International Science Journal of Engineering & Agriculture
2022; 1(5): 77-85
https://isg-journal.com/isjea/
doi: 10.46299/j.isjea.20220105.10
ISSN: 2720-6319

Solution of the contact task of the elbow orthosis prototype

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To cite this article:
Lavrenko Iaroslav, Lebedynskyi Bohdan. Solution of the contact task of the elbow orthosis prototype. International Science Journal of Engineering & Agriculture. Vol. 1, No. 5, 2022, pp. 77-85. doi: 10.46299/j.isjea.20220105.10.
Received: 10 12 2022 p.; **Accepted:** 10 17 2022 p.; **Published:** 12 01 2022 p.

Abstract: Over the past two decades, upper limb exoskeletons used for service delivery and rehabilitation have attracted attention from the biomedical and engineering sectors. Technology is becoming one of the key solutions for physically weak or disabled people. Mechanical devices were developed to improve the performance and strength of the user. Devices that help the patient during postoperative or post-traumatic rehabilitation after joint damage of various types are orthoses. There are different types of orthoses, such as mechanical, active with EMG functions, exoskeletons, and others. In this work, an overview of various types of orthoses is given, problems of fixing orthoses elements are considered. In the review of the literature related to these studies, the advantages and disadvantages of bolted connections are given. Two contact problems of the orthosis were also considered and the stress-strain state of the bolted joint of the structural elements of the elbow orthosis prototype under study was determined using the FEMAP with NASTRAN software package. Based on the necessary operating conditions, a prototype model of the orthosis was presented.
Keywords: elbow orthosis, bolt joint, stress-strain state, aluminum plates, modeling prototype, FEMAP with NASTRAN.

1. Introduction

One of the methods of rehabilitation, prevention and treatment of lost functions of the musculoskeletal system during post-operative or post-traumatic recovery of joint damage is orthotics. The method consists in fixing the elbow joint with an orthosis, in the correct anatomical position, preventing incorrect movements.

A number of requirements are put forward to orthoses, such as compactness, low weight and creating movements as close as possible to the movements of a healthy person.

During the design of the orthosis and exoskeleton in general, its mobility is important, namely the details and actuators with the help of which movement will occur. Therefore, it is advisable to review the literature related specifically to the structure and individual details of the orthosis of the upper limbs. The orthosis of the elbow joint can be conventionally divided into several parts: the mechatronic one, which controls and includes the actuator, the mechanical one, 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. A compact motor [1] is used as an actuator in active elbow orthoses, and such devices are usually controlled using EMG sensors [2] that measure the activity of signals generated by muscles.

2. Object and subject of research

The object of the study is the elbow joint orthosis, since in view of the extensive studies of exoskeletons of the upper limbs, very few articles cite the construction of the exoskeleton, which reproduces complex anatomical movements in the shoulder and wrist joints of the hand and the hand as a whole. Existing commercial offerings and prototypes are bulky devices designed exclusively for home rehabilitation that have a high cost. There is also no information on the reliability of the orthosis design elements and the orthosis as a whole.

3. Target of research

The main task of this scientific work is the modeling and research of contact problems of the structural elements of the elbow joint orthosis. Determining the stress-strain state of the bolted connection that fixes the orthosis plates, on which the orthosis fiction elements are attached to the patient's arm and the motor and orthosis control units as a whole. The material, design and determination of the stress-strain state of the orthosis plates were referred to in scientific work earlier.

4. Literature analysis

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, in the following works, studies of upper limb exoskeletons prototypes are considered: shoulder exoskeleton with parallel drive [3], robotic suit for upper limbs (CRUX) [4], upper limb exoskeleton [5], UB-EXO developed by Aalborg University [6] , compact 3-degree-of-freedom (DOF) scissors for the upper limb exoskeleton [7], NESM [8], Exo-jacket Stuttgart [9], CAREX 7 [10], [11], 6-DOF upper limb exoskeleton model [12] and many others.

In [13], the main topic is the elbow joint mechanism designed to increase the ratio of torque to weight. As the authors point out, after reviewing the literature, it was determined that most elbow exoskeletons developed or commercially available have motors directly connected to its joint.

Connections of orthosis elements to which the motor is attached, movable elements that change the direction of movement, orthosis control elements, such as EMG, are fixed by means of a bolted connection [14].

