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DESIGN OF THE EDUCATIONAL WORKPLACE FOR WORKING WITH A COLLABORATIVE ROBOT

The article deals with the issue of development, design, production and revival of a test workplace equipped with a collaborative robot and human service. The proposed solution is based on the need to train the company's employees during the completion of gear sets. Since it is not a large-scale production, it was necessary to design the educational equipment in such a way that it is portable and can be placed within different workplaces and offers sufficient variability. The variability of the device makes it possible to modify the device so that the difficulty of the training is adapted to the knowledge of a trained worker. The developed device allows improving the manual, logical and programming competences of a worker.

Keywords: *Collaborative robot; collaborative effector; system of gears; cooperation.*
Fig.: 5. Table: 1. References: 9.

Relevance of the research. The twentieth century can be described as the century of a robot based on its development. In this period, there were already simple often referred to as primitive drive systems, and the first control systems also appeared. Companies' requirements and goals for higher production reached a high level. The development in the field of robots recorded the greatest progress in the field of electronics and control systems [1].

In the last decade, the idea of Industry 4.0 and the Smart factory, in which collaborative robots would play a key role, dominated the sphere of the manufacturing industry. The application of collaborative robots brought about a revolutionary change in production lines, relieving workers of some activities and at the same time maintaining the continuity of the production flow. This change concerned the transition from robots working independently to activities in which the robot collaborates with a worker who is also its operator. Many concepts were put into practice that ensured a safer and simpler working environment. The main goal of these steps was to create an environment where people and collaborative robots could work together [2].

Problem statement. The mutual cooperation of a person and a robot to perform a specified task makes it possible, especially in small-scale production, to reduce the costs necessary for the reconstruction of the workplace. This leads to the need to create an educational robotic workplace, enabling to improve the competence of human operators. At the same time, it places increased demands on the operator's technical knowledge and the need for creative thinking, which will enable the assembly process to be optimized at the robotic workplace. For this reason, the need for the design and creation of such a collaborative workplace was defined, which will enable the modification of tasks. Modifying tasks for each of the trained workers should be based on their previous knowledge and practical experience.

Analysis of recent research and publications. The term Cobot names a collaborative robot in the field of robotics. Edward Colgate, Witaya Wanaasuphoprasit and Michael Peshkin were the first to use this name in 1996. They defined a cobot as “a robotic device that manipulates objects in collaboration with a human operator [3].

Cobots were initially designed based on the requirement to facilitate operator movements while performing certain activities during their work. At the same time, human contact with the object was to be maintained. A simple example of how a cobot works is a unicycle. With this device, the wheel can rotate independently, but the steering and thus turning is controlled by the rider sitting on it. This means that one degree of freedom is controlled by a person, but at the same time one degree of freedom is controlled by a means or device. In summary, it can be said that collaborative robots were designed in the past to help people manipulate real objects. It follows from the definition that the mechanical bond that exists between a person and an object in a real manipulation task also exists in cobot applications. Their task is to adjust the available degrees of freedom, for example by restricting movement. In other words, the cobot modifies pre-existing human-object bonds, while new bonds are created using haptic devices. In the last decade, collaborative robotics has achieved success mainly due to implementation in small and medium-sized enterprises. The use was subject to only two conditions – security requirements for employees and the complexity of programming and operations. However, the use of collaborative robots in more complex situations such as patient care in hospitals, quick intervention during surgical operations or rescue operations requires the use of artificial intelligence elements for active cooperation with people in rational situations [3].

The definition of collaborative robots in this wording can be dated to 2016, when the first international conference for interactive collaborative robots took place (Interactive Collaborative Robotics. ICR 2016, Budapest). As the name implies, the new category of cobots involved active cooperation between a person and a robot, and therefore not only assistance in performing simple operations, but a certain form of dialogue [3].

Uninvestigated parts of a common problem. One of the trends of the modern phase of scientific and technological development is the socialization of robots into various branches of human activities. The concept of collaborative robots was derived from this, or cobots. According to the international standard ISO 8373:2021-11 “Robots and robotic devices” (2021), collaborative robotic operations include those activities in which a person cooperates with a robot in the same workplace [4]. A robot that has elements of artificial intelligence and a developed information sensory system becomes such a partner of a person that performs even more sophisticated tasks. In view of this, a new concept was created - Interactive collaborative robots. The application of logical elements led to a significant expansion in the field of use of collaborative robots, covering all new human activities and interests [5]. Developments in the field of remotely controlled manipulators led to the emergence of a new group of remotely controlled systems. These were defined as remotely controlled collaborative robotic systems. An important representative of this field is the robotic surgical system Da Vinci (Fig. 1), which facilitates and helps the surgeon's work. This system is not directly a robot, but rather a robotic smart tool operated by a surgeon. This area also includes, for example, systems with use in space or underwater, with elements of artificial intelligence, which are controlled by a person at the same time with the active support of robotic systems [3].

