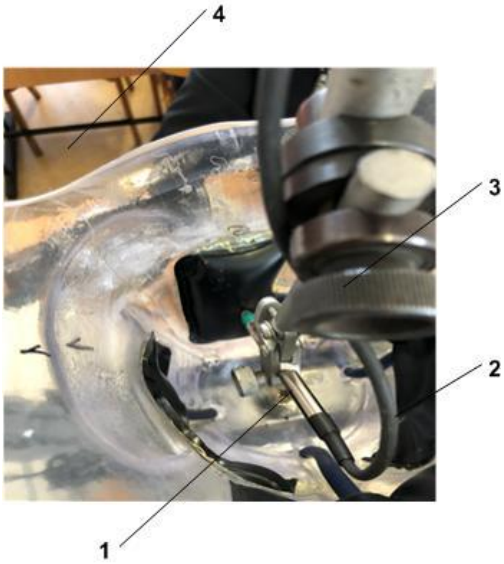

Figure 5: The maximum level of deformation for the inflated cell

Meantime, due to the friction coefficient of the material (COF) a friction force is acting with a shear stress effect, which is an unfavorable situation that could influence the stress distribution.

There are two main aspects that has to be taken into account, so the first one is the soft tissue can tolerate moderately high load values applied intermittently and not continuously, and the second one at a sufficient high level of shear stress the pressure causing the blood flow occlusion will be reduced [1].

As we may observe from figure 3, we have found the possibility of monitoring the humidity level inside the cup, because of its importance in stress effects. Sweating for example will increase the shear stress. If the interface is extremely wet the shear stress will decrease, so a middle level will be recommended.

According to the mathematical equations (1) and (2) presented above, we have computed the maximum deformation of the external shape of the cell for the following numerical application: radius R=0.085 m; length L=0.17 m; pressure p = 105000 N/m^2; normal force N=1.5173e+03 N; the shear force was computed [2] F=6.38*N; thickness t=0.001 m; for the material the cell is made of E=440000 N/m^2. The result was ΔR = 0.0264 m. The maximum value measured with the encoder was 23.58 mm.

Considering the pressure variation as it is presented in the figure 2, we have verified the variation of the cell deformation, following the theoretical assessment. The figure 6 presents this variation.

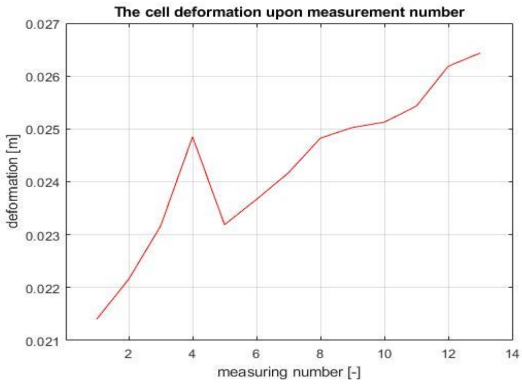

Figure 6: The variation of the cell deformation

As we may infer from the figure 6 the deformation is increasing more at the beginning of the working period, and after that it has a smooth variation.

As future work, we aim to analyse the influence of this contact force, directly proportional to the cell deformation area, dynamically during patient walking.

4. Conclusions

The paper points out the new proposed suspension system for the lower limb prosthesis based on a network with thin wall cells inflated with dry air.

The working cycle comprises an active period of inflation and a passive period of deflation affording the ventilation inside the cup. The humidity level has an important role regarding the friction with the stump.

The normal and shear forces acting at the suspension level are directly influenced by the area of the cell. This area is obtained by deformation of cell external shape, so the material properties and the process characteristics are essential.

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