Reliability and strength of the bolted connection of parts depends on many structural and technological factors. For example, from the materials, the type of bolted connection, the tightening force of the bolts, the nature and magnitude of the load, and others [15, 16, 17]. In work [18], it was established that the bolted connection works not only in shear, but also in bending. The results of fatigue studies of bolted joints are presented in scientific papers [19, 20].

The magnitude of the torque when tightening the bolts has a significant impact on the reliability of the bolted connection. In the course of research, it was established that with an increase in the tightening moment, the bearing capacity increases [21, 22, 23, 24, 25, 26, 27]. In work [24] it is stated that the increase in rigidity is possible due to the reduction of shear deformations in the connection.

In [28], it is stated that the consideration of bending stresses arising as a result of the appearance of eccentricity in the calculations of the durability of a bolted connection is not sufficiently studied. This can be done only on the basis of refined numerical calculations.

In connection with the above, the development and research of an elbow orthosis that can perform a motor function instead of a person is relevant.

5. Research methods

As mentioned above, the orthosis should be compact, light in weight and perform the functions assigned to it. The following conditions were used for the design of the mechanical part: full flexion and extension of the arm of an average adult 150-170 degrees in 1s, an additional load of 1 kg, which the patient must lift with the help of an orthosis. Then according to the calculations, in turn, the moment of force, taking into account the moment of the hand, the moment of the orthosis and the additional weight, should be at least 17 Nm. Taking into account the obtained results, a model and assembly of an elbow joint orthosis was created in the Kompas 3D V18 environment (Fig. 1).

The orthosis is fixed on the patient's arm due to bandages attached in two places of each of the plates. On one of the plates, an engine is installed that activates the bevel gear. The connection of the lower plate with the gear wheel is made by three standard bolts A.M5-6gx10. The plates are connected to each other using the A.M6-6gx16 bolt and A 8.37 washer [14].

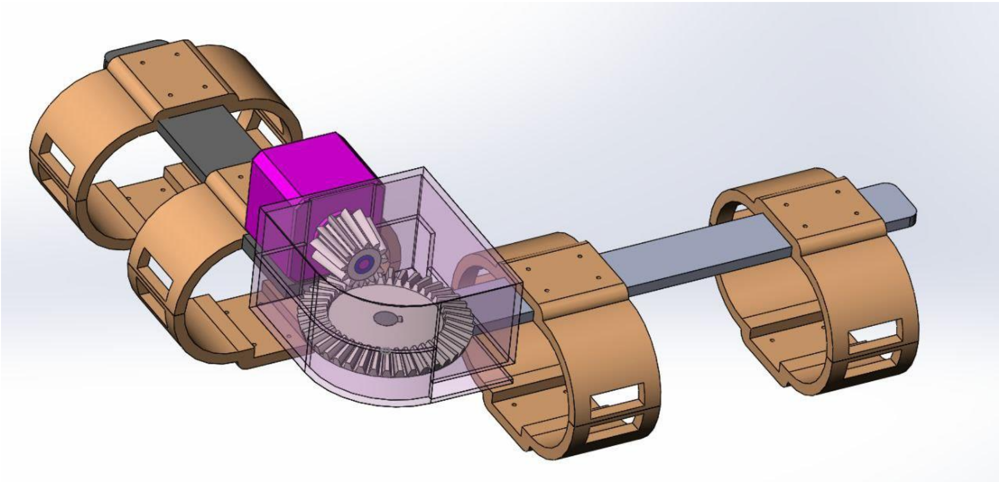


Fig. 1. Elbow orthosis model.

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

For the calculation of the first contact task between the gear and the plate, a simplified model of the conical gear and bolts is considered, for fixing the gear with the plate, for the optimization of the overlap and calculation of the mesh of finite elements (FE). When modeling a gear, it is enough to specify only one tooth profile, and replace the others with one average thickness. Bolts are simplified by removing the slot on the head, as well as the chamfer of the bolt rod. The simplified model is shown in Fig. 2.

