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MODELING AND SIMULATION OF A KNEE ORTHOSIS: A PRELIMINARY STUDY

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Abstract: *Studies revealed that in the present times several persons suffer neural-motor injuries and need medical rehabilitation. The orthoses are used for improving the human motor functions or diminishing the symptoms of a disease. A research group from Transilvania University of Brasov works on a project that aims to develop and implement an intelligent orthosis for the rehabilitation of the inferior/ superior articulations of the persons suffering of neural-motor problems. The training of the injured member is done by the information received from the healthy member, through a command and control unit. The device is attached to the injured arm/ leg, in the region the rehabilitation is required and it may be programmed in terms of the desired task. The present work addresses the questions that occur during the stage of the mechanical system constructive design, related to the load transmitted to the orthosis during its operation phase. As a complementary method to the experimental approach, the computational modelling and analysis – FEM – is used for prediction of load distribution in the orthosis to be designed.*
Keywords: *medical rehabilitation, orthosis, stresses state, finite element modelling and analysis.*

1. INTRODUCTION

Within the medical rehabilitation a specific category is represented by the persons who have suffered neural-motor injuries. In order to improve the motor functions or to diminish the symptoms of the disease, the orthoses are used for quite a long time by now.
The present work is part of the research project ID_147, financed by the Romanian National Council for Scientific Research in Higher Education and developed at *Transilvania* University of Brasov. The project aims to develop and implement an intelligent orthosis for the rehabilitation of the inferior/ superior articulations of the persons suffering of neural-motor problems. The training of the injured member is done by the information received from the healthy member, through a command and control unit [1]. The device is attached to the injured arm/ leg, in the region the rehabilitation is required and it may be programmed in terms of the desired task.
One of the main roles of such an orthosis is to give the chance to the person with disability to have a life close as much as possible to the normal one. This can be achieved by the advantages such a solution offers: low cost, easy to adapt for personalized features.
There are several target groups that may benefit of the proposed mechatronic device: persons suffering an accident with partially or completely lost of the moving ability for a leg/ arm [2]; persons having been subjected to surgical intervention and who need locomotion rehabilitation; sportsmen in training or medical rehabilitation after suffering an accident; aged persons who need neural-motor rehabilitation; children with neural-muscular dystrophy, persons who have temporarily lost the locomotion function due to different reasons, etc.
The orthosis design process is complex, it involves the following steps: the biomechanical modelling of human locomotion for identification of the main functional features of the system to be designed, the development of the mechanical system – with static, kinematic and dynamic analysis, and, finally, the development of the command and control system – which should ensure the complete synchronizing between the healthy leg and the leg subjected to rehabilitation aiding the orthosis.
The present work addresses the questions that may occur during the stage of the mechanical system constructive design, related to the pressure transmitted to the orthosis during its operation phase. Although the pressure distribution can be measured experimentally aiding pressure sensors, due to "technical difficulties" such as the lack of an appropriate technology for experimental measurements the load transfer mechanism and the stress state is difficult to determine. As

a complementary method to the experimental approach, the computational modelling and analysis – FEM – represents a useful tool for prediction of load distribution in the orthosis to be designed.

2. THE MECHANICAL SYSTEM DESIGN

The mechanical system design is primarily based on the anthropomorphic dimensions of the human body in seated position [3].

Another important input information is related to the maximum movement of the leg. Studies performed in this subject put into evidence the following: the orthostatic displacement amplitude measured on vertical axis is of maximum 130° forward and of 180° when the leg is balanced back-forward. In the seated position, the displacement towards exterior of the stretched leg is of maximum 45°. In the same position, considering the knee as pivot, the shank can be moved towards left-right with maximum 30° and forward with 80-90° - optimum angle being of maximum 45°.

Considering these data, the orthosis mechanical design has been conceived, as presented in Fig. 1.

