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DETERMINATION OF THE STRESS-STRAIN STATE OF THE STRUCTURAL ELEMENTS OF THE ELBOW ORTHOSIS PROTOTYPE

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Abstract: Rehabilitation of patients should not be limited only to the time of intensive treatment in the hospital, but also to therapy in the following stages, especially during daily activities, if the patient's condition requires it. Such devices that help the patient during postoperative or post-traumatic rehabilitation after joint damage are orthoses. This paper provides an overview of various types of orthoses, selects material for structural elements of the orthosis, and determines the stress-strain state of the sample under study. Also, based on the necessary operating conditions, the engine and bevel gear are selected. The model of the orthosis prototype is presented and the stress-strain state of the structural elements of the elbow orthosis prototype is determined.

Keywords: elbow orthosis, stress-strain state, aluminum plates, modeling prototype, FEMAP with NASTRAN.

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1. Introduction

Orthotics has long proven itself as a method of rehabilitation, prevention and treatment of lost functions of the musculoskeletal system during post-operative or post-traumatic recovery of joint damage. This method consists in fixing the joint with an orthosis, in the correct anatomical position, preventing incorrect movements.

This device should be quite compact, have a low weight for comfortable use by the patient, be rigidly attached to the hand, and at the same time be able to perform the most approximate functions of the hand of a healthy person.

Over the past two decades, upper limb exoskeletons used in industry and rehabilitation have attracted attention from the biomedical and engineering sectors. Technology is becoming one of the key solutions for physically weak people or people with disabilities [1].

Systems such as Ekos Vest [2] and FORTIS [3] have been developed to improve performance and user strength.

Conditionally active elbow orthosis can be divided into three parts: mechatronic, which controls and includes an actuator; mechanical, which is considered in this article, which is responsible for the transmission of motion and the body in which all structural elements are mounted, which is directly attached to the patient's hand. In the role of an actuator in active elbow orthoses, a stepper motor [4] is used, and such devices are usually controlled using EMG sensors [5], which measure the activity of signals generated by muscles. An Arduino Uno microcontroller will be used for signal processing.

Mechanical design and kinematic analysis are the most important issues in the development of an ergonomic exoskeleton system. In a number of scientific articles, exoskeletons of the upper limbs are considered, especially for industrial and medical applications. For example, a research prototype of an upper limb exoskeleton: Shoulder Exoskeleton with Parallel Drive [6], Robotic Suit for Upper Limbs (CRUX) [7], Upper Limb Exoskeleton [8], UB-EXO developed by Aalborg University [9], Compact Scissors 3 degrees of freedom (DOF) for the upper limb exoskeleton [10], NESM [11], Exo jacket Stuttgart [12], CAREX 7 [13], [14], 6-DOF upper limb exoskeleton model [15] and many others.

However, given the extensive research on upper extremity exoskeletons, very few articles report on exoskeleton construction related to complex anatomical movements in the shoulder and wrist joints of the arm and hand in general.

Existing commercial offerings, for example [16], as well as prototypes, for example [17], [18] are bulky devices intended exclusively for home rehabilitation, which have a high cost.

In connection with the above, the development of an orthosis that can perform the motor function, in this case, of the elbow joint, instead of a person is relevant.