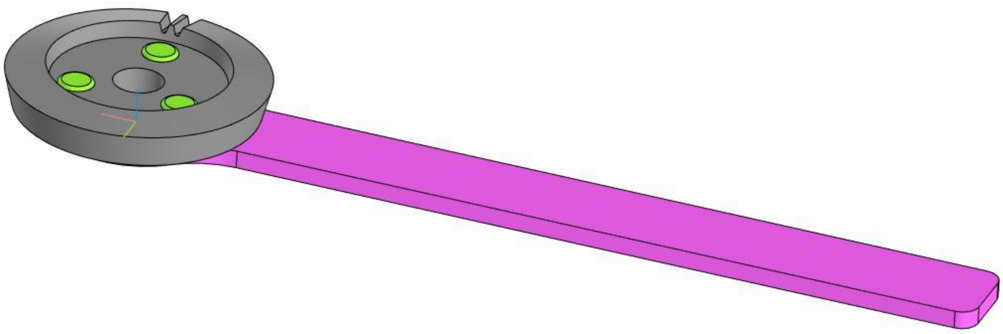
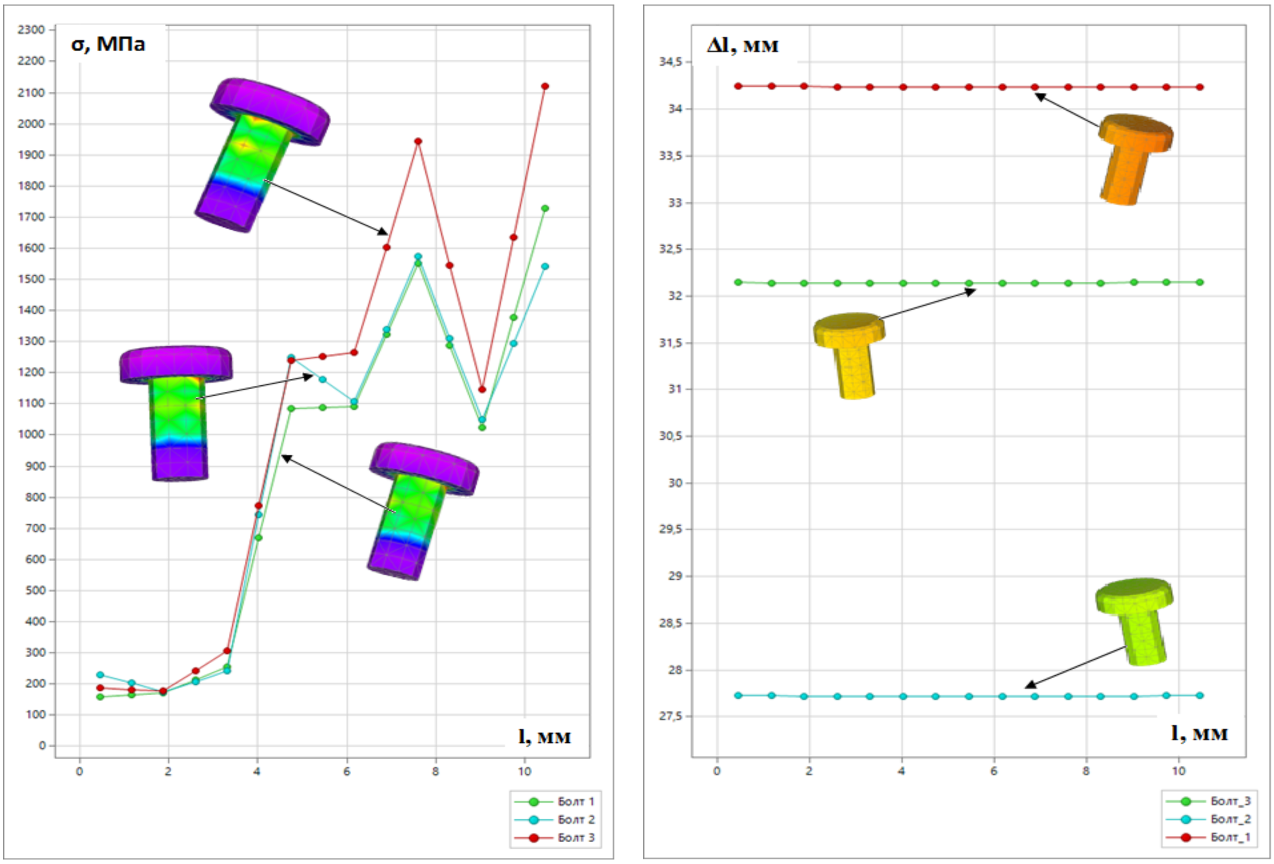


Fig. 2. A simplified 3D orthosis model for the first contact task

Boundary conditions were applied taking into account the Saint-Venant principle. Fixation of the end of the plate was performed, and forces were applied at the place of attachment of the bandages and on the plane of the tooth. For calculations, forces of 10 N at the edge of the lower plate and 20 N at the point of engagement of the wheel were chosen.