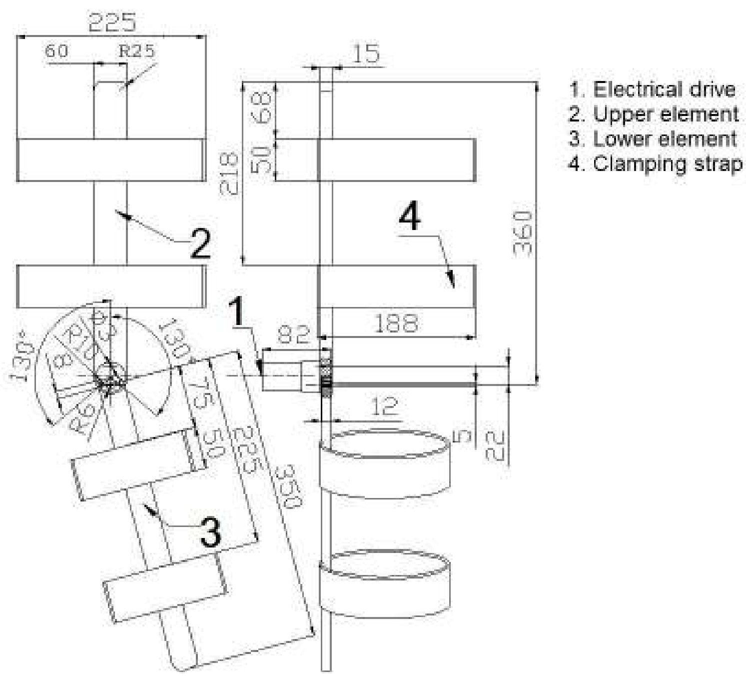

Figure 1: The mechanical system constructive design

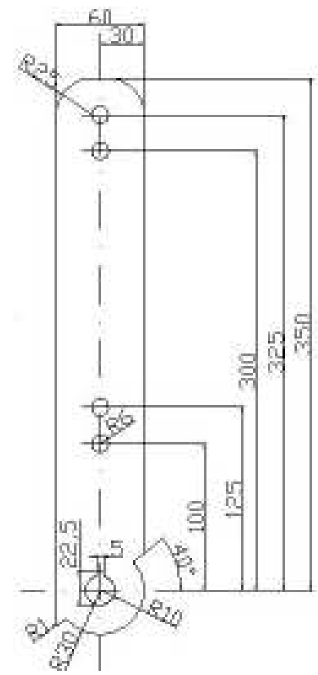

Figure 2: The upper element design

For walk identification the stereo metric techniques have been used. They allow the 3D reconstruction of the instantaneous points fixed on a mobile segment, called target points, which are represented by markers on the skin. The forces acting on the human body during walking are internal and external. The external ones are inertial and soil reaction. The soil reaction is measured and the inertial forces acting on each segment are estimated in terms of mass and gravity centre, by geometrical approximation (the irregular shapes of different segments are approximated by regular geometrical shapes, allowing a simple mathematical description). The internal forces are analytically estimated, assuming that the forces and moments between segments keep the adjacent segments in the same dynamic state as the one before their imaginary separation. Using this assumption, together with the anatomic and functional information about soft tissues, the internal load during walking can be estimated.

3. MODELING AND SIMULATION

In the preliminary study conducted and presented in this paper, of first interest is the behaviour of the orthosis upper element. The analysis performed aims to help the designer in choosing the most appropriate material for the construction of the parts. In these sense, the finite element model has been developed for the orthosis upper part and the static analysis had been performed, taking into consideration three types of materials: steel, aluminium and carbon fiber. The material properties are presented in Table 1. Figure 3 presents the finite element model of the orthosis upper part, considering the following loading conditions:

- the four upper holes of 12 mm diameter are clamped, simulating the orthosis attachment to the leg;
- the load of 1000 N is transmitted to the lower hole of 20 mm diameter.

