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MODELING AND OPTIMIZATION OF A KNEE ORTHOSIS USING VIRTUAL PROTOTYPING

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Abstract: *Simpler foot orthoses allow the muscles, tendons and bones of the feet and lower legs to function at their highest potential. When appropriately prescribed, these orthoses can decrease pain and increase stability in an unstable joint, along with preventing potential progression or development of a deformity. Improved quality of life often results from the application of the principles of orthotics. In this paper the authors provide some models of virtual prototypes of orthoses device for foot rehabilitation where enforce some law of motions for optimizing the real motion for a healthy food.*

Key words: *CAD, Virtual Prototype, MSB, Orthoses, Motion.*

1. Introduction

An orthosis is a device used to support a weakened, unstable, injured or overloaded part of the body. There are orthoses for the back, the arm and shoulder, the lower limb, the neck and so on. Many types are produced just for the foot. Even a small custom made shoe insert which appears simple to the eye is the end result of a process of carefully matching a product to the specific needs of the recipient. We fabricate custom orthoses which are anatomically matched to each patient. Each custom made or custom fitted orthosis is prepared following a prescription by a physician.

Orthotics is an allied health care medical profession or field that is concerned with the design, development, fitting and manufacturing of orthoses, which are devices that support or correct musculoskeletal deformities and/or abnormalities of the human body. The term is derived from the "ortho", meaning to straighten. Sciences such as materials engineering, gait analysis, anatomy and physiology, and psychology contribute to the work done by orthotists, professionals engaged in the field of orthotics. Individuals who benefit from a complex orthosis may have an orthopedic condition such as scoliosis or a fracture or have sustained a physical impairment from a stroke or spinal cord injury, or a congenital abnormality such as spina bifida or cerebral palsy.

The professionals listed above: doctors and therapists, along with ancillary clinical support personnel, also can be found fitting orthotic devices. The orthotist generally works by prescription. Some prefabricated orthoses can be found in a pharmacy. Some prefabricated orthoses, or supports, are soft and can be purchased as a retail item. Care in proper fit of any device that applies force to the body must be taken to

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ensure good results and to prevent unwanted problems from an orthosis that is too tight or otherwise uncomfortable [8].

2. Orthoses Function

Foot orthotics takes various forms and they are constructed of various materials. All have the goal of improving foot function and minimizing stress forces that could ultimately cause foot deformity and pain. There are three broad categories of orthotics: those that primarily attempt to change foot function, those that are mainly protective or accommodative in nature, and those that combine functional control and accommodation. While orthotics can be made by several different processes, most orthotist's make a plaster mold of the patient's foot and send it to a laboratory with a prescription. At the lab, technicians pour plaster into the mold, and when it hardens; it exactly reproduces the bottom of the individual's foot, although it is common for labs to "cast correct" by partially filling in the arch. This decreases the arch height of the orthotic and is done for comfort reasons.

Rigid orthotic devices are designed to control foot function, and may be made from a firm material such as plastic or carbon fiber. These types of orthotics are mainly designed to control motion in two major foot joints, which lie directly below the ankle joint. This type of orthotic is often used to improve or eliminate pain in the legs, thighs and lower back due to abnormal function of the foot.

Soft orthotic devices help to attenuate shock, improve balance and take pressure off uncomfortable or sore spots. They are usually made of soft, compressible materials. This type of orthotic is effective for arthritis or deformities where there is a loss of protective fatty tissue on the side of the foot. They are also helpful for diabetic people [5], [8].

Semi-rigid orthotic devices are often used to treat athletes. It allows for dynamic balance of the foot while running or participating in sports. By guiding the foot through proper functions, it allows the muscles and tendons to perform more efficiently. It is constructed of layers of soft materials, reinforced with more rigid materials.

Calibrated orthotic devices are those based on the correction model and manufacturing technique advocated by Glaser (MASS position). It factors in the individual's body weight, foot flexibility and activity level to deliver a custom calibrated level of support that delivers firm but comfortable functional control while maintaining the properties of an accommodative device. Pedorthists, Osteopaths, Podiatrists, Chiropractors, physical therapists and sports medicine practitioners will often recommend custom foot orthoses as part of a treatment regimen. They are prescribed to reduce the symptoms associated with many foot related pathologies, provide support, accommodate foot deformity, provide better positioning, relieve pressure on a certain area of the foot and improve the overall biomechanical function of the foot and lower extremity.