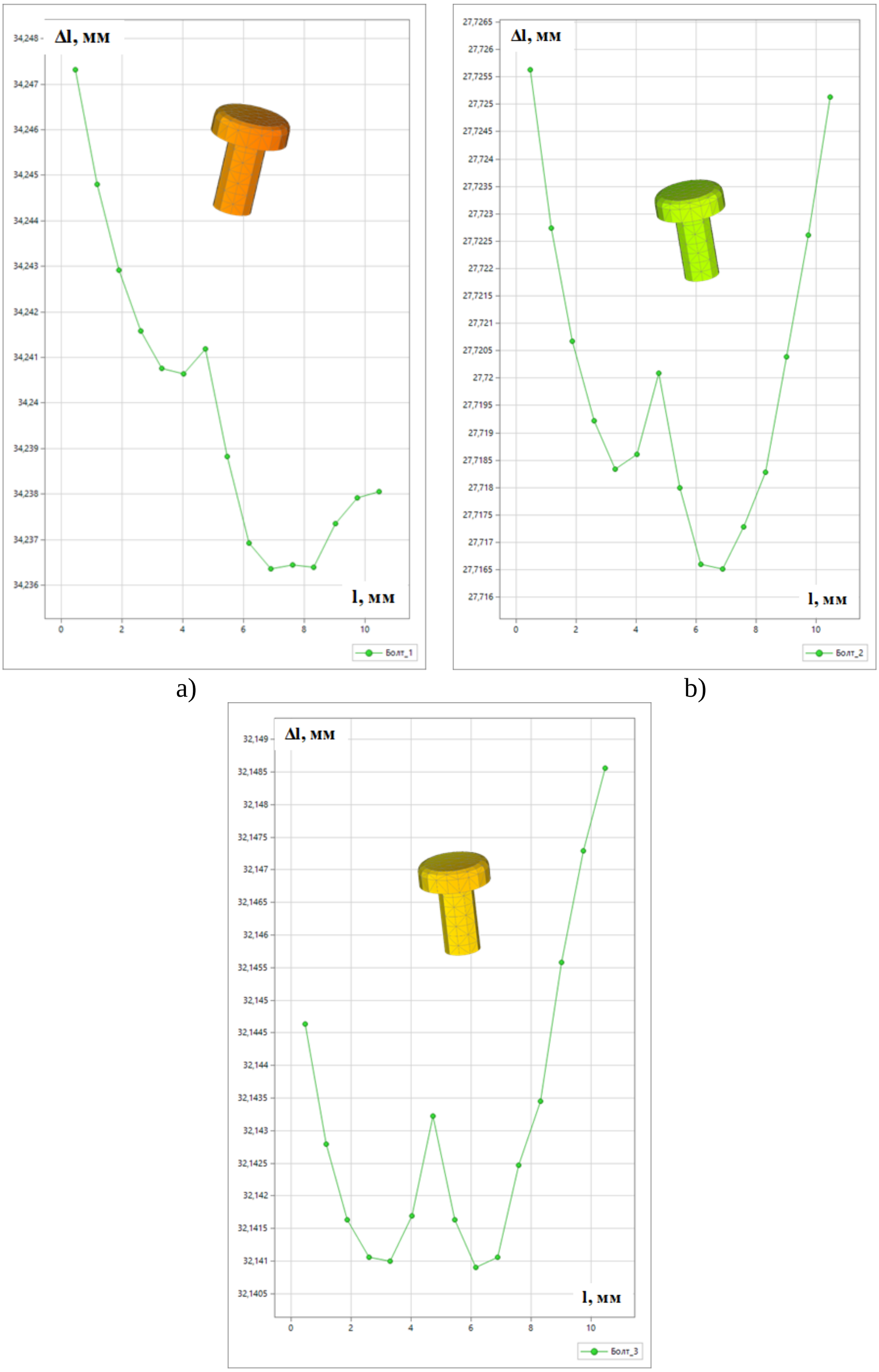
To consider the stresses on the bolt rods, let's choose tangent lines to the surface of the bolt rod. The obtained results of numerical calculations of the stress-strain state are shown in Fig. 3.



a) b)

Fig. 3. Von Mises stress a) and strain b) distribution in the bolt joint orthosis prototype

In Fig. 4 provides a detailed analysis of the distribution of movements along the bolt rod.



a) b)

c)

Fig. 4. Strain a), b), c) distribution in the bolt joint orthosis prototype

Along the rods of the bolts, the stress-strain state has a similar character, but in the places where the diameter of the bolt changes, there are spikes in stress concentration, which is indicated in the graph (Fig. 3, a). For further design and modeling for structural reasons, you need to choose a bolt with a larger diameter. And according to the graphs in the figure (Fig. 4), the largest movement is in the first bolt.

