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The Efficiency of Collaborative Assembling Cells

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Abstract. To produce competitive products, it is necessary to consider their permanent modernization and adaptation to the emerging needs of a consumer. This feature of up-to-date production inevitably leads to design complexities. As a result, the complexity of a technological assembly process increases, which is a new challenge for enterprises. Simultaneously, in most cases, assembly operations are performed manually due to the complexity or impossibility of automating the assembling process for an extensive range of products. This fact is due to the insufficient flexibility of automation systems. Remarkably, this approach has significant drawbacks, i.e., low productivity and risk of chronic diseases. To solve this problem, the use of collaborative systems was proposed. Such systems have the advantages of both humans and automation tools. As a result, industrial robots can be applied as automation tools. However, when using industrial robots next to workers, the safety requirements are significantly increased since the infliction of industrial injuries is unacceptable. After considering all the above, the article deals with a new scientific and methodological approach to designing security systems of collaborative production cells and their design and effectiveness verification.

Keywords: industrial gripper, manufacturing engineering, assembling efficiency, industrial growth.

1 Introduction

Nowadays, manufacturers of machine-building products face modern production and technological challenges associated with the need to intensify production processes. Under these conditions, one of the effective methods of increasing competitiveness is the automation of production using industrial robots. Since there is a complication in the design of products due to the need for constant improvement of their characteristics and personalization, manual work is still relevant for assembly operations. This fact is due to the complexity of full automation due to the insufficient flexibility and adaptability of the first-generation robots and the inability to perform tasks where human intervention has required a level of intelligence and skills [1].

Also, consideration of the state of assembly automation is due to the popularity of industrial robots in assembly processes. According to the study [2], with all the features of using industrial robots for assembly automation, this task is the third most popular among new installations of industrial robots in the world as of 2020.

Although the robots of the first generation are quite effective in automating monotonous and dangerous work, they cannot fully interact with the production environment and people. Therefore, separate areas are allocated for robot safety, while the workers do not have access to the work area of the industrial robot of the first generation during his work.

However, thanks to advances in the field of robotics, the development of electronics and intelligent sensors, increasing the productivity of computing equipment, and reducing the cost of the solutions mentioned above, more and more tasks can be automated with the help of industrial robots every day while maintaining high quality, productivity, and reliability [3]. These changes made the appearance of second-generation robots (or collaborative robots). They can interact with the environment and directly with humans.

According to the results of the study [4], due to the possibility of combining the flexibility and adaptability of people and the capabilities of collaborative robots (e.g., repeatability and the ability to work continuously for a long time), it became possible to increase the efficiency, economy, flexibility, and productivity of production cells.

Additionally, in work [5], which is devoted to the design of a robotic section for collaborative assembly of pneumatic cylinders, it is additionally indicated that if the accuracy of the collaborative robot is insufficient, a person can compensate for it with the help of tactile sensations.

In addition, according to research, the implementation of collaborative robots significantly reduces the risk of developing occupational diseases. For example, the paper [6] is devoted to the system for evaluating the productivity of a collaborative cell for the assembly of electronic components and the risk of occupational diseases. It was made due to the frequent absence of workers due to absenteeism caused by occupational diseases of the musculoskeletal system. The use of a collaborative robot helped to reduce the number of awkward positions and reduce the burden on the worker. Work [7] is devoted to the design of a collaborative robotic cell for the assembly of a hinge of equal angular velocities. The use of a collaborative robot helped to reduce the load on the operator by approximately 60%. Complete automation of this process is impossible due to the need for high accuracy and flexibility.

This became the reason for the growing popularity of collaborative robots: the number of new installations from 2017 to 2020 doubled – from 11,000 up to 22,000 pcs. [2]. In addition, each famous industrial robot manufacturer has several collaborative robot models in their catalog (e.g., ABB YuMi, Fanuc CR Series, and KUKA LBR IIWA) [8].

Also, collaborative production cells increase production efficiency and are generally economically beneficial.

