Ministry of Education and Science of Ukraine

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2023

PROCEEDINGS

ODESA, ONUT 2023

Ministry of Education and Science of Ukraine

Odesa National University of Technology

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2023

Proceedings

Odesa, ONUT
2023

RESEARCH OF MECHATRONIC GRIPPER DEVICES ON THE BASIS OF BIONICS WITH EXTENDED FUNCTIONAL CAPABILITIES

Authors: Yurii Yakymchuk
Dmitry Danyuk
Advisor: Mykola Iakymchuk
National University of Food Technologies (Ukraine)

Annotation: *Moving complex packaging designs, created on the basis of the use of new packaging materials with improved physical and mechanical characteristics requires the development of new designs of gripping devices with enhanced functionality. This task is currently very relevant and can be solved by creating a new philosophy of designing such objects, which is based on the principles of bionics.*

The authors consider the advantages and disadvantages of using the design of gripping devices created on the basis of bionics with extended functionality for the performance of technological packaging operations. The opinion is expressed that fingers have the simplest design for finger gripping devices, which are created using the technology of an elastic loop, which was borrowed from the structure of the tail fin of a fish and has the name «Fin Ray® Effect»

An improved design of the finger of a mechatronic gripping device with an effect is proposed «Fin Ray®». Investigation results concerning the following catching device functional characteristics and reconstructing fingers of the contour of the generator surface of different objects by the working platform with possibility to fix them additionally banding fingers' ends on the object block are suggested.

The results of an analytical and experimental study of the durability and quality of the structural elements of the finger gripping device with the effect are presented by «Fin Ray®», made of various polymer materials.

It was established that finger samples made of PET material are characterized by the greatest functional capabilities. The printed fingers showed stable performance within 80,000 cycles. Its further use leads to a slow decrease in stiffness and load. The destruction of the sample occurs around 200,0000 cycles.

Keywords: *Mechatronic gripper device, bionics, «Fin Ray®» effect, gripping the object, changing the effort.*

I. INTRODUCTION

Recently, revolutionary changes have been observed in the designs of modern gripping devices. They are associated with the active emergence of new structural materials with improved physical and mechanical characteristics and technologies for creating complex structures using 3D printers. However, even these factors are only part of the forces that led to the emergence of a new philosophy of design and function of gripper devices. This idea is based on the principles of bionics.

The word "bionics" was proposed by Jack Steele, probably from the Greek βίον - "unit of life» and the suffix -ic «-similar», i.e. "bionics" means «life-like».

A science that studies the structure and functioning of living organisms, used to solve engineering problems, creation of new devices and mechanisms is called bionics (from Greek bios «Life»). The designs and methods of gripping objects by living organisms (animals and humans) led to the emergence of a new generation of gripping devices for the packaging industry.

Designs of devices can be conditionally divided into three groups.

The first group includes adaptive gripping devices that imitate the work of human fingers or animal tentacles.

An example of such devices is a three-finger gripper with three phalanges. The design of the gripping device and its operation is built on the basis of researching the operation of the fingers of the human hand. Unlike the existing finger gripping devices, the new generation has two significant advantages: precise adjustment of the clamping force of the object and complex movement of the fingers, which provide an additional opportunity to manipulate various forms of packaged objects, taking into account the change in their dimensions and the texture of the packaged material and product, as well as managing the complex position of the packaged objects in space.

Such gripping devices are ideal for creating packaging equipment of the fifth generation - robotic packaging complexes with their subsequent integration into the production of the future - Industry 4.0

The second group includes frameless adaptive gripping devices that imitate the work of elastic organs, such as animal tentacles. Such gripping devices were called «soft hands». The main difference is the absence of a frame and the use of soft materials, various types of windings, etc. The "soft" structure of the gripper allows to ensure the necessary flexibility of the tentacles and their adaptability to the shape of the packed object, uniform distribution of the clamping force over the entire contact surface. An example of the use of vacuum in the control of frameless gripper devices is a design that imitates the operation of an octopus tentacle. They do not have a skeleton and are almost entirely made of soft muscles, which provide them with extreme flexibility and maneuverability. It can be stated that the main advantages of frameless gripping devices include the ability to gripper and hold packaged objects of arbitrary shaped and rigidity.

The third group of gripper devices differs from the previous two and is created by simulating phase transitions of granular materials when the amount of external influence changes. Although it should be noted that this principle of operation resembles, for example, the work of a chameleon's tongue, which is able to catch various insects by reliably grabbing the appropriate prey with its tongue. The basis of the design idea was the well-known vacuum packaging of coffee, which has a high hardness. But as soon as you break the integrity of the package, it becomes soft and pliable. By placing such a gripper, in its softened state, on any packaged object, it can be made to follow the shape of the object's surface. After that, the air is pumped out of the internal space of the gripper, the gripper device hardens and reliably grippers the packaged object of a rather complex shape, which can subsequently be lifted, moved and held without violating its integrity.

II. ANALYTICAL REVIEW OF LITERATURE

Recently, a lot of attention has been paid to issues related to the development of equipment for creating packaged products and forming structural elements of group or transport packaging from them [1-4]. In general, the technological processes of the formation of group and transport packaging are an integral part of the automated lines of any enterprise [1,4]. For example, works [5-8] describe the designs of equipment for packing products and provide methods for calculating individual working bodies of mechanisms and devices. However, in these works, little attention was paid to the layout equipment methods based on the mechatronic approach using gripper modules and there are no methods of selection of executive mechanisms taking into account the methods and forms of their control. We may combine into aspecial group the works that describe the methods and principles of selecting gripping devices for the packaging industry [9, 10]. However, these methods need to be supplemented and clarified within the use of new packaging materials, reduction in their thickness and increase in the variety of forms of packaged products.

Studies of the kinematics and dynamics of gripping devices, as the main elements of industrial robots, methods of developing their control algorithms, and other automation issues are given in works [11-14]. However, the given designs of gripping devices and schemes of manipulators are used for technological operations only with unpackaged metal products and have limited use in packaging equipment.

The question of automation of technological processes with the use of devices for manipulating artificial objects on the basis of bionics are dedicated works [15-19]. The works consider the design of a new generation of robot elements and gripping devices based on bionics. Compressed air is used as a working agent for such devices. The given methods of calculation and selection of pneumatic gripping devices do not fully take into account the physical and mechanical properties of the packaged product and can only be used approximately for the design of pneumatic gripping devices in the packaging industry.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

The purpose and tasks of the research: development of the scientific and technical foundations of the creation of the structure of the mechatronic module of the gripping device on the basis of bionics with extended functional capabilities.