To calculate the second contact task, the connection between both plates of the orthosis, a simplified model of the bolt and upper plate of the orthosis was added to the previous model. The simplified calculation model is shown in Fig. 5.

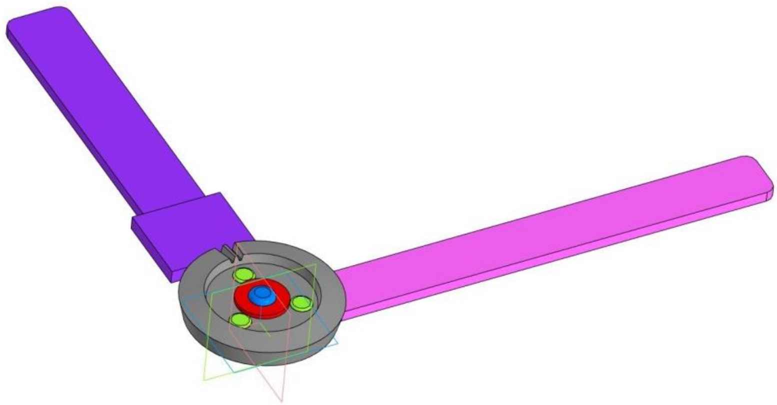
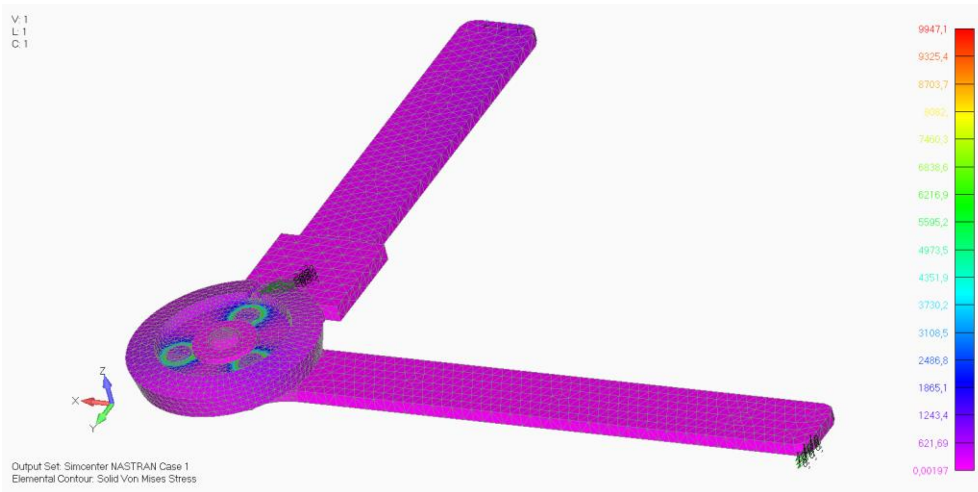
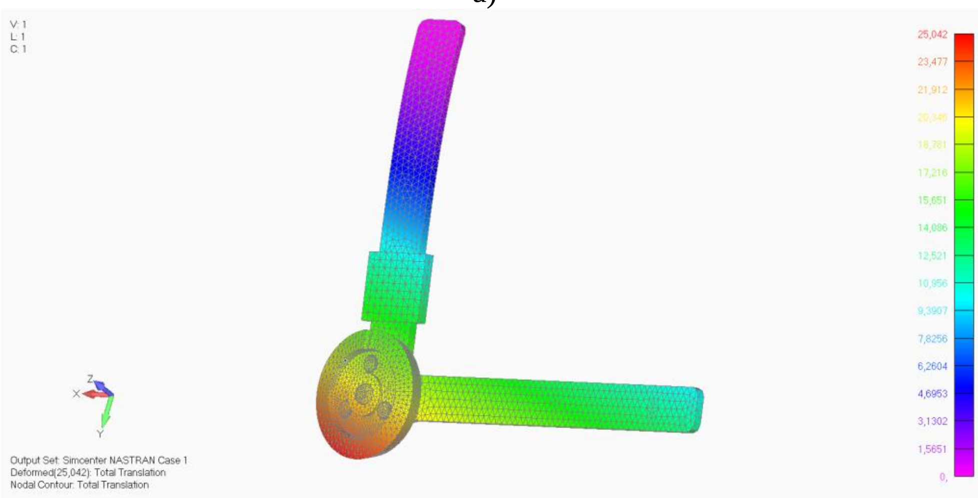