2. Orthosis design

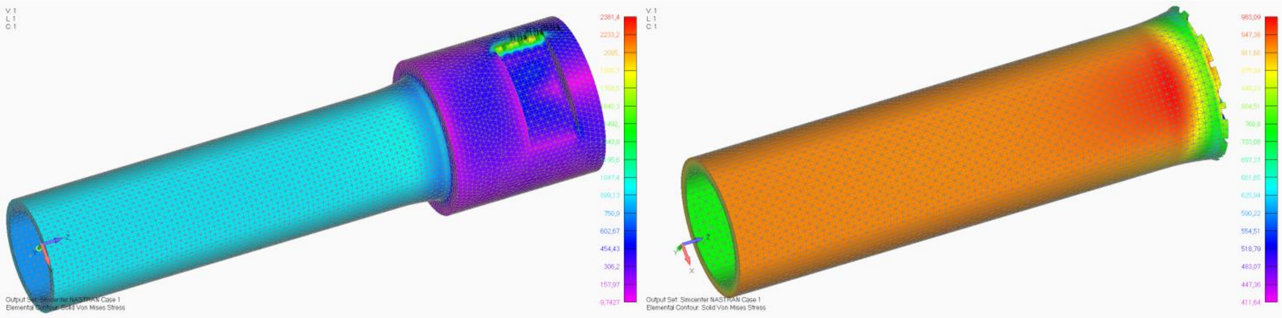
2.1. Selection and study of material

Aaccording to the review of the literature, it can be concluded that the orthosis material should be: light weight, reliable and durable. To meet the given conditions, aluminum alloy D16T was chosen. This is an aluminum alloy of increased strength, which is 3 times lighter than steel, which is not inferior to it in terms of hardness and some characteristics. The main alloying elements are manganese and copper, which increase the consumer qualities, stability and durability of the material. It belongs to the alloys of the Al – Cu – Mg system (aluminum, copper, magnesium) and is alloyed with manganese. D16T aluminum is a heat-strengthened structural material. The alloy goes through the procedure of natural aging even at the stage of production of blanks. The material is plastic, has low electrical conductivity and thermal conductivity. The main disadvantage is low anti-corrosion resistance, which is partially leveled by coating, anodizing and other methods.

The experimental tubular sample was modeled using FEMAP with NASTRAN for torsion. The nature of fastening is adopted such that there is no rotation and movement perpendicular to the plane of intersection, in the cylindrical coordinate system.

The finite-element mesh is made in automatic mode based on the geometry, provided that there are at least two finite elements along the wall thickness of the sample.

Using the FEMAP software, the stress-strain state (SSS) of the sample in the elastic region was calculated (Fig. 1).



a) b)

Fig. 1 Stress a) and strain b) distribution in the specimen

As a result of modeling, it was determined that the stress concentration coefficient $\alpha = \frac{\sigma_{max}}{\sigma_{nom}} = \frac{927}{925} \approx 1.002 < 1.05$, where σ_{max} – maximum calculated stresses (MPa), and σ_{nom} – nominal stresses (MPa). It was established that there is no high stress concentration, that is, the test sample was designed correctly. The material satisfies the necessary conditions, therefore it was chosen for use in the design of the plates of the elbow orthosis prototype.