For example, due to the increasing complexity of the design of cars, the possibility of automating production with the help of collaborative robots was considered, considering the cycle time and the number of people and robots. The parameters of the work of humans and robots separately and together were compared. The results indicate a significant increase in the productivity of the assembly area. One of the reasons the authors cite the ability to allocate human and robotic resources in real time for the work plan execution [9]. Also, collaborative works can support the execution of tasks by a person at low costs [1], thus ensuring the profitability of partial automation of the assembly process.

Optimum planning is necessary to ensure the economic efficiency of the assembly area using collaborative robots. As an example of research in this direction, researchers for the correct assessment of the workstation launched a simulation model, with the help of which they received more data to understand the system, which allows making the right decision about the means that are used on the cell [4].

Increasing the efficiency of human-collaborative robot cooperation is facilitated by the fact that the robot can perform several functions, for example, be a basic assembly device, feed a tool, apply grease, and glue. For example, BMW is trying to introduce collaborative robots that help people with tools during assembly [10].

Moreover, thanks to the development of end-effector elements, these tasks can be combined, as the robot can quickly change the end-effector, for example, with the SCHUNK SWS Series pneumatic replacement system.

Also, collaborative work during assembly can perform various tasks, be a device with many degrees of freedom, feed a tool, apply a coating, and more. At the same time, task data can be combined due to the possibility of quick tool change.

In addition, to increase the efficiency of interaction between a person and a collaborative robot, it is necessary to evaluate the effectiveness of various options for information exchange. According to work [5], there are the following types of human-robot interaction:

– transmission of information through effort: in this type, the interaction occurs through explicit and intentional contact, while the robot must be able to respond adequately to the application of force;

– contactless data transfer, for example, through gestures or voice commands;

– data transmission through the interface, for example, buttons, touch screen.

Also, the introduction of collaborative robots has enabled the implementation of a learning-by-demonstrating system through efforts to simplify precinct commissioning, made possible by advanced sensors and artificial intelligence tools that recognize whether human interaction was intentional or unintentional and smooth out errors for smoother control. This allows you to reduce the time of production preparation due to the absence of the need to create and debug a control program and perform a collision check [11].

Using robots next to people requires ensuring the safety of people from injuries that the robot can inflict on them. Article [12] is devoted to analyzing the state of development of collaborative systems, including employee safety. According to the study, several ISO standards have been introduced to classify the interaction of humans and collaborative robots. For example, the ISO 8373 standard defines terms related to manipulating industrial robots used in industrial settings, including human-robot interaction.

The ISO 10218 standard, in two parts, defines the safety requirements and limitations of an industrial robot when interacting with people.

The ISO 15066 standard complements the previous standard and describes the procedure for limiting the speed values of the robot links, which in turn affects the maintenance of force and moment values at a safe level for humans. Based on these requirements, the following control modes were defined:

– the controlled speed with a safety rating (the robot stops when a person enters an unwanted zone);

– method of manual control (no restrictions on the speed of the elements, but the person himself generates commands for complete control of the robot);

– control of speed and distance (depending on the distance between the person and the robot, the maximum possible speed of the robot elements also changes);

– limitation of power and force to a safe for threshold person.

In addition, a classification of interaction levels directly affects security requirements: coexistence, cooperation, and interaction, in which interaction can be physical and non-contact [13].

Additionally, the following strategies for ensuring human safety have been implemented recently [12, 14]:

– robot stop functions, separately both protective and emergency stop;

– limitation of the speed of the central point of the tool;

– a visual indication of the state of the collaborative robot is necessary;

– limiting the robot's working area to the minimum necessary volume;

– establishing the minimum permissible distance between a person and a robot;

– assessment of the possibility of a collision in real-time, e.g., using machine vision systems [7];

– technological and ergonomic requirements: it is necessary to minimize the number of objects with sharp edges, ensure the absence of vibrations transmitted to a person, and analyze the area for enough free space to prevent the possibility of a person being pinched.

The work aims to improve the efficiency of the assembly processes of the connecting rod-piston group by existing safety standards.

To achieve the set goal, the following tasks have been formulated. Firstly, to investigate the current state of development of collaborative systems and justify the feasibility of implementing a collaborative assembly cell. Secondly, to develop assembly technology and design and technological support of a collaborative assembly cell. Finally, evaluate the effectiveness of the collaborative assembly cell.