Fig. 5. A simplified 3D orthosis model

The results of the distribution of stresses and deformations according to the model of the complete assembly of the orthosis are shown (Fig. 6).



a)

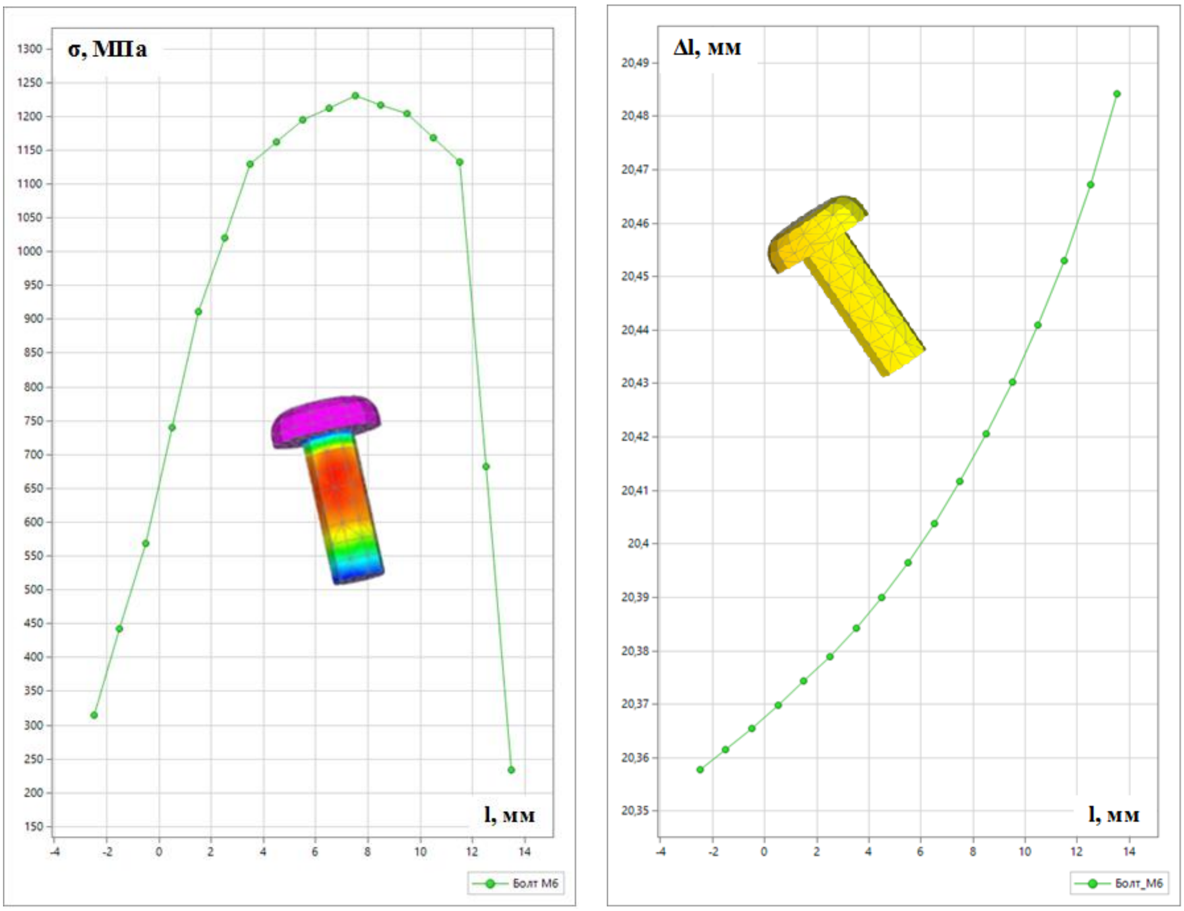


b)

Fig. 6. Graphs of Mises stress distribution a) and displacements of plate faces b)

According to the images (Fig. 6), the concentration of stresses further occurs in the wheel-plate connection, but we are interested in the connection of two plates by the M6-16 bolt.