2.2. Mechanics and actuation

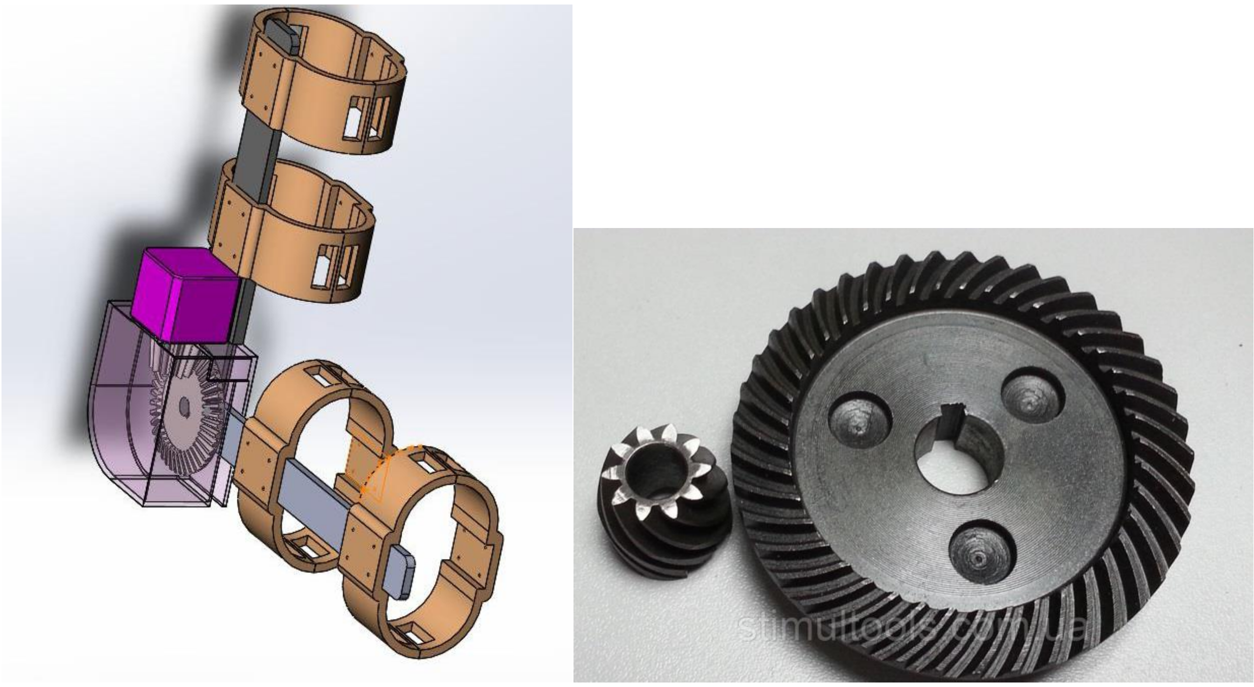
According to the literature review, the mechanical part of the orthosis should consist of three main parts, such as: the upper plate, the lower plate, and the reducer, which will transmit the torque.

Fixation of this orthosis on the patient's arm is performed by means of bandages attached in two places of each of the plates. On one of the plates, an engine is installed that activates the gear. The finished assembly is shown in Fig. 2 (engine, gear, protective case and tires are installed separately).

For the availability of orthosis manufacturing, a bevel gear with a circular tooth profile (d1 14*74 / d2 9*21 /h2 21) was chosen (Fig. 2, b).

Based on the detail drawings, models and assembly of the elbow joint orthosis were created in the Kompas 3D V18 program. The connection of the lower plate with the gear wheel is made using three standard bolts A.M5-6gx10 [19]. The plates are connected to each other using the A.M6-6gx16 bolt [19] and the A 8.37 washer [20].

The following conditions were used for the design of the mechanical part: full flexion and extension of the arm of an average adult man 150-170 degrees in 1s, an additional load of 1 kg, which the patient must lift with the help of an orthosis. In turn, the moment of force, taking into account the moment of the hand, moment of the orthosis and additional weight, should be at least 17 Nm, then the required power is 25.6 W. The necessary characteristics are provided by the DSHY 200-1-1 engine.



a) b)

Fig. 2 Elbow orthosis model a) and bevel gear b)

2.3. Numerical modeling of structural elements of the prototype

To determine the stress-strain state (SSS) of the assembly, the model is imported into FEMAP with NASTRAN, and the contact planes are assigned with the subsequent addition of connections between them (Fig. 3).

Separate finite element meshes are created for each part to optimize the calculation according to PC power. For this, the lower plate was divided into two parts, where the finite elements are larger and do not affect the accuracy of the calculation. At the points of application of forces, the mesh has a cluster of nodes. The total number of created finite elements is 30005, and nodes are 50367.

Boundary conditions are applied, taking into account the Saint-Venant principle. Therefore, the end of the plate is fixed, and the forces are applied at the place of fixation of the bandages and on the plane of the tooth. For example, forces of 10 N at the edge of the bottom plate and 20 N at the point of engagement of the wheel were chosen.