This goal is realized by solving the following problems:

- to conduct analysis of technological schemes and existing samples of robotic complexes for group packaging of food products in order to determine the features of the technological process of forming group packaging, typical designs of mechanisms and devices;

- to create a new design of a mechatronic module of a gripping device based on bionics for group packaging operations with enhanced functionality;
- to provide the new design of the mechatronic module with the ability:
  - reliable gripper and retention of packages of various shapes;
  - preservation of the commercial appearance of packages with a food product in the process of their movement;
  - system of redistribution of holding force between gripping elements;
  - to produce an experimental installation of a mechatronic gripper module based on bionics for performing group packaging operations with extended functionality and to verify its functionality in accordance with the research objectives.

Object of study: the process of gripping packaged objects by a mechatronic gripper device based on bionics and the relationship between its structural, kinematic and dynamic parameters to expand functionality.

Subject of study: constructive implementation of a mechatronic gripping device based on bionics.

Research methods - theoretical studies were carried out using complex methods, taking into account the mechatronic-modular construction of gripping devices. To analyze the geometric, kinematic and dynamic parameters of the operation of the mechatronic gripping device on the basis of bionics the basic laws of mechanics, the theory of thermo- and gas dynamics for power pneumatic drives were used. Experimental studies were carried out using the theory of experiment planning and mathematical statistics, the methodology of an active experiment and with the help of pressure sensors, displacement, effort and loss, a block of analog-to-digital converters, a computer and software packages: Labview, FluidLab_PA. Experimental data processing and calculations were performed in Microsoft Excel, MathCad and Autodesk Inventor software packages.

IV. WORK RESULTS

4.1 Mathematical modeling of the process of gripping packaged objects by a mechanical gripper device based on bionics.

The mathematical model of the process of gripping consumer packages with a mechanical gripping device based on the principles of bionics was based on the use of subsystems of a flexible gripper and a robotic arm. The mathematical model was developed on the basis of the Denavit-Hartenberg model [16]. The grip force ranges were determined during the analysis of similar technical grip systems [11,12]. It was assumed that the created mathematical model describes the change of forces in the gripping device required for the robotic system during the movement of the consumer package by the flexible gripping device.

DH displacement matrices were created to model the system. It was assumed that a six-by-six matrix contains three rotational and three translational movements, and a four-by-four matrix contains two rotational and two translational movements. The formed forces generated during the movement of the gripping device can be described using the Lagrange torque model, (Fig. 4.1) The resulting mathematical model describes the influence of the inertia component A, the Coriolis force component C, the centripetal component B and the gravitational component G. The calculation of the force vectors was determined using equation (1).

$$A(q)[\ddot{q}] + B(q)[\dot{q}q] + C(q)[\ddot{q}] + G(q) = \tau \quad (4.1)$$

where, q is a vector of connection angles. A (q) is a symmetric, bounded, positive definite inertia matrix . C (q) - Coriolis forces. B (q) - centripetal forces. G (q) - gravitational force. τ - is the drive torque vector.

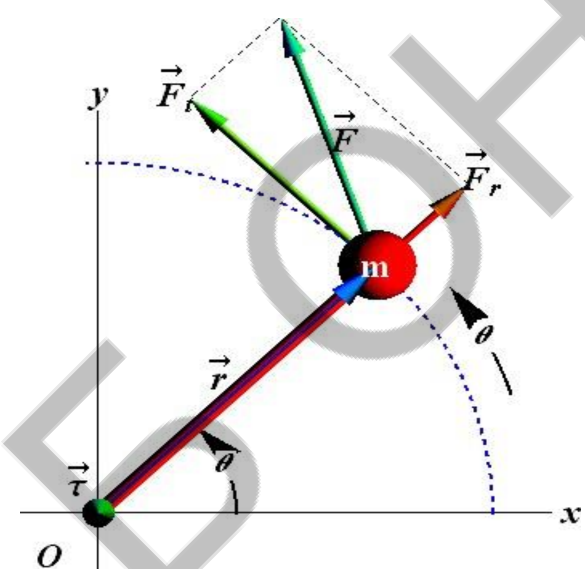


Fig. 4.1. A model of the distribution of forces during the movement of an object by a robotic arm

The quality of gripping and holding the moving object depends on the kinematic and dynamic characteristics of the movement of the gripping device and the reliability of its design [13, 14].

The objective of the analytical studies of the design of the gripping device was to investigate the reliability and durability of the operation of the finger of the gripping device. For this purpose, the shape and design of the proposed finger was used during modeling of its movement in the Autodesk Inventor program (Fig. 4.2).

The virtual model of the gripping finger during bending provided the pressing force of up to 13 N along the X-axis. The maximum reduction in size when rotating the finger along the x axis was up to 9.45 mm.

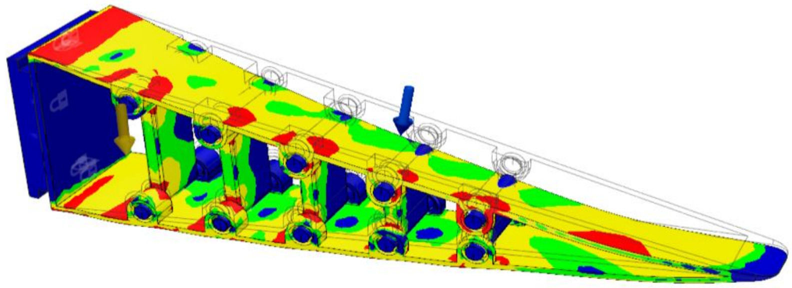
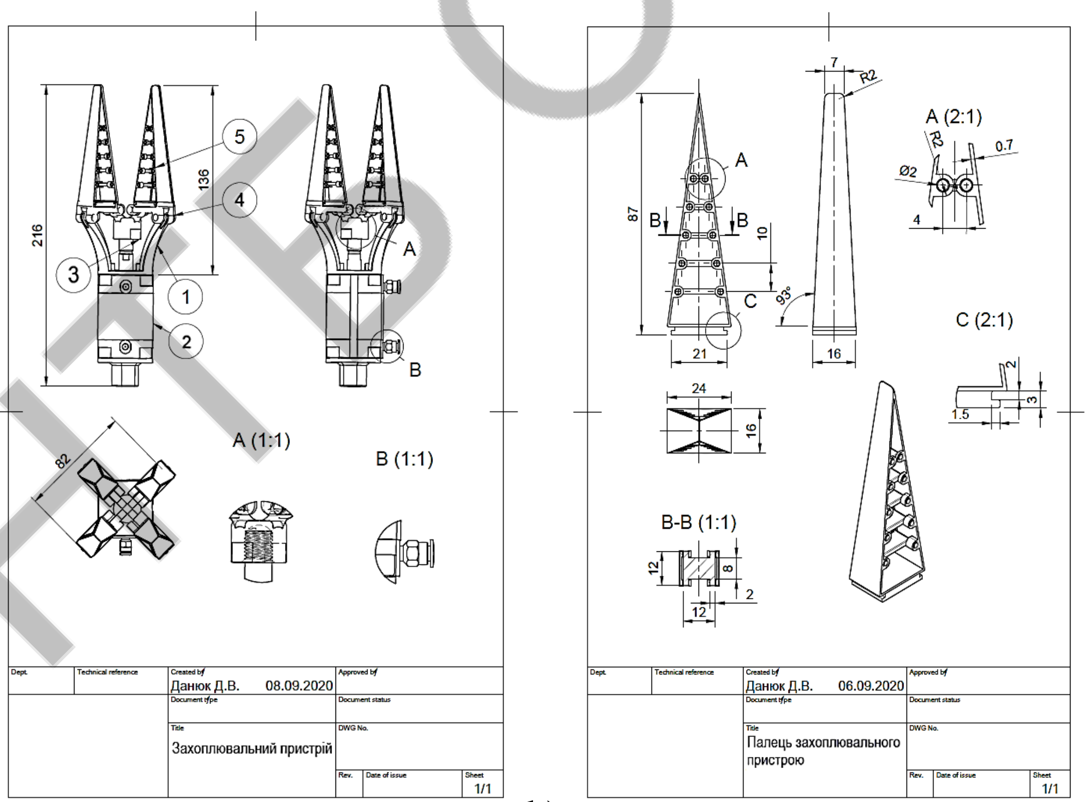