3. The Virtual Prototypes of Orthoses

One of the most important for virtual prototyping concept is to test as it simulates. Physical testing of the hardware prototypes in classical (traditional) laboratory tests in various configurations involves high costs and time. The virtual prototyping concept it's used to reproduce the test procedures and operating conditions of the product at much lower cost and time. Virtual prototyping allows building models that simulate the actual operation of the product, for example facilities (stands) for testing any type of dynamic system. Testing is an important component of virtual prototyping during the design cycle. Virtual testing is performed continuously while the physical testing is introduced only in certain stages to model virtual revalidated after a finishing significant.

To simulate the dynamics of orthoses's mechanical system was used specialized software MBS (multi-body systems) and this software involves going through three stages:

- preprocessing (system modeling);
- processing (model run);
- postprocessing (processing results).

In mechanical systems using dynamic simulation are frequently addressed three working models:

- structural model, containing only the elements and links between them (joints) and which is fixed transmission provided laws of movement (mobility system);
- kinematic model, which, in addition to the structural and geometric parameters includes defining the system and to establish laws of motion (position, speed and acceleration) of elements in the movement of time (known/required) element leader;
- dynamic model, which, in addition to the kinematic model, and contains the mass of elements (mass, moments and products of inertia) and the forces (external and internal) acting on the system, this model determines the movement elements under the action of forces.

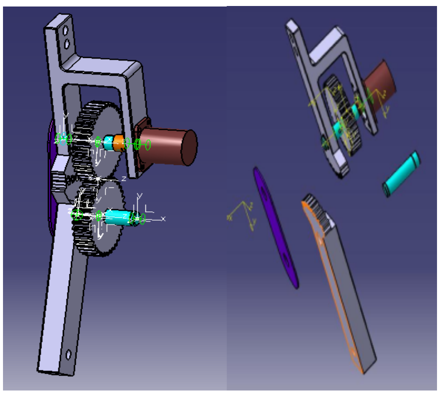

Fig. 1. *The virtual prototype for ortheses device with gears joint (components view)*

In this case was creating two model orthoses device with particular design and functionality. For choose the optimizing model to be made for laboratory testing and we make two virtual prototypes using CAD models and MBS software [1-4].

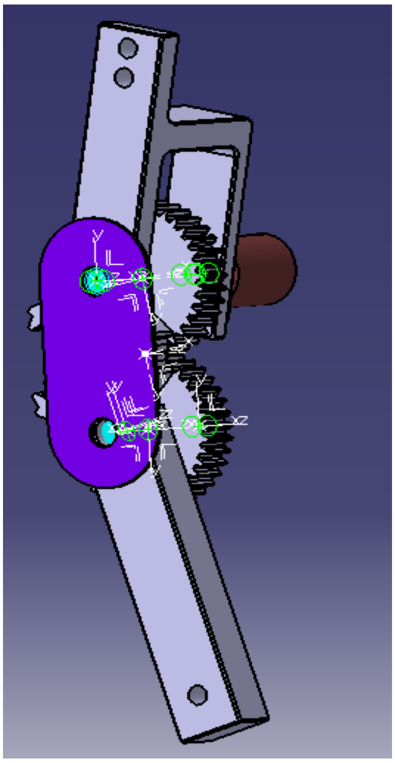

Fig. 2. *The virtual prototype for ortheses device with gears joint (overview of the system)* [8]

The virtual prototype for ortheses device with gears joint is a model which uses two gears to improve control of movements as well as to withstand high forces that occur when the load of the orthoses is used in rehabilitation programs for patients with mobility problems.