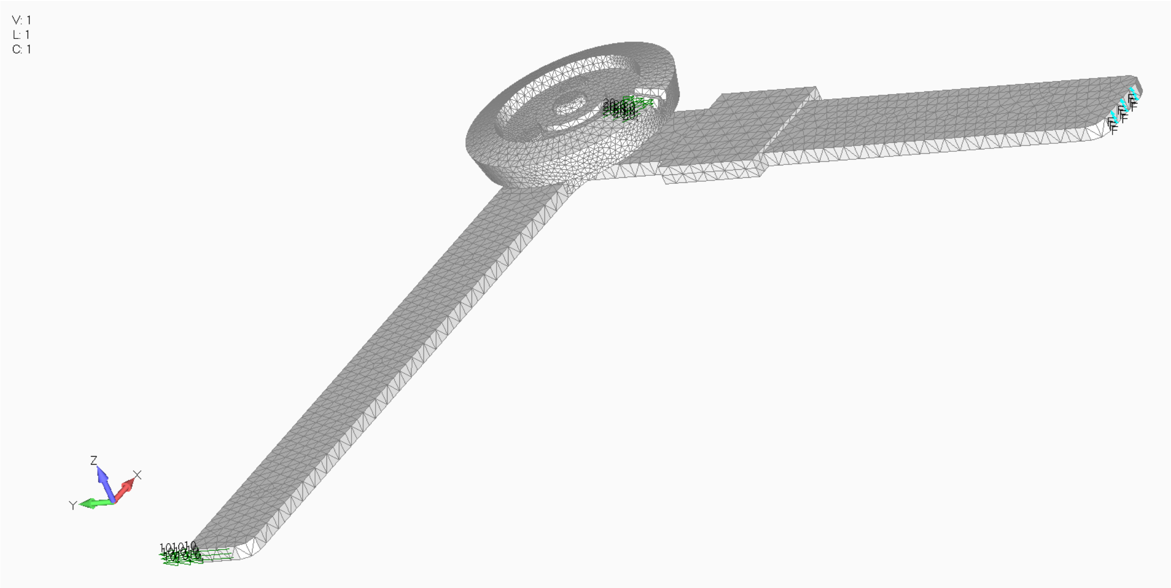
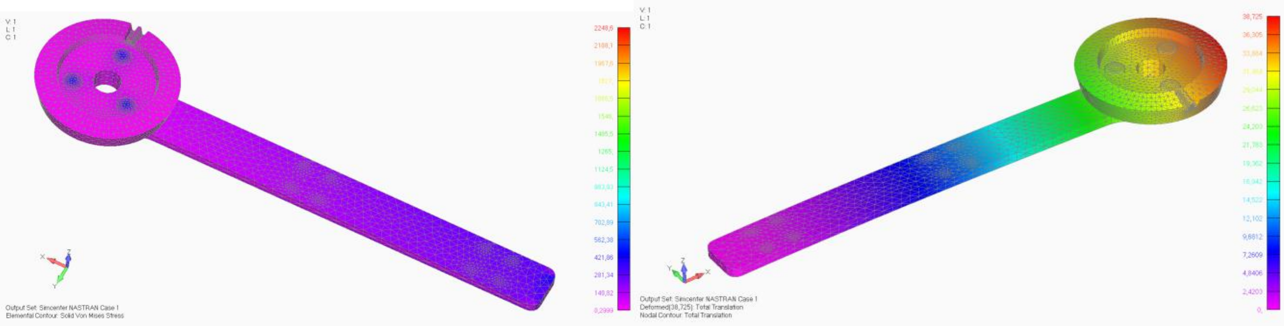


Fig. 3 Calculation scheme

After the calculations, a graphic distribution of stresses according to Mises according to the model (Fig. 4, a) and deformations (Fig. 4, b) was obtained.