The analysis results, for the three types of materials considered, are presented in Fig. 4 - Fig. 7 and listed in table 2.

Tabel 1: Material properties considered for the FE analysis

Property	Symbol	Units	Material 1 Steel (S97)	Material 2 Aluminium (L65)	Material 3 Carbon fibre (Std CF Fabric)
Young's Modulus 0°	E1	GPa	207	72	70
Young's Modulus 90°	E2	GPa	207	72	70
In-plane Shear Modulus	G12	GPa	80	25	5
Poisson's Ratio	v12		0.3	0.33	0.1
Density	ρ	g/cc	7.8	2.7	1.6

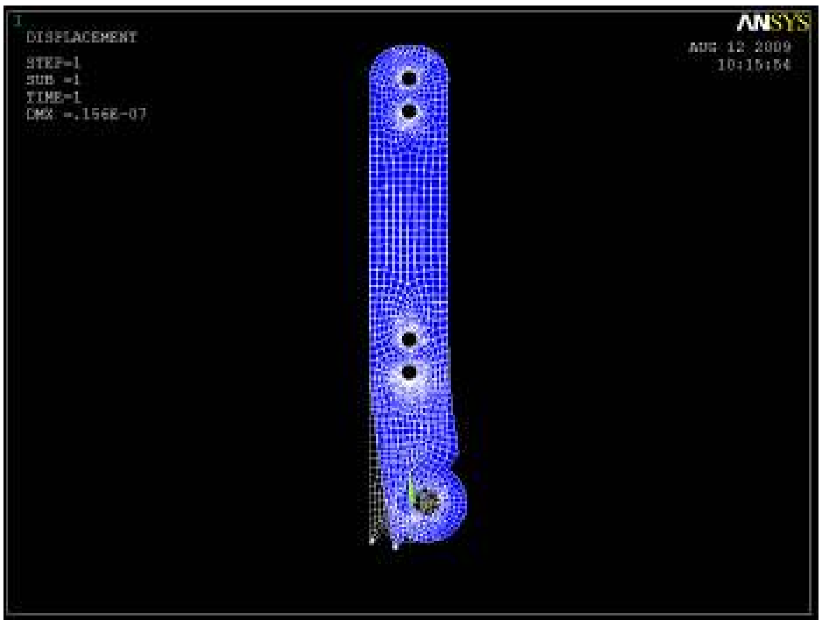

Figure 3: The finite element model of the upper element

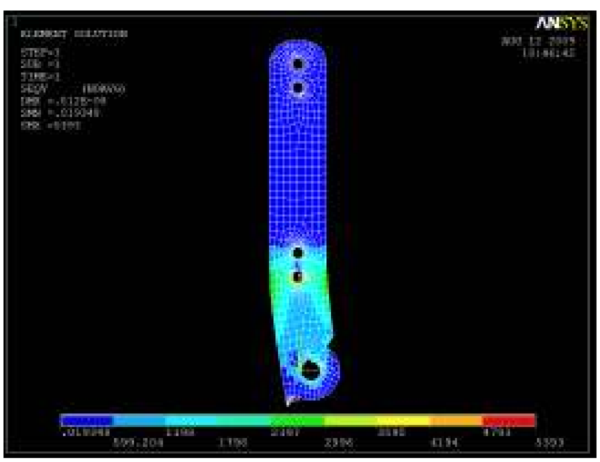

Figure 4: The element solution for material 1

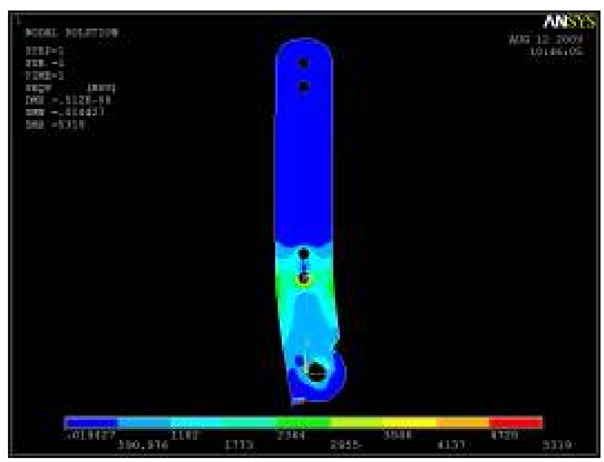

Figure 5: The nodal solution for material 1

The analysis leads to the conclusion that the lower-medium hole is the most sensitive one to the load, for all types of materials. As one may expect, the strain has the highest value for carbon fiber and the lowest value is registered for steel (Table 2).

Tabel 2: The maximum value of strain for the three materials, in the same loading conditions

		Material 1, Steel (S97)	Material 2 Aluminium (L65)	Material 3 Carbon fibre (Std CF Fabric)
Strain maximum value		0.256E-07	0.810E-07	0.818-07

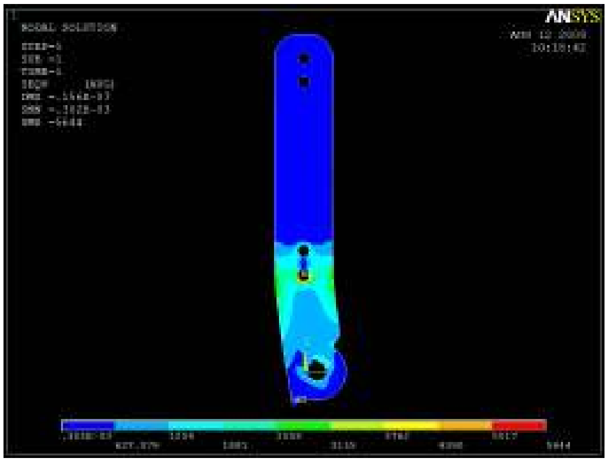

Figure 6: The nodal solution for material 2

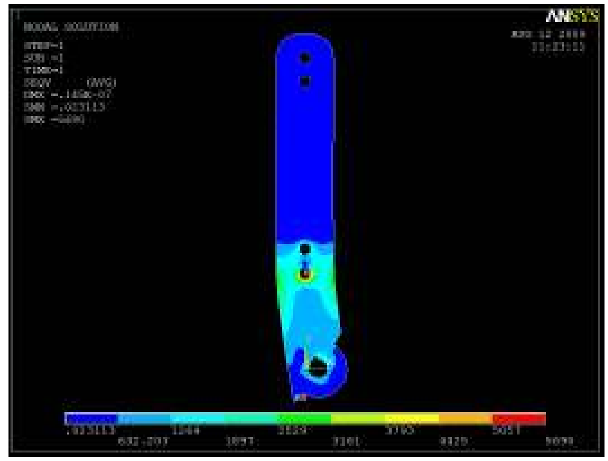

Figure 7: The nodal solution for material 3

Therefore, in the design of the orthosis upper element a specific attention should be paid to the deformation of the lower hole designated for clamping the structure on the leg. Whatever the material, this is the region the structure may break in the first place. Experimental tests for accurate load estimation is for utmost importance in the decision making process regarding the appropriate type of material for this part of the orthosis.

4. CONCLUSION

The present work addresses the questions that occur during the stage of the mechanical system constructive design of an orthosis, related to the load transmitted during its operation phase. As a complementary method to the experimental approach, the computational modelling and analysis – FEM – is used for prediction of load distribution in the orthosis to be designed. Three types of materials have been considered for the analysis: steel, aluminium and carbon fibre. Regardless the material type, the lower medium hole designated for clamping the structure on the leg is the most affected, the highest strain value being associated to the carbon fibre structure. The FEM model should be used complementary to the experimental measurements for accurate load estimation, leading to relevant information for the orthosis mechanical design.

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