The numerical calculation showed that there is a stress concentration along the bolt rod. To construct a graphical distribution of Mises stresses and displacements along the bolt rod, a tangent line parallel to the axis of rotation of the bolt was chosen Fig. 7.



a) b)

Fig. 7. Von Mises stress a) and strain b) distribution in the bolt joint orthosis prototype

According to the obtained graph (Fig. 7, a) of stress distribution, it can be seen that the greatest stresses occur in the middle of the length of the rod, and the graph has a parabolic character. The movement graph also has a parabolic character, which can be seen in Fig. 7, b. To reduce stresses in the further design of the elbow orthosis, it is necessary to choose a bolt with a larger diameter.

6. Research results

As a result of numerical calculations, it was established that along the bolt rods, which fasten the bevel gear wheel to the bottom plate, the VAT has a similar character, and in the places where the diameter of the bolts changes, bursts of stress concentration occur. It was established that the largest displacements occur in the first bolt. For further design and modeling, it is necessary to choose bolts with a larger diameter.

Analyzing the obtained numerical results, it was established that the stress and strain distribution graphs along the rod of the bolt, which fixes the aluminum plates of the elbow orthosis, are parabolic in nature.

7. Prospects for further research development

In the future, it is planned to design and model an elbow orthosis made of composite materials or made with the help of rapid prototyping, taking into account all the obtained results, with the aim of reducing the weight of the orthosis and improving the functional characteristics.

8. Conclusion

With the help of Kompas 3D V18 and FEMAP with NASTRAN software packages, 3D models of the elbow orthosis were created and the stress-strain state of two contact tasks were determined, namely the bolt connection of the bevel gear and the bottom plate, as well as the connection of the entire model due to the central bolt.

Список літератури:

1) Nilsson, M.; Ingvast, J.; Wikander, J.; von Holst, H. (2012). The Soft Extra Muscle system for improving the grasping capability in neurological rehabilitation. In Proceedings of the IEEE-EMBS Conference on Biomedical Engineering and Sciences, Langkawi, Malaysia, 17–19 December 2012, 412–417.

2) Gustaw Rzyman, Jacek Szkopek, Grzegorz Redlarski, Aleksander Pałkowski. (2020). Upper Limb Bionic Orthoses: General Overview and Forecasting Changes. Applied Science. 2020 10(15), 5323. DOI:10.3390/app10155323.

3) Hsieh, H.C.; Chen, D.F.; Chien, L.; Lan, C.C. (2017). Design of a Parallel Actuated Exoskeleton for Adaptive and Safe Robotic Shoulder Rehabilitation. IEEE/ASME Trans. Mechatron. 22, 2034–2045.

4) Lessard, S.; Pansodtee, P.; Robbins, A.; Trombadore, J.M.; Kurniawan, S.; Teodorescu, M. (2018). A soft exosuit for flexible upper-extremity rehabilitation. IEEE Trans. Neural Syst. Rehabil. Eng. 26, 1604–1617. [PubMed].

5) Vlachos, E.; Jochum, E.; Demers, L.P. (2018). HEAT: The harmony exoskeleton self-assessment test. In Proceedings of the 2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), Nanjing, China, 27–31 August 2018, 577–582.

6) Bai, S.; Christensen, S.; Islam, M.R.U. (2017). An upper-body exoskeleton with a novel shoulder mechanism for assistive applications. In Proceedings of the 2017 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), Munich, Germany, 3–7 July 2017, 1041–1046.

7) Castro, M.N.; Rasmussen, J.; Andersen, M.S.; Bai, S. A compact 3-DOF shoulder mechanism constructed with scissors linkages for exoskeleton applications. Mech. Mach. Theory 2019, 132, 264–278.

8) Crea, S.; Cempini, M.; Moisè, M.; Baldoni, A.; Trigili, E.; Marconi, D.; Cortese, M.; Giovacchini, F.; Posteraro, F.; Vitiello, N. (2016). A novel shoulder-elbow exoskeleton with series elastic actuators. In Proceedings of the 2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob), Singapore, 26–29 June 2016, 1248–1253.

9) Ebrahimi, A.; Gröninger, D.; Singer, R.; Schneider, U. (2017). Control parameter optimization of the actively powered upper body exoskeleton using subjective feedbacks. In Proceedings of the 3rd International Conference on Control, Automation and Robotics (ICCAR), Nagoya, Japan, 24–26 April 2017, 432–437.

10) Mao, Y.; Agrawal, S.K. (2012). Transition from mechanical arm to human arm with CAREX: A cable driven Arm EXoskeleton (CAREX) for neural rehabilitation. In Proceedings of the 2012 IEEE International Conference on Robotics and Automation, Saint Paul, MN, USA, 14–18 May 2012, 2457–2462.