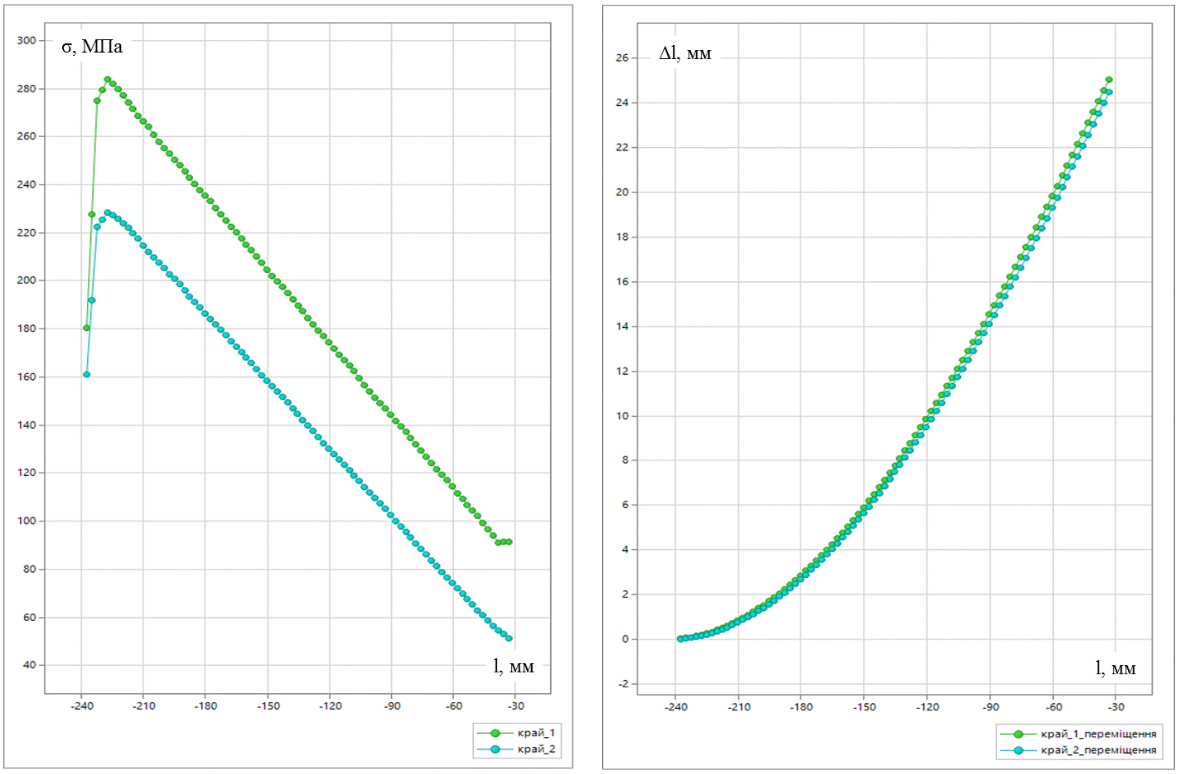


a) b)

Fig. 4 Von Mises stress a) and strain b) distribution in the orthosis prototype

From the obtained data, it can be seen that there is a concentration of stresses in the wheel-plate fastening, which does not affect the studied elements, due to the above-mentioned Saint-Venant principle.

Graphs of Mises stress distribution and displacements along the axis of the plate at the edges are shown in Fig. 5.



a) b)

Fig. 5 Graphs of Mises stress distribution a) and displacements of plate faces b)

3. Conclusion and Future Work

A new model of a prototype orthosis for the rehabilitation of patients after traumatic treatment is presented. The device requirements listed in the introductory section have been taken into account.

Examining the graph of stresses along the axis of the plate at the edges, it was established that the dependence is linearly proportional and the value of the stress decreases in the direction of the center of the connection of the parts of the orthosis. Analyzing the graph of movements, it can be seen that the movements have a quadratic dependence and do not particularly differ from one axis of symmetry.

The prototype model is designed for the elbow joint, but can be modified for other joints.

It is planned to recognize the stress-strain state of the bolt connection, consider contact problems and the entire model of the elbow orthosis prototype.

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