Fig. 4.2. Zones of stress distribution during bending of the finger of the gripping device

The resulting deformation of bending and stretching of the structural sections of the finger work in the form of stress changes is shown in fig. 4.2. Areas highlighted in red have the greatest deformation. In the future, it can be assumed that it is in these zones that the destruction of the elements of the finger will begin. To reduce bending stresses, the shape of the finger construction elements was optimized.

4.2 Development of technical documentation of the mechatronic module of the gripping device on the basis of bionics.

According to the results of the analysis of gripping devices based on the principles of bionics, a four-finger gripping device with flexible finger surfaces was proposed and subsequently designed in the "compass" program (Fig. 4.3).



a) b)

Fig. 4.3. Design of a four-finger gripping device with flexible fingers: a - working drawing of the general view; b - working drawing of a finger of the gripping device

The design of the four-finger gripper consists of a body 1, to which a pneumatic cylinder 2 is rigidly fixed in the lower part. In the upper part of the case, on the hinges 3, four fixing plates 4 are fixed for holding the fingers 5. The inner side of the fingers 5 acts as the working surface of the grip. The rear parts of the fixing plates 4 are attached to the bar 7 through the hinges 6, which is rigidly connected to the rod of the pneumatic cylinder 2. The module of the gripping device is connected to the mechanism of moving the robot through an additional cover 8, which is fixed on the back of the cylinder 2.

The main element of the design of the mechatronic module of the gripping device is the fingers. Their design involves the use of two flexible flat polymer plates of a given width, which are connected to each other in the shape of a triangle. Special stiffeners are provided in the middle of the triangle to stiffen the structure. Each rib is attached by two hinges to the surface of the generatoring plates. This design of the finger provides great elasticity when bending the surfaces of the plates.

An experimental installation was made according to the working drawings. The design of the experimental setup consists (Fig. 4.4) of plate 1, to which rack 2 is rigidly fixed in the lower part. In the upper part of the rack 2, a rotation module 3 with a fixation angle ranging from 0° to 90° is attached to the hinge. The device for moving the gripping device 4 is attached to the rotation module 3. Experiments were conducted on gripping devices with different types of drives: servo and pneumatic (Fig. 4.4).

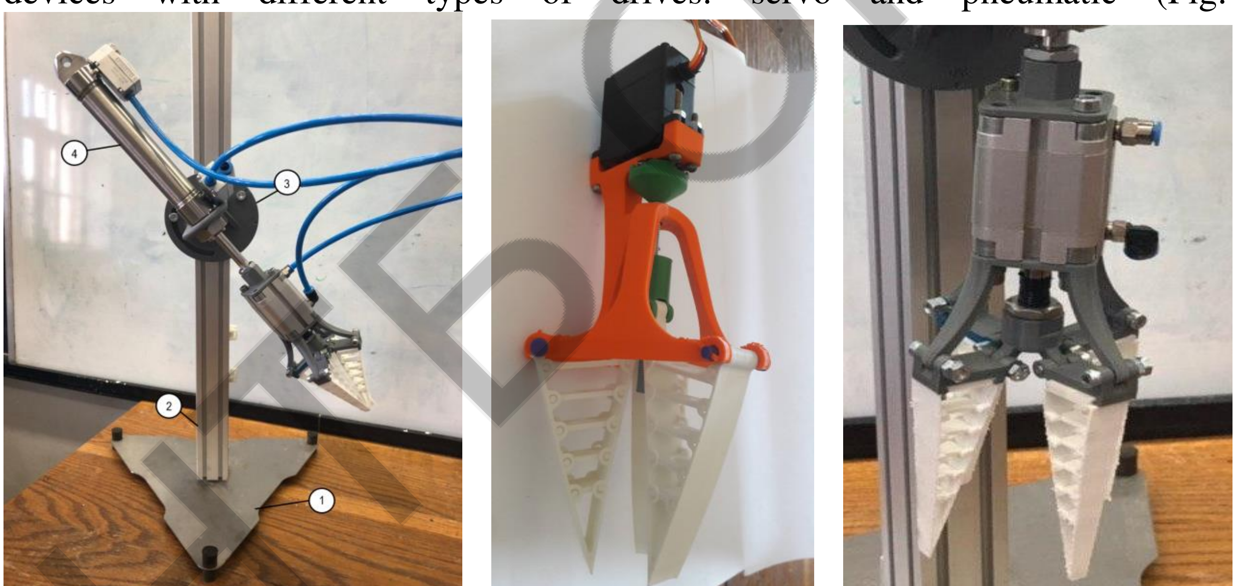
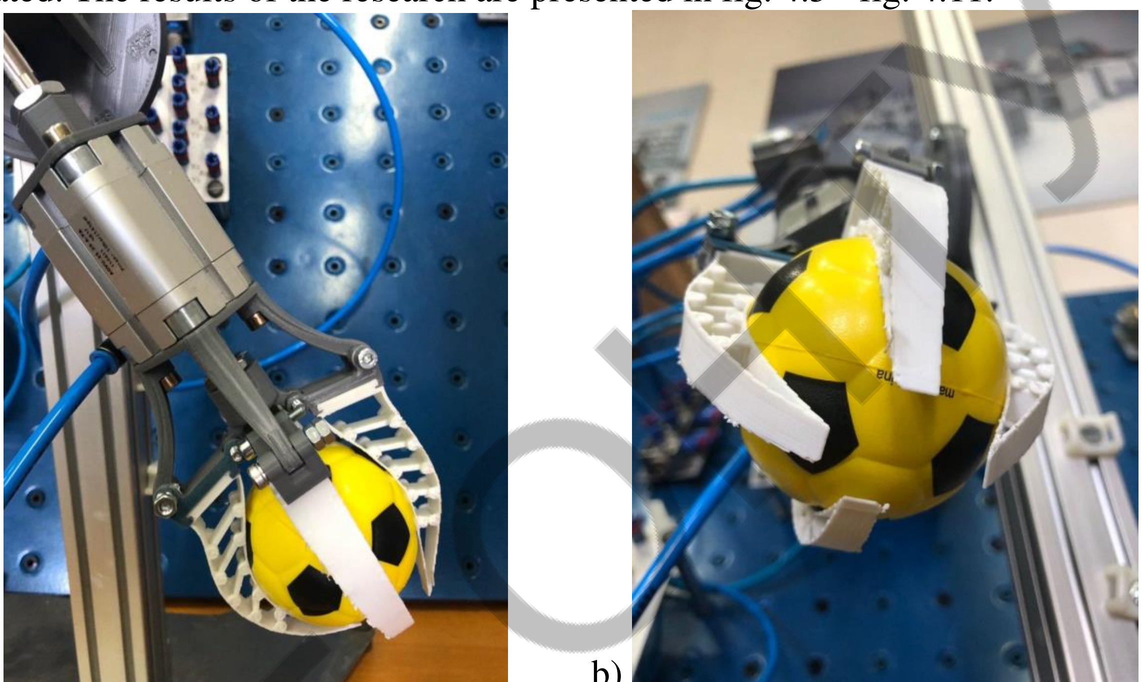