The steps followed are:

- designing the CAD models of the orthoses's mechanical system components;
- computing the mass and inertia properties of the bodies in a MBS software environment, Figures 1, 2 and 3;

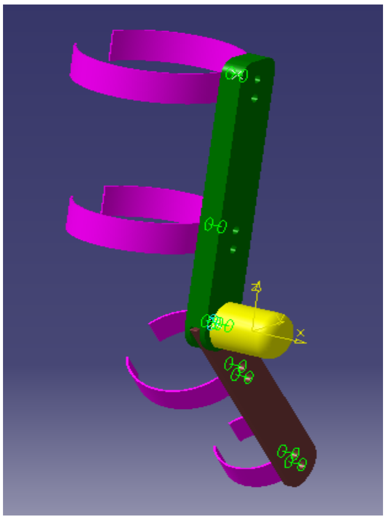

Fig. 3. *The virtual prototype for ortheses device with revolute joint* [8]

- modeling the connections between the bodies (geometric restrictions/constraints), in this case by using cylindrical joints;
- modeling the motion law of the driving element, using a hyperbolic function, thus being possible to determine the torque that is required to generate the movements (the task that occur in the joint).

After calculating, the law of motion with hyperbolic mode was simulated in the dynamic movement and the results appear as can be seen in the Figures 4, 5 and 6.

Following mathematical modeling and simulations the results were not what as you want. To trigger the mechanical design was required forces and torques too high and that determine sizing electrical system that was to design and to be used to control mechanical system.

Thus it was decided redesigning the mechanical system by introducing a gear mechanism to be designed to amplify forces and torques calculated their previous system. This resulted in the new model appears in the following figures.

The new model has a new concept comprising a gear mechanism consisting of a housing with an internal gear ring, which is rigidly connected to the housing by a clamp.

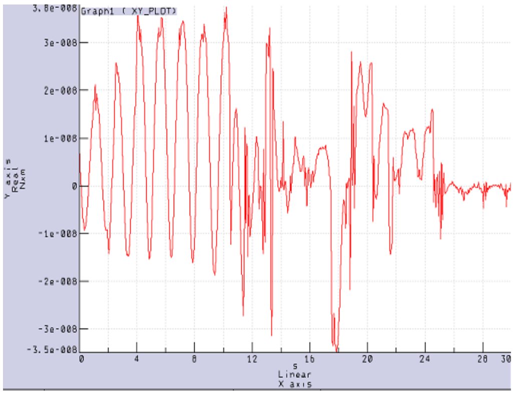

Fig. 4. *The force, that occurs in the revolute joint of virtual prototype, from revolute axis (z-axis from model)*

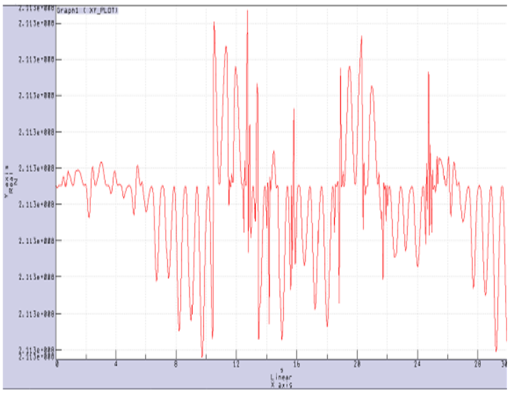

Fig. 5. *The force, that occurs in the revolute joint of virtual prototype, perpendicular to the axis of rotation (y - axis from model)*

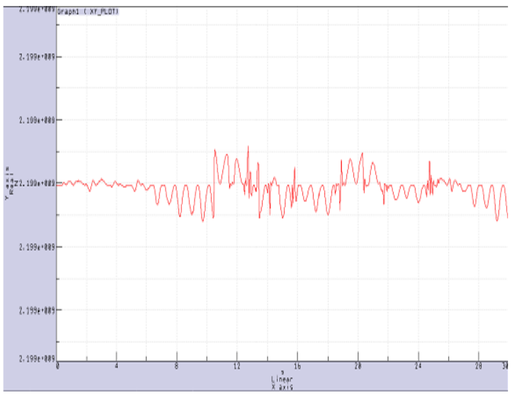

Fig. 6. *The torques, that occurs in the revolute joint of virtual prototype, from axis of rotation (z - axis from model)*