The object of research is the design of a robotic cell. The subject of the study: designing a collaborative production area for the assembly operations of the connecting rod and piston group.

2 Research Methodology

2.1 Justification of the need to design a collaborative assembly cell

Research methodology is based on the theoretical foundations of mechanical engineering technology, the foundations of designing gripping devices for industrial robots, standards in designing collaborative robotic areas, and the method of finite element analysis.

Since collaborative work has proven its effectiveness in industry, analysts predict a significant increase in the number of enterprises in the coming years and the next decade [15].

It is proposed to design and implement a collaborative assembly area for assembly operations of the connecting rod-piston group (Figure 1).

The connecting rod-piston group is used in internal combustion engines, for example, in cars, motorcycles, brush cutters, gasoline saws, and other small equipment, as well as in piston compressors. This technique is quite widespread and is available to many consumers around the world.

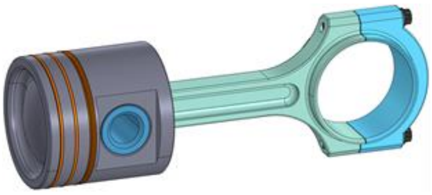


Figure 1 – Connecting rod-piston group

Simultaneously, the complexity of automation lies in the high accuracy of the elements. In addition, the constant change in environmental emission standards forces manufacturers to permanently improve internal combustion engines' efficiency. That is why the assembly section must be flexible and work with various designs of the connecting rod and piston group. In addition, the use of manual labor is associated with the danger that arises since certain structural implementations of this unit involve heating the connecting rod, which can lead to industrial injuries. That is why the most rational option for implementing the assembly process is the implementation of collaborative assembly.

2.2 Planning the structure of the assembly operation

The assembling process for connecting the rod-piston group consists of the following stages:

1) install the rod into the device (this stage ensures accurate positioning of the rod relative to the piston);

2) apply oil to the outer cylindrical surface of the rod;

3) apply oil to the holes in the piston for locating the rod;

4) heat the neck of the connecting rod to the temperature of 280-320 °C (to prepare for pressing);

5) clamp connecting rod in the jaws;

6) connect the connecting rod, the piston, and the rod (it is necessary to pay attention to the correctness of the mutual location of the parts);

7) remove the rod from the device;

8) check the smoothness of the connecting rod's movement relative to the piston (after cooling the parts);

9) put the assembly unit in the container.

With manual assembly, all operations are performed sequentially, which increases the time spent on the operation.

Since the use of collaborative robots makes it possible to perform certain stages in parallel, it is proposed to organize the work of the collaborative section according to the following scheme (Figure 2).

To perform the assembly operation according to this scheme, it is necessary to develop a plan for the collaborative cell (Figure 3).