Fig. 4.4. The design of the experimental installation of the mechatronic module of the gripping device is based on the principles of bionics: 1 - plate; 2 - rack; 3 - rotary modulus at the fixation angle within 0° to 90°; 4- the device for moving the gripping device (Double-acting pneumatic cylinder of the brand DSNU-12-200-P-A of the company "FESTO"); 5 - four-finger gripping device.

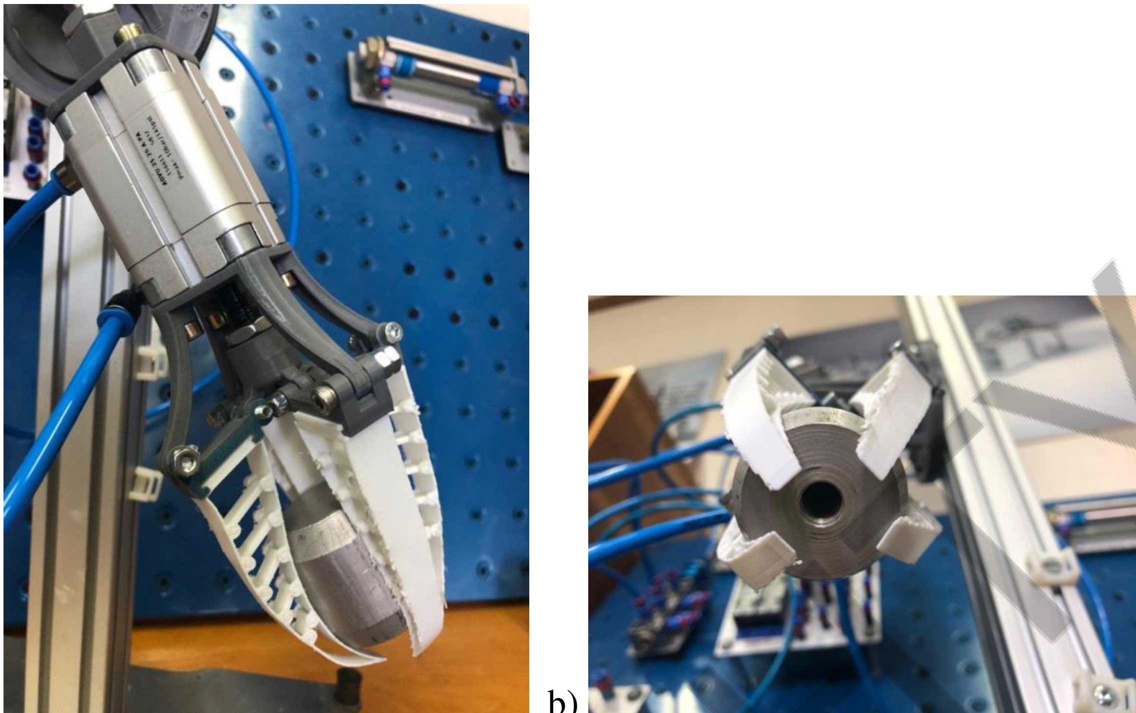
4.3 Study of the functional characteristics of the mechatronic module of the gripping device

At the first stage, the functional characteristics of the mechatronic module of the gripping device were studied, in relation to the reproduction of the contour of the generator surface of the gripping object by the working surface of the fingers. The place of contact of the surface of the fingers with the object and the ability of the fingers to provide additional fixation of the object by bending their limbs at the ends of the object were investigated. The results of the research are presented in fig. 4.5 - fig. 4.11.