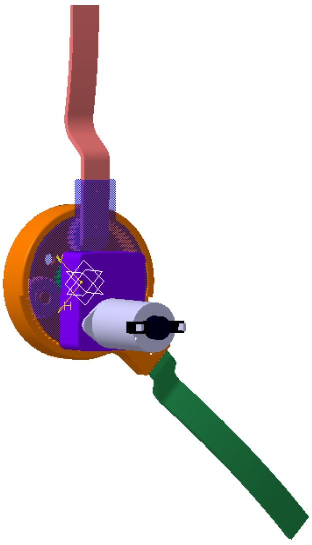

Fig. 7. *The new redesigning model with gear mechanism (lateral view)* [8]

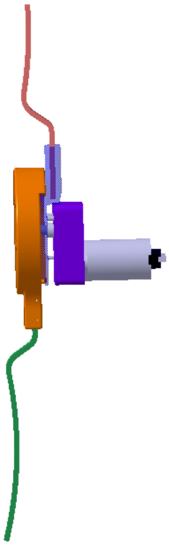

Fig. 8. *The new redesigning model with gear mechanism (front view)* [8]

The ring gear of the housing is in engagement with the gear position of the satellites and they engage with a toothed wheel which transmits the movement to the second flange, as in the Figure 7.

Testing the new model at the virtual prototype level, results a new parameters. The new forces and moments of torque have lower values than previously studied systems, these being required for to calculate and to design the electronic system which will control the orthoses.

Simulation results show that the forces and torque are lower than previous models, this situation gives us the solution for the electric motor to be mounted in the console pinion shaft and this shall be transmit the movement to the satellites and from there to the mechanism's housing, Figures 8.

The simulation results lead to the conclusion of making a real prototype of the mechanical system and also achievement of the electronic controls to go to lab tests to perform the operation and effectiveness of the orthosis in order to produce concrete effects of locomotors recovery patients with problems, arrived in such cases due to accidents [5-7].

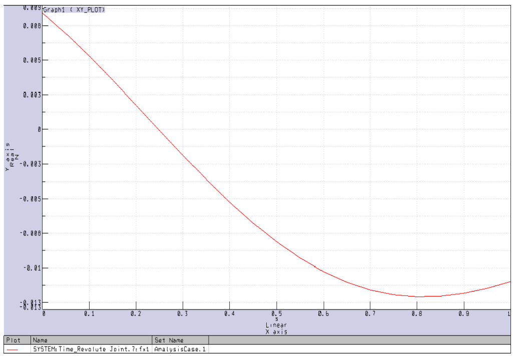

Fig. 9. *The new force, that occurs in the revolute joint of virtual prototype, from revolute axis (z-axis from model)*

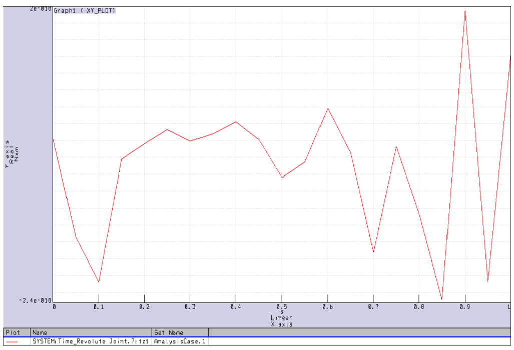

Fig. 10. *The new torques, that occurs in the revolute joint of virtual prototype, from axis of rotation (z - axis from model)*

4. Conclusions

The mechanical models designed to be used as orthotics have been studied in order to measure the mechanical parameters (forces and moments), and to assist in choosing electric drive system that control the orthoses.

After the virtual prototypes simulations reached the following conclusions: each of the models are functional in virtual prototyping but only once will be choice to be manufacturing for laboratory testing in real mode. Most important is the values of forces and torques calculated from mechanic system, which are necessary for choose the electrical motors for orthoses motion, as in the Figures 9 and 10.

Features of the new model designed and researched, is improved, that new track parameters, forces and moments of torque, have lower values than previously studied systems. The forces are with 55% lower than others forces from others systems and the torque with 34% lower than others study systems, which shows a significant improvement.

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