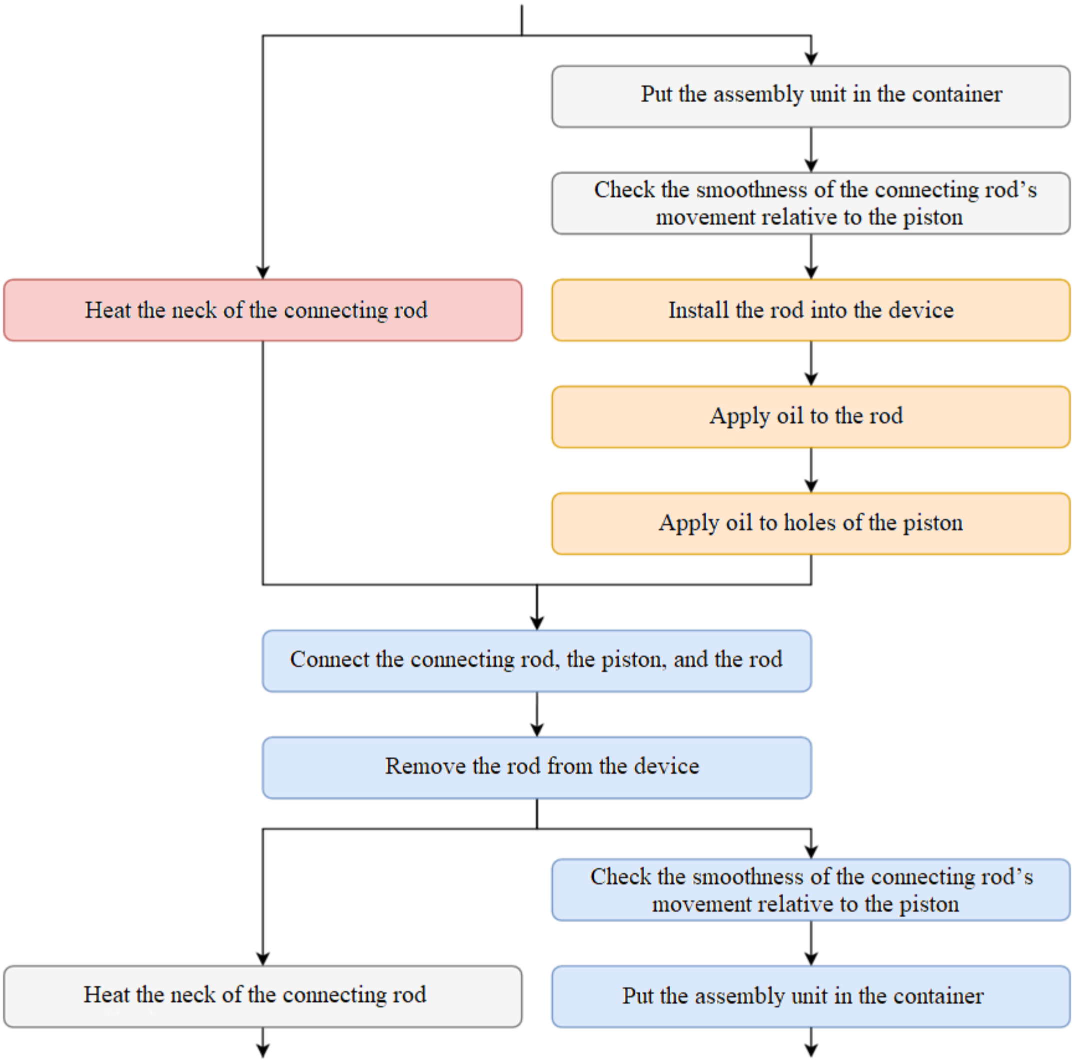


Figure 2 – Assembling chart

The collaborative section works as follows: parts for assembly are fed by a conveyor in random order, after which a delta robot, using machine vision systems, sorts of rods, connecting rods and pistons into sets. Next, the collaborative robot feeds the connecting rod into the installation for its heating, feeds the piston and pin for their further preparation for assembly, and feeds the tested assembly unit to the output conveyor.

Using a robot for heating will allow accurate control of the heating time and ensures the absence of human contact with dangerous equipment. During the heating of the connecting rod, the operator installs the rod in a special device that will ensure the correct location of the rod relative to the piston and applies oil to the outer cylindrical surface of the rod and the piston holes.

After preparing the piston and pin and heating the connecting rod, the collaborative robot hands the connecting rod to the operator for the assembly process.

According to the drawing, the operator connects the rod and piston and waits for the assembly unit to cool down. To ensure safety, the working table is monitored by a machine vision system for the contact of the hot connecting rod with the operator. After that, the operator removes a special device from the rod. Next, the operator checks the smoothness of the stroke of the piston relative to the connecting rod, and the collaborative robot feeds the new connecting rod into the installation for its heating.