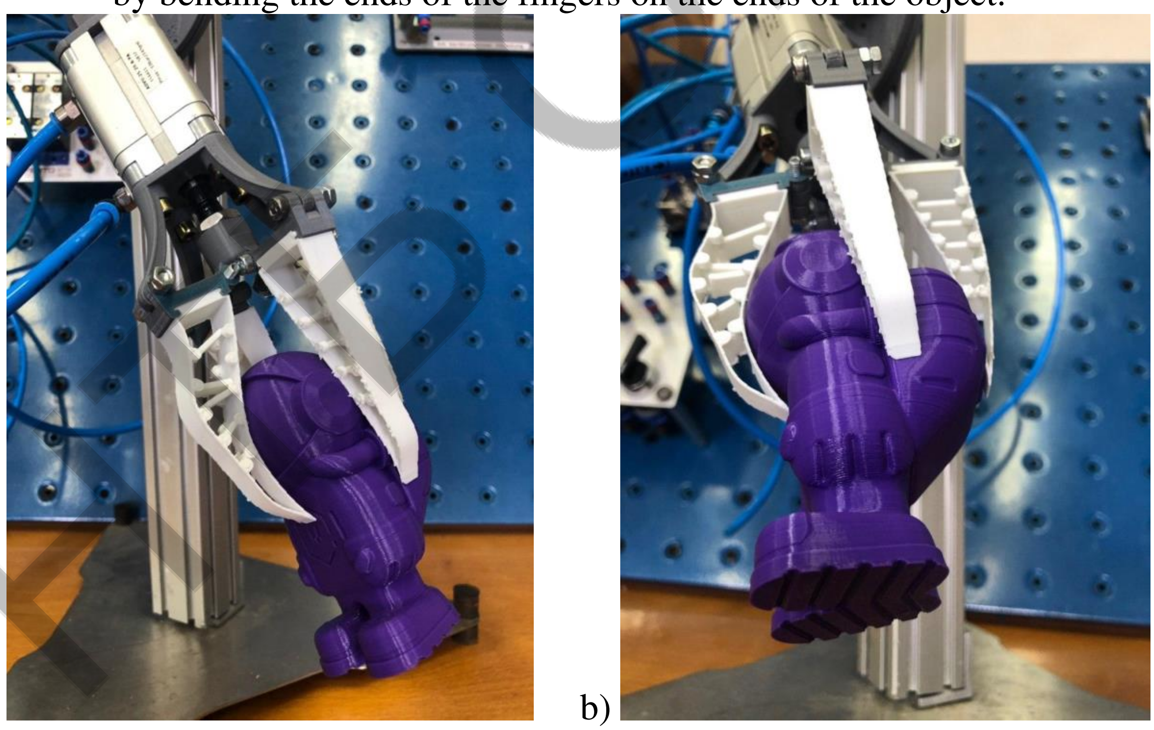
a) b)

Fig. 4.5. Study of gripping round artificial objects: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object



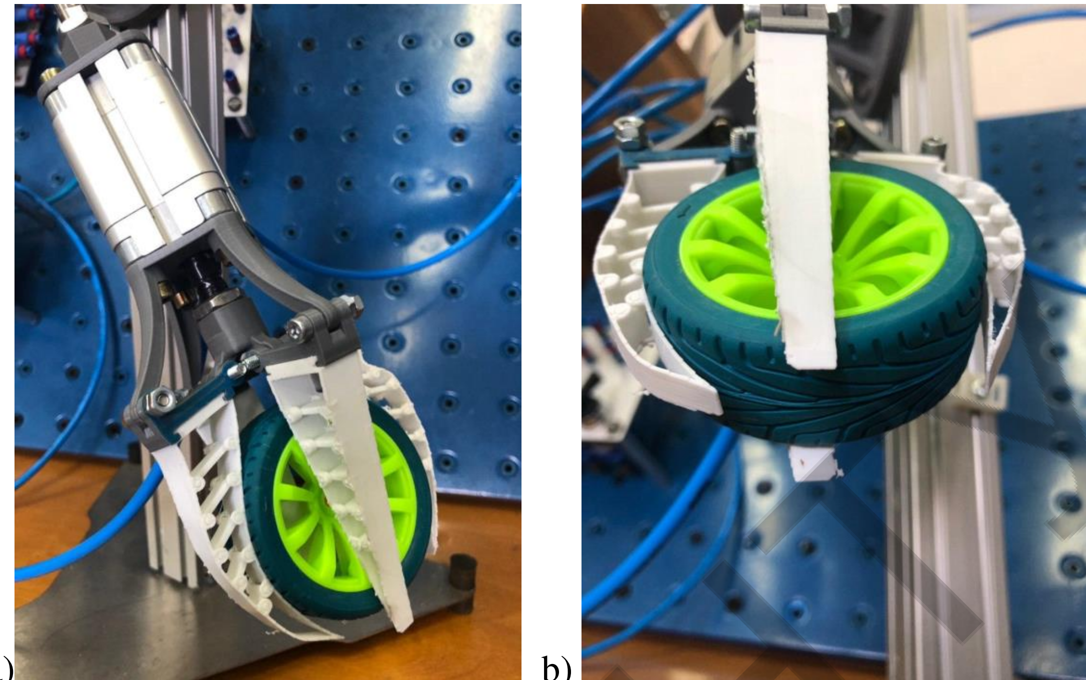
a) b)

Fig. 4.6. Study of gripping of artificial objects of cylindrical shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object.



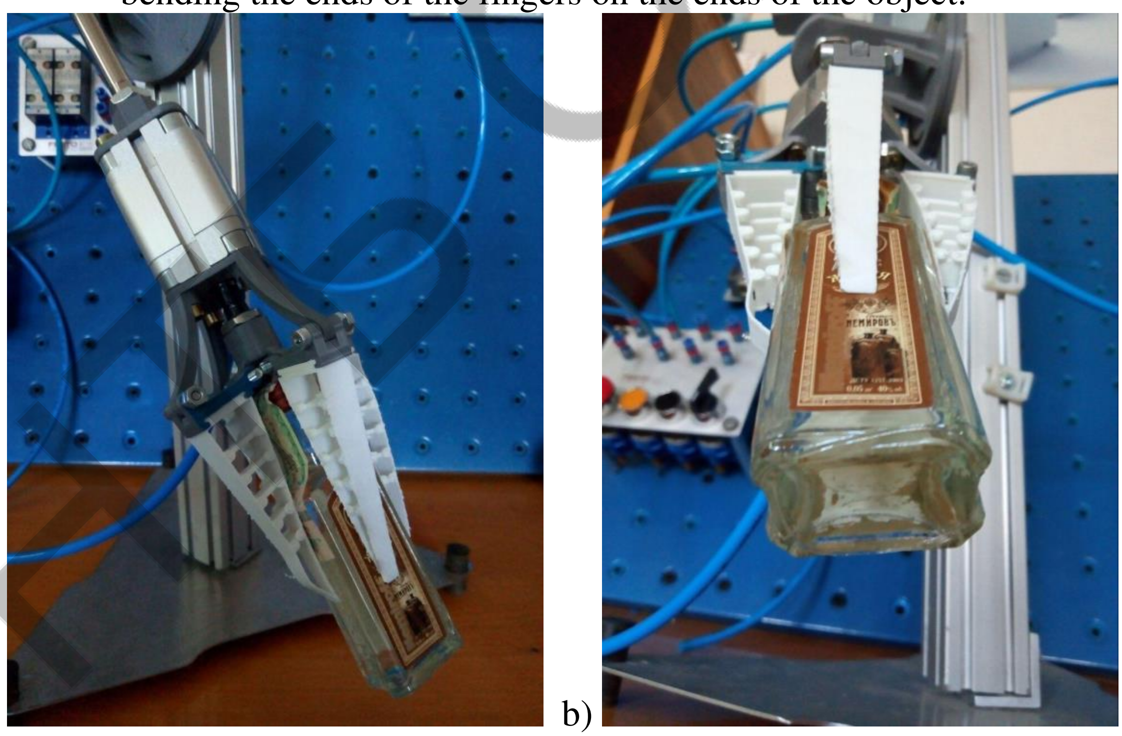
a) b)