11) Mao Y, Jin X et al. (2015). Human movement training with a cable driven arm exoskeleton (CAREX). IEE Transactions on Neural Systems and Rehabilitation Engineering. 23(1), 84. doi:101109/TNSRE.2014.2329018.

12) F. Xiao et al. (2016). Design of a wearable cable-driven upper limb exoskeleton based on epicyclic gear trains structure. PMID: 28582886. DOI 10.3233/THC-171300.

13) Soumya K. Manna, Venketesh N. Dubey. (2017). A Mechanism for Elbow Exoskeleton for Customised Training; Member, IEEE.

14) Lavrenko Ia., Lebedynskyi B. (2022). Determination of the stress-srain state of the structural elements of the elbow orthosis prototype. International Science Journal of Engineering & Agriculture. 1(3), 29-36. doi: 10.46299/j.isjea.20220103.3.

15) Гребеников А.Г., Клименко В.Н., Ефремов А.Ю., Трубаев С.В. (2007). Проектирование срезных болтовых соединений элементов самолетных конструкций из титанового сплава ВТ6 с учетом усталостной долговечности / Открытые информационные и компьютерные интегрированные технологии. – Х.: НАКУ "ХАИ", 34, 60-70.

16) Работнов Ю.Н. (1988). Механика деформируемого твердого тела: Учеб. пособие для вузов. М.Наука, 712.

17) Биргер И.А., Шорр Б.Ф., Иосилевич Г.Б. (1979). Расчет на прочность деталей машин: Справочник. М. Машиностроение, 702.

18) Рудаков К.М., Добронравов О.А. (2013). Про вплив величини зазору між болтом та отвором на напружений стан болта однозрізного болтового з’єднання в зоні "зрізу". Вісник НТУУ "КПІ". Сер. Машинобудування, 3(69), 62-71.

19) Гребеников А.Г., Клименко В.Н. (2006). Исследование влияния радиального натяга, осевой затяжки болтов и поверхностного упрочнения элементов срезного соединения из титанового сплава ВТ6 на их усталостную долговечность. Открытые информационные и компьютерные интегрированные технологии. Х. НАКУ "ХАИ", 31, 41-54.

20) Воробьев А.З., Олькин Б.И., Стебнев В.Н., Родченко Т.С. Сопротивление усталости элементов конструкций. М. Машиностроение, 199.

21) Amit P. Wankhade and Kiran K. Jadhao (2014), “Design and Analysis of Bolted Joint in Composite Laminated”, Journal of Modern Engineering Research (IJMER), 4 (3), 20-24.

22) Counts, W.A. and Johnson, W.S. (2002), Experimental study on clamping effects on the tensile strength of composite plates with a bolt-filled hole / International journal of Fatigue. 24.

23) Karlsson, K. (2012) An experimental study of rotation in a composite single bolted joint. Teknisk-naturvetenskaplig fakultet UTH – enheten.

24) Manalo, A.C., Mutsuyoshi, H., Asamoto, S. and Matsui, T. (2008) Mechanical behavior of hybrid FRP composites with bolted joints. In: 20th Australasian Conference on the Mechanics of Structures and Materials (ACMSM 20): Futures in Mechanics of Structures and Materials , 2-5 Dec 2008, Toowoomba, Australia.

25) Pakdil, M., Sen, F. and Sayman O. (2009). Damage development in bolted composites with clearance subjected to preload. International Journal of Engineering and Applied Sciences (IJEAS), 1(4), 52-66.

26) Sen, F., Sayman, O., Ozcan, R. and Siyankoc, R. (2010), Failure response of single bolted composite joints under various preload. Indian Journal of Engineering & Materials Sciences Vol. 17, February 2010, 39-48.

27) Younis, N. (2012), Experimental Strain Investigation of Bolt Torque Effect in Mechanically Fastened Joints. Engineering, 4, 359-367. doi:10.4236/eng.2012.47047 Published Online July 2012 (http://www.SciRP.org/journal/eng.

28) Решетникова Р.Ю. (2013). Влияние осевого натяга на локальное напряженное состояние в односрезных болтовых соединениях. Вопросы проектирования и производства конструкций летательных аппаратов: сб. науч. тр. Нац. аэрокосм. ун-та им. Н.Е. Жуковского «ХАИ». 1 (73), 87-99.