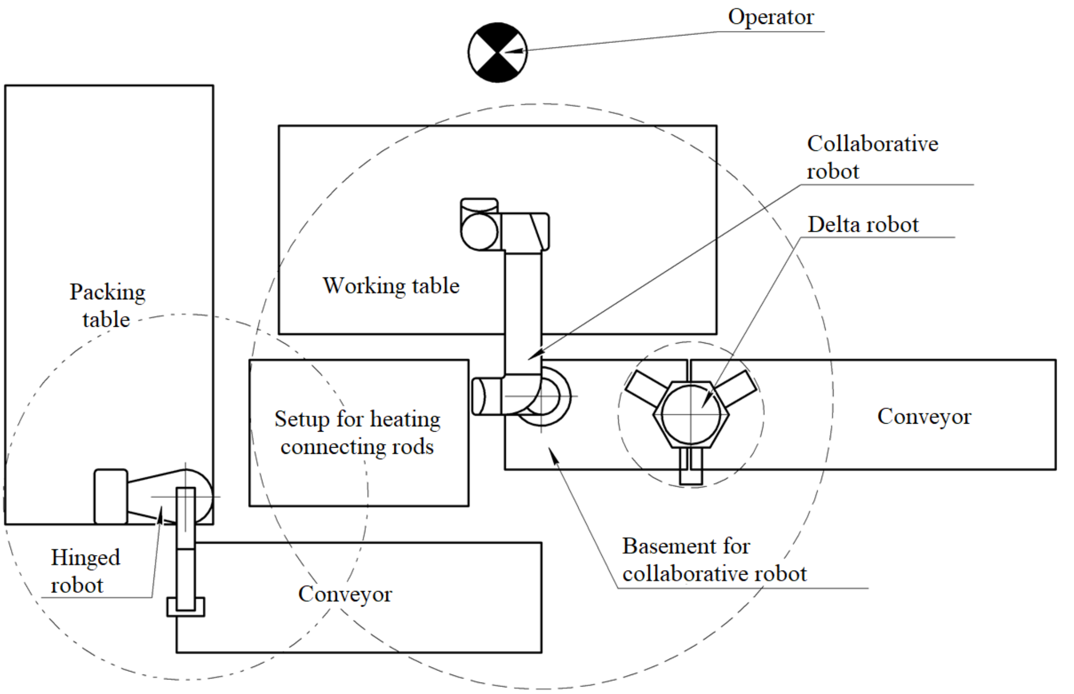


Figure 3 – Assembling cell

2.3 Selection of technical support for the mechanical assembly cell

Using a delta robot based on Delta XS [16] is suggested for sorting parts. Robots with delta kinematics are best suited for sorting because the low moving mass allows for high movement speeds. Open drawings and software for its management will allow it to be modernized in the future according to production needs.

As a gripping device, it is proposed to use adaptive rods of the DHAS series and a parallel pneumatic gripper of the HGPL-B series (Festo) [17].

Using a pneumatic gripper allows for sufficient clamping force, and using adaptive polyurethane rods allows for flexibility (the ability to clamp parts of different standard sizes without readjustment). At the same time, using polyurethane provides temperature resistance, resistance to the action of lubricants, and wear resistance.

To work with the operator, it is suggested to use the Universal Robot UR5 collaborative robot (Figure 4). This solution has a sufficient load capacity for these tasks, a working area, and protection against splashes.

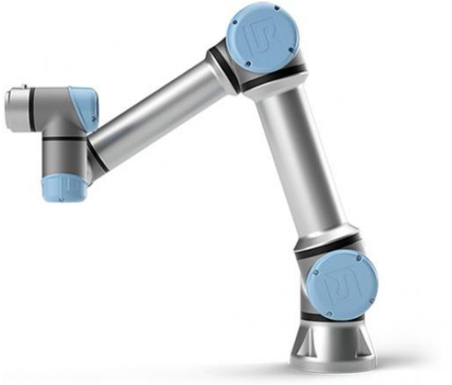


Figure 4 – Collaborative robot “Universal Robot UR5”

A new design of a grasping device for a collaborative robot is proposed. The general view of the capturing device is shown in Figure 5.

The flexibility of the gripping device allows you to clamp parts of various standard sizes reliably. To ensure operator’s safety, rubber pads are provided in places with sharp edges. The weight of the gripping device is 3 kg, and the carrying capacity of the robot is 5 kg.