Fig. 4.7. Study of gripping artificial objects of complex shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the extremities of the fingers.



a) b)

Fig. 4.8. Study of gripping artificial objects of cylindrical shape: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers on the ends of the object.



a) b)

Fig. 4.9. Study of gripping artificial objects of rectangular shape: a - the working surface of the fingers takes the shape of the object; b- additional fixation of the object by bending the ends of the fingers on the ends of the object.

a)  b) 

Fig. 4.10. Study of gripping of artificial objects of complex shape on the inner surface of their body: a - the working surface of the fingers takes the shape of the object; b - additional fixation of the object by bending the ends of the fingers along the inner wall of the object.

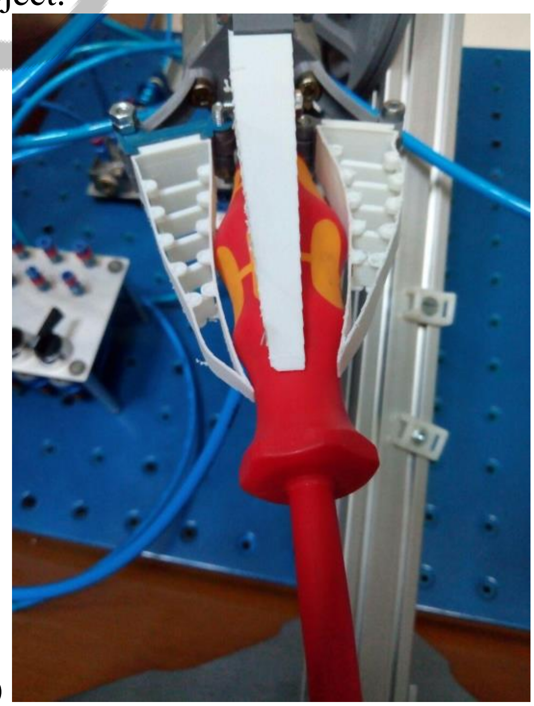
a)  b) 

Fig. 4.11. Study of gripping artificial objects of complex shape:
a - the working surface of the fingers takes the shape of the object; b- additional fixation of the object by bending the extremities of the fingers.

4.4 Study of the durability of the elements of the gripping device on the basis of bionics

At the second stage, the durability and quality of the structural elements of the gripping device were investigated. The prepared drawing of the fingers was created using Autodesk Inventor software and manufactured on a 3D printer from various materials (Fig. 4.12).

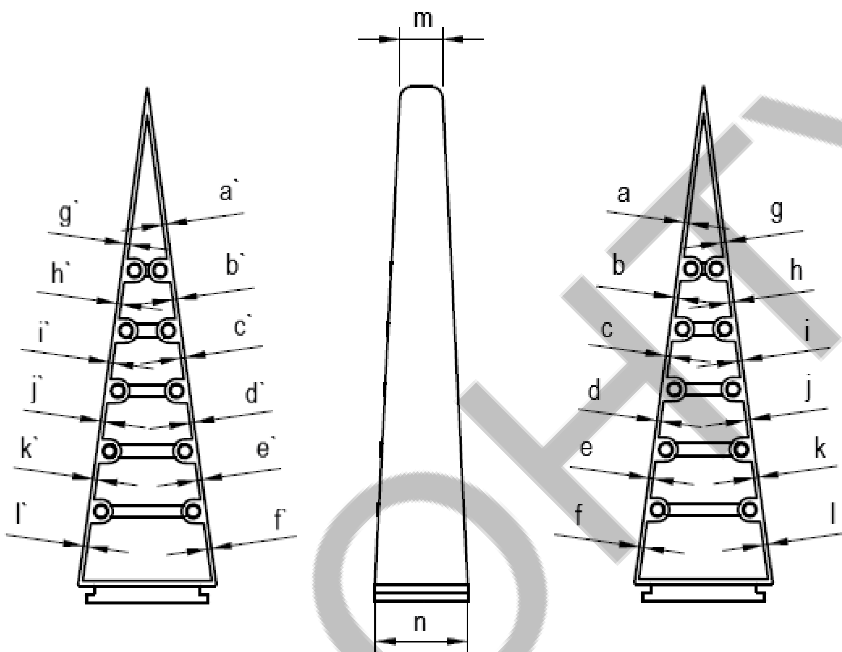


Fig. 4.12. Scheme of the gripping finger with selected areas of measurement of the structure working surfaces in section (a -1) and height (m)

It is common knowledge that inexpensive three-dimensional printing technologies are known for some inaccuracies in production [16]. In most cases, there are defects in filling the material of products and problems with printing thin walls. Therefore, after printing the models, the fingers were checked for size compliance. To do this, the thicknesses of individual sections of the structures working surface in places of the most possible destruction during cyclic loading and the height k were measured (Fig. 4.12).

To obtain a more accurate result, 5 attempts were made for each measurement, from which the maximum and minimum sizes were set and the average size obtained from them. On the basis of conducted measurements, the structural locations that have the largest spread of dimensions m were determined. It was established that such discrepancies are caused by shrinkage of the processed material from which the component is made (Fig. 4.13).

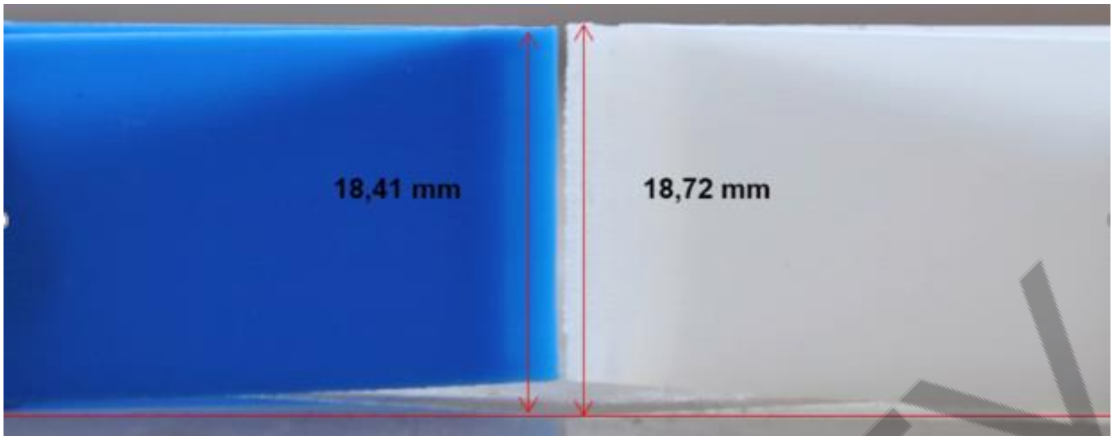


Fig. 4.13. The results of measuring the width of the gripping devices working surface of made of different materials

The next stage of the research was the fatigue test of the obtained finger structures (Fig. 4.14).