Research objective. The goal of the research was to design such a device that would be intended for assembly purposes. This means that the operator of the device should demonstrate its skills not only manually but also logically. Since the request was based on the needs of the company, in which different types of gears are most often used in assembly activities, it was necessary to implement them into the device. Another requirement was the portability of the device, so that it was possible to place the device on an adjustable work table, according to the current needs at the workplace. For this reason, a total of three variants of the workplace were created. Next, the most optimal variant in terms of price and ease of production was selected.

The statement of basic materials. The collaborative robot Fanuc CRX – 10iA was used at the test site, Figure 1. With its properties, it exceeds the requirements set for the task and enables it to be performed safely and reliably. Among its advantages there is the function of a quick stop by touch, which ensures the prevention of accidents in contact with the robot or work objects. The sensor technology mounted in the robot's body enables an immediate emergency stop when it comes into contact with an obstacle or a human body [6].

Fig. 1. Fanuc CRX-10iA

The robot offers easy-to-use additional software that allows a user to easily install interfaces for peripheral devices. It is also possible to program the robot using the manual guidance function, the so-called Manual guide. This means that the operator guides the robot to the desired location and saves this location in the tablet using the drag & drop function. The robot is controlled by a compact, lightweight controller R-30iB Plus Mini [7]. The technical data of the robot are listed in Table.

Table – Fanuc robot parameters CRX-10iA [8]

Namely the load	*10 kg*
Number of controlled axes	*6*
The range of movement of the controlled axes	*360 až 570°*
Movement speed of controlled axes	*120 až 180 °/s*
Robot range	*1249 mm*
Repeatable positioning accuracy	*+/- 0.04 mm*
Weight	*40 kg*

The main and inseparable equipment of the robot for performing the work task is a collaborative electric gripper from the company Schunk with the designation EGP-C 40-N-N-FCRXID (Fig. 2). The gripper is size 40 with a lift of 6 mm per jaw and the greatest force per jaw $F = 70\ N$ [9]. The gripper is connected to the robot using a flange and screws with a metric thread, signal transmission is ensured by a cable. The gripping fingers of the flange were modeled with respect to the shape and dimensions of the work objects and are manufactured using 3D printing.

Fig. 2. Schunk collaborative grip effector

The design of the workplace was implemented in such a way that the task of the collaborative robot is to assemble a system of gears on a prepared work surface. Using a gripping effector with fingers designed for the given operation, the robot removes and places wheels on a steel plate with pins for wheel storage. The gears are mounted serially behind each other in the axis. The last wheel of the gear has a cylindrical turned drum attached to the side for unwinding the connecting cable. The last, driven wheel can be changed to a wheel with a different number of teeth and thus the gear ratio would also change. In Figure 3 shows a view of the proposed solution.

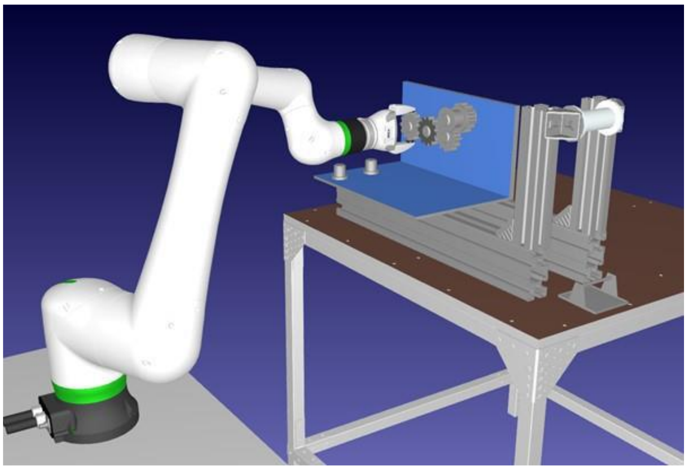

Fig. 3. 3D design of the solved robotic workplace

The gears are placed in trays on the plate in front of the robot. From this position, the robot takes them to the pins that are on the base plate in front of the robot. Multiple wheel alignment options are available. Even when changing the order of the gears, the functionality of the transmission will be preserved and thus the teeth will engage. The resulting gear ratio can be changed so that it is larger, smaller or equal to one.

The manipulation task is performed at a workplace with a pair of work tables. On one table the robot performing the task is stored and screwed, on the other table the task is performed and all the parts of the work task are stored on it. Base plates with dimensions of 160 x 400 are placed on aluminum profiles of length $l = 530\ mm$. The assembled gear assembly will be powered by a Faulhauber servo motor with a Faulhauber planetary gearbox. This drive will guarantee a constant torque that will be transmitted through the gear for winding the connecting cable onto the drum, which is connected to the platform. The mechanism is constructed from aluminum profiles of size 40 x 40 mm, on which a system of pulleys, a drum, a connecting element - a cable and a platform for lifting are mounted.

The design solution of the variant is composed of several units. The supporting elements of the assembly are formed by two steel plates, which are connected to each other by fillet welds. The bearing plate on which the pins are attached has dimensions of 160x300x10 mm, the bottom plate on which the magazine for gears is located has dimensions of 160x400x10 mm. Holes are drilled in the plates for the pins on which the gears are mounted. The axial distances of the holes were designed according to the values of the pitch circles of the gears and allow the configuration of the used wheels to be changed. The holes in the plate are made with a tolerance of H7. The resulting dimension of the system, consisting of two plates, is 400x170 mm and 160 mm high. The drive is located on the support plate, where it is connected by means of a connecting element. The torque from the engine is transmitted by means of a flexible coupling that connects the output shaft of the engine and the shaft of the drive wheel. A cable is attached to the drum mounted on the driven wheel, which lifts the platform through a system of pulleys. In Figure 4 shows a view of the proposed assembly.

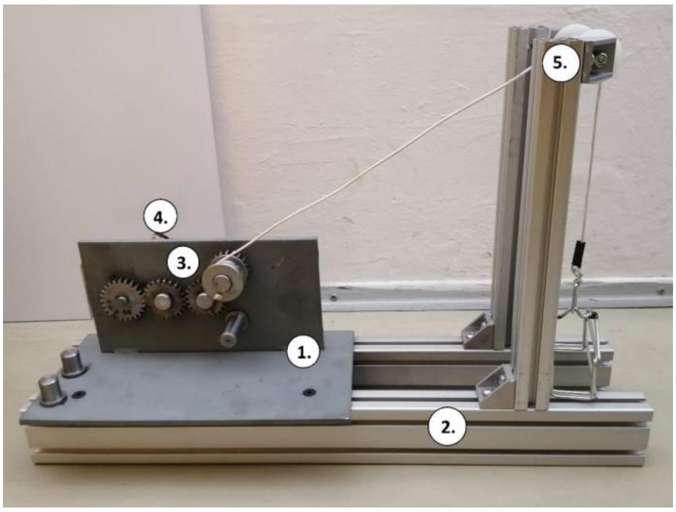

Fig. 4. The proposed assembly assembly:
1 – Base plates; 2 – Support structure; 3 – Gear wheels; 4 – Lifting mechanism

The procedure for working out a work task at the workplace is graphically illustrated using the attached diagram, Figure 5. The diagram clearly presents the relationships between individual elements and parts of the work task. The signs and shapes used in the diagram have their own special meanings and are distinguished by their purpose. Individual shapes are connected by arrows that determine the continuity of the process.

The attached diagram graphically describes the work process at the workplace with a collaborative robot whose task is to create a system of gears. According to the assignment, the robot cooperates at the workplace with an operator who assists him and at the same time checks the work being performed. The task of the robot is to take the gears from the magazine and place them on the prepared pins. After fitting the gears, the operator puts on the demarcation washer and the insurance (seger) washer. After completing the assembly, he manually turns on the voltage source for the servo drive, which causes the gear to move.

At the beginning of the work task, the collaborative robot is in its home, basic position (HomePosition), from where it starts to perform operations. The grasping effector of the robot is in the open state - Open. From the basic position, the robot moves above the magazine with gears, from where it takes the first gear. The robot moves to a safe distance above the magazine with a Jog type movement, then moves in a vertical direction up to just above the gear wheel. In the gear grip position, the fingers of the grip effector are closed with the Close command and the robot moves back to the home position with the gear gripped. From the basic position, the robot moves with a Jog type movement towards the pin for fitting the gear wheel. It is very important to maintain the predefined positions of the gears in the magazine as well as the position of the drive gear for proper engagement and engagement of the gears. These positions are marked with lines on the base plates. Near the pin, the robot with the manipulated wheel is adjusted so that the axis of the pin is identical to the axis of the gear. After the correct setting, the wheel is pushed onto the pin using a Linear movement. In the storage position, the end gripper effector is opened with an Open instruction and the robot returns to the home position to allow the operator to perform his task of placing the locating and locking washer on the stud. During the execution of commands by the robot, its movement is visually checked by the operator. If the robot registers resistance during any of its operations with one of its sensors, it repeats the movement once more. After unsuccessfully performing any of the operations again, the movement of the collaborative robot stops and it is necessary to reconfigure the work task.