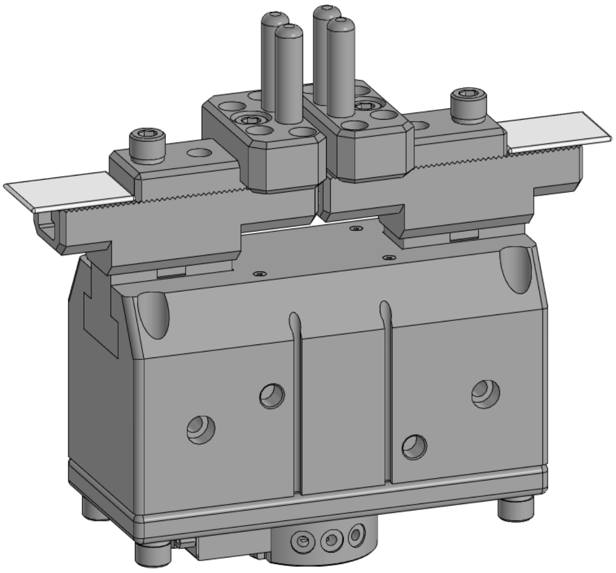


Figure 5 – Fixture design

The proposed design of the gripping device ensures a reduction of time spent on production preparation, increasing the degree of flexibility, which contributes to the expansion of the range of sizes of parts to be installed, and compensation for errors related to the technological process of obtaining blanks.

It is suggested to use the Annin Robotics AR3 robot for packing ready-made assembly units. Its advantages include sufficient carrying capacity for these tasks, simplicity, availability of access to technical documentation for future modernization, and cheapness. As a gripping device, it is proposed to use the adaptive rods of the DHAS series and the parallel pneumatic gripper of the HGPL-B series (Festo).

3 Results

3.1 Strength calculations

To check the gripping device for the strength and reliability of fixing the workpiece, it is necessary to perform calculations of the mechanical system “gripping device – part” using finite element analysis in the ANSYS Workbench software.

Friction coefficients were used in the calculations: steel-steel pair – 0.15; steel-aluminum pair - 0.17.

The value and direction of the applied effort when capturing the part are given in Figure 6.

The calculation results (movement and deformation of elements of the gripping device) are shown in Figure 7.

The analysis results indicate that the gripping device can be used to clamp and move parts in production.

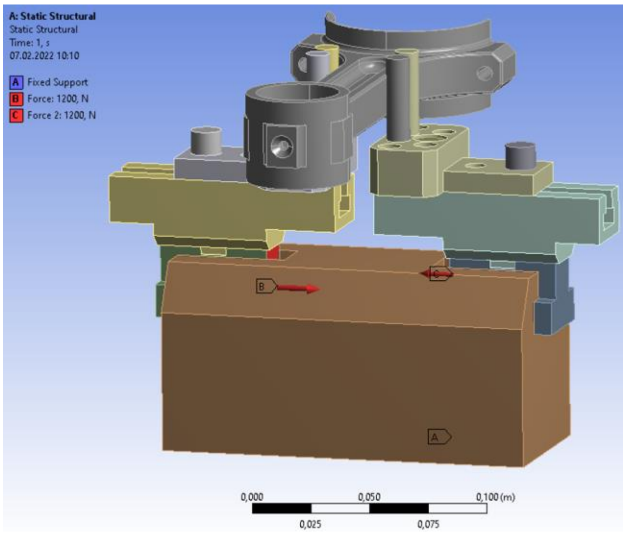
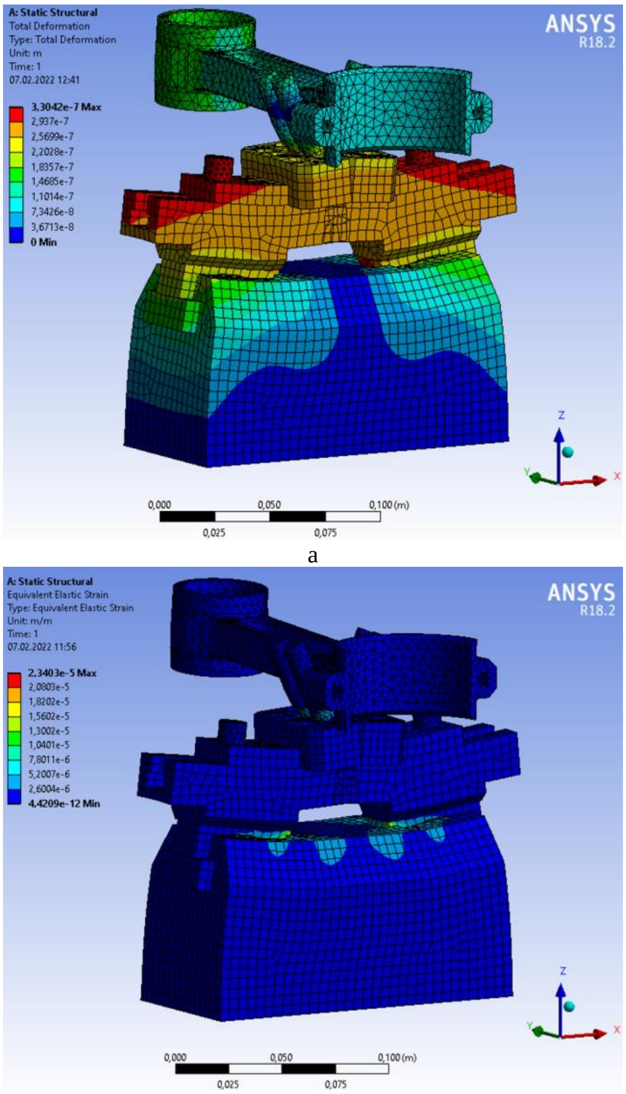