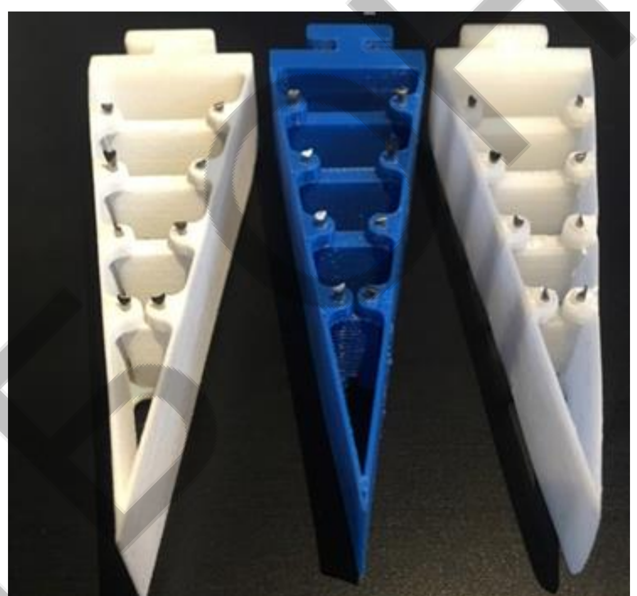


Fig. 4.14. Designs of fingers from different materials

For this purpose, the experimental setup was programmed in the automatic mode of operation with cyclic operation of the fingers by gripping. The amplitude and frequency of the deflection of the fingers working surfaces was up to 10 mm and 2 Hz, respectively. It was established that the fingers of the gripping device, which are made of ABS (acrylonitrile-butadiene-styrene) material, were destroyed in the area of application of the maximum mandrel load (Fig. 4.15). The place of destruction of a finger made of such material coincides with the results of analytical studies of structural elements According to the research results, the safety factor for the ABS material was calculated, which is about 1.39.

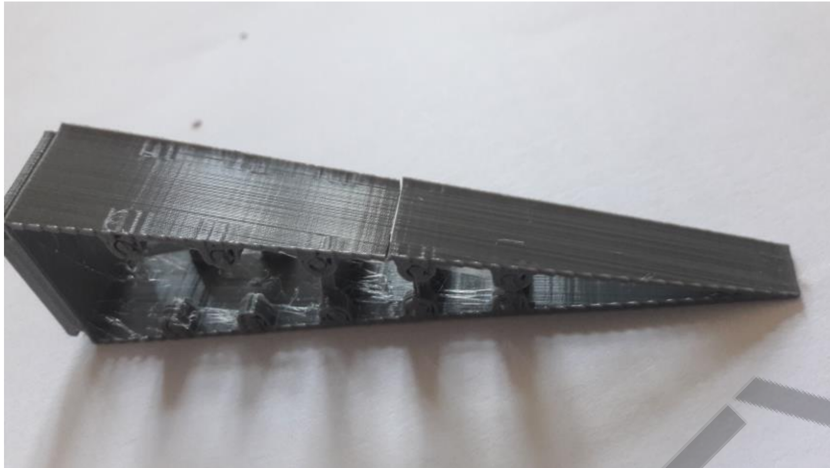


Fig. 4.15. Type and location of failure of a finger made of ABS material after a fatigue test

It was investigated that the gripping fingers made of PLA material (polylactic acid) were destroyed at the base - in the place of attachment to the bar (Fig. 4.16). Based on the results of research, the estimated safety factor for the material - PLA is about 1.68.

Fig. 4.16. Type and location of failure of a finger made of PLA material after a fatigue testing

It was established that the grip rods made of Elastan material (Polyethylene terephthalate) were destroyed in the place where the stiffeners were connected. (fig. 4.17). Based on the results of research, the safety factor for this material - Elastan, which is about 1.18, was calculated.

Fig.4.17. Type and location of failure of a finger made of Elastan material after fatigue testing

According to the results of experimental tests, the dependence of the number of cycles of the gripping finger before destruction was determined as a function of the force applied by the finger to the object. The obtained results are presented in the form of a graph for fingers made of materials: ABS . PLA and Elastan (Fig. 4.18).

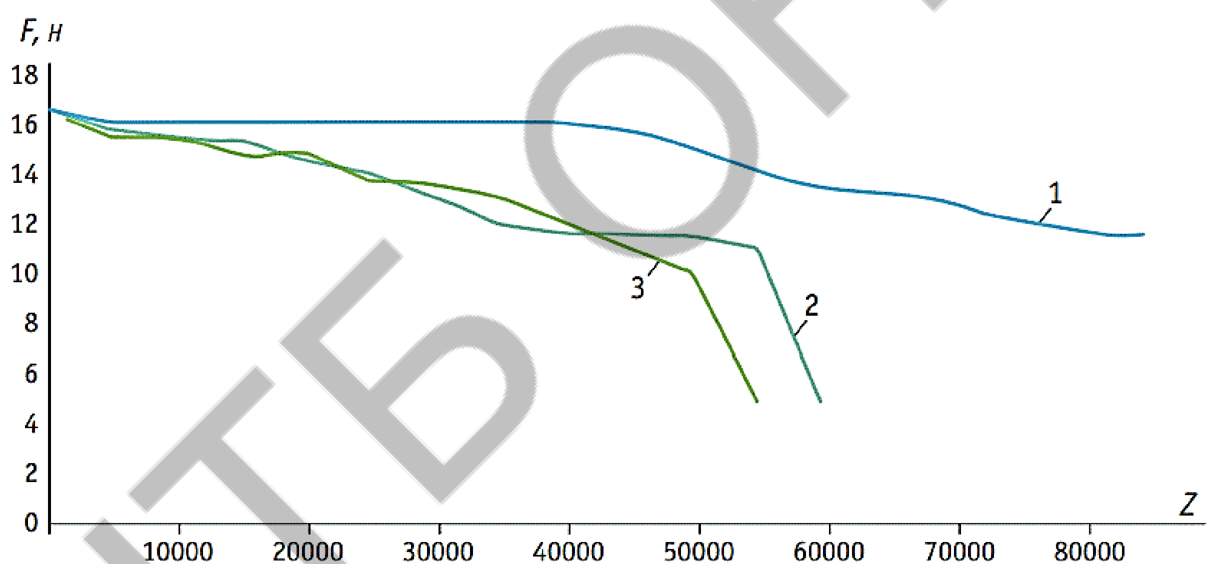


Fig. 4.18. Results of experimental research on the number of work cycles of the gripping finger to destruction as a function of the force applied by the finger to the object for materials: 1- PLA; 2- ABS; 3- Elastane

V. CONCLUSIONS

According to the research of modern gripping devices:

- It has been established that the philosophy of creating a new generation of gripping devices for group packaging is based on the principles of bionics. It is the methods of gripping objects by living organisms - animals and humans that have led to the appearance of innovative designs of gripping devices adapted for the packaging industry.

- A new design of the mechatronic module of the gripping device based on bionics with enhanced functionality for performing group packaging operations is proposed.
- Technical documentation has been developed for the production of a mechatronic module of a gripping device based on bionics with enhanced functionality for performing group packaging operations.
- An experimental installation of a mechatronic module of a gripper device based on bionics was developed and manufactured.
- It has been studied that finger samples made of ABS flex material can work stably up to 55,000 cycles, characterized by a change in force from 16.5 N to 12N. In subsequent cycles, the load rapidly changes from 12N to 4N. The destruction of the sample occurs around 60,000 cycles.
- It has been studied that samples made of PLA material are characterized by the greatest functional capabilities. The printed finger showed the possibility of stable operation up to 80,000 cycles. Its further use leads to a slow decrease in stiffness and load. The destruction of the sample occurs around 200,0000 cycles.
- It has been studied that finger elements made of Elastan material (polyethylene terephthalate) are characterized by functional capabilities of stable operation up to 40,000 cycles. Its further use is characterized by only a slight effort, which leads to the destruction of the stiffness elements around 55,000 cycles.
- The stress change analysis made on the 3D CAD model in Autodesk Fusion allowed to determine the zones of maximum stress changes on the elements of the gripping finger during its operation. The location of the failure of the samples made of PLA and ABS materials coincided with the most probable zones of maximum stress in the Autodesk Fusion 360 software.

VI. References

1. Пакувальне обладнання : підручник / О.М. Гавва, А.П. Беспалько, А.І. Волчко, О.О. Кохан. — К.: ІАЦ Упаковка, 2010. — 746 с.
2. Гавва О. М. Пакувальне обладнання. Обладнання для групового пакування : підручник / О.М. Гавва, А.П. Беспалько, А.І. Волчко. — К.: ІАЦ Упаковка, 2007. — 136 с.
3. Шредер В.Л. Упаковка из картона : книга / В.Л. Шредер, С.Ф. Пилипенко. – К.: ИАЦ Упаковка, 2004. – 560 с.
4. Моделювання процесів пакування : підручник / А.І. Соколенко, В.Л. Яровий, О.Ю. Шевченко та ін. – Вінниця : Нова книга, 2004. – 271 с.
5. Пакетоформирующие машины / А.П. Кривопляс, А.А. Кукибный и др. – М. : Машиностроение, 1982. – 239 с.
6. Гавва О.М. Наукові основи розрахунку параметрів потоково – транспортних систем харчових виробництв: дис. докт. техн. наук / О.М.Гавва; НУХТ. – К., 1966. – 562 с.

7. Волчко А.И. Повышение технического уровня линий укладки штучных грузов пищевой промышленности в транспортную тару : дис. канд. техн. наук / А.И. Волчко; НУПТ – К., 1986. – 286 с.
8. Пітра М.М. Виконавчі механізми в укладальних машинах/ М.М. Пітра, О.І. Ковальов // Упаковка – 2003. – № 4. – С. 24-27.
9. Костюк В.С. Оптимизация параметров рабочих процессов и совершенствование конструкцій автоматов для загрузки и розгрузки транспортной тары в пищевой промышленности : дис. канд. техн. наук / В.С. Костюк; НУПТ – К., 1989. – 277 с.
10. Беспалько А.П. Пакетоформувальна техніка / А.П. Беспалько, О.М. Гавва, М.В. Якимчук // Упаковка – 2001. – № 4. – С.46-47.
11. K. Murakami and T. Hasegawa, "Novel fingertip equipped with soft skin and hard nail for dexterous multi-fingered robotic manipulation," in Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on, vol. 1. IEEE, 2003, pp. 708–713.
12. K. Hosoda, Y. Tada, and M. Asada, "Anthropomorphic robotic soft fingertip with randomly distributed receptors," Robotics and Autonomous Systems, vol. 54, no. 2, pp. 104–109, 2006.
13. A. M. Dollar and R. D. Howe, "The highly adaptive sdm hand: Design and performance evaluation," The international journal of robotics research, vol. 29, no. 5, pp. 585–597, 2010.
14. E. V. Eason, E. W. Hawkes, M. Windheim, D. L. Christensen, T. Libby, and M. R. Cutkosky, "Stress distribution and contact area measurements of a gecko toe using a high-resolution tactile sensor," Bioinspiration & biomimetics, vol. 10, no. 1, p. 016013, 2015.
15. Chen, X.; Wang, C.; Zhang, T.; Hua, C.; Fu, S.; Huang, Q. Hybrid Image Stabilization of Robotic Bionic Eyes. In Proceedings of the 2018 IEEE International Conference on Robotics and Biomimetics (ROBIO), Kuala Lumpur, Malaysia, 12–15 December 2018. [Google Scholar]
16. Song M, Xu Z, Wang X, Li X, Fang Y. Research on kinematics and biomechanics of the bionic mechanism. IOP Conf Ser Earth Environ Sci. (2018) 170:042060. doi: 10.1088/1755-1315/170/4/042060
17. Zhumadil Zh. Baigunchekov and Rustem A. Kaiyrov "Direct Kinematics of a 3-PRRS Type Parallel Manipulator", International Journal of Mechanical Engineering and Robotics Research Vol. 9, No. 7, pp. 967-972, July 2020
18. Gui Won Hwang, Heon Joon Lee, Da Wan Kim, Tae-Heon Yang, Changhyun Pang, Soft Microdenticles on Artificial Octopus Sucker Enable Extraordinary Adaptability and Wet Adhesion on Diverse Nonflat Surfaces, Advanced Science, 10.1002/advs.202202978, 9, 31, (2022)
19. Disheng Xie, Zhuo Ma, Jianbin Liu, Siyang Zuo, Pneumatic Artificial Muscle Based on Novel Winding Method, Actuators, 10.3390/act10050100, 10, 5, (100), (2021).