Figure 6 – Clamping forces



a

b

Figure 6 – Displacements (a) and elastic strain (b)

3.2 Calculations of labor intensity

To evaluate labor efficiency, it is necessary to calculate the cycle time for fully manual and collaborative assembly.

The assigned time norms for all transitions of the assembly operation for manual and collaborative assembly are indicated in Table 1.

It should be noted that some technological transitions are performed in parallel, and therefore, it reduces the time spent in implementing the scalding process. Calculations confirmed that manual assembly takes 6.16 minutes and collaborative assembly – 4.1 minutes, which is 34% less.

Table 1 – Labor intensity of assembly, min

No.	Content	Assembling type	
		Manual	Collaborative
1	Install the rod into the device	0.60	N/A*
2	Apply oil to the outer cylindrical surface of the rod	0.17	
3	Apply oil to the holes in the piston to locate the rod	0.17	
4	Heat the neck of the connecting rod to the temperature of 280-320 °C	2.60	2.6
5	Clamp connecting rod in the jaws	0.12	–
6	Connect the connecting rod, the piston, and the rod	0.90	0.9
7	Remove the rod from the device	0.60	0.6
8	Check the smoothness of the connecting rod's movement relative to the piston	0.50	N/A
9	Put the assembly unit in the container	0.50	
	Total values:	6.16	4.1

* Simultaneously with heating.

Therefore, the productivity of the assembly operation increases. Additionally, the automation of the assembly process due to the implementation of a collaborative area ensures a reduction in the risk of burns for the fitter-assembler and reduces the load on him during the performance of tasks.

4 Discussion

The scientific novelty of the obtained results is as follows. Firstly, a new approach to designing the technology of assembly of products in the conditions of multi-item production by introducing a collaborative assembly area, which increases production efficiency, is proposed.

Secondly, the expediency of the design was substantiated, and the design and technological support of the collaborative assembly cell was developed, which allows for an increase in the assembly process of the connecting rod-piston group in the conditions of multi-item production.

Finally, a new design of a gripping device for a collaborative robot is proposed, which expands the production area's technological capabilities due to the possibility of installing parts in a specific range of standard sizes, increasing the assembly process efficiency.

The practical significance of the obtained results for the machine-building industry consists of developing design and technical documentation for a collaborative assembly cell, design documentation for a new gripping device, and practical recommendations.

5 Conclusions

Thus, the current development of collaborative systems in mechanical engineering has been studied. The expediency of implementing a collaborative assembly cell to increase the assembly process efficiency in multi-item production conditions has been substantiated.

A new approach to the design of the structure of the assembly operation is proposed on the example of the assembly process of the connecting rod-piston group using robots, which made it possible to reasonably redistribute the technological transitions between the operator and the robots.

Also, a design solution for a collaborative assembly area for assembling a connecting rod-piston group is proposed. It improves the product assembly process in conditions of multi-item production by 34% compared to manual assembly.

Finally, a new design of a gripping device for a collaborative robot is proposed and developed, which reduces the time spent related to production preparation, increases the degree of flexibility, and compensates for errors related to the technological process of receiving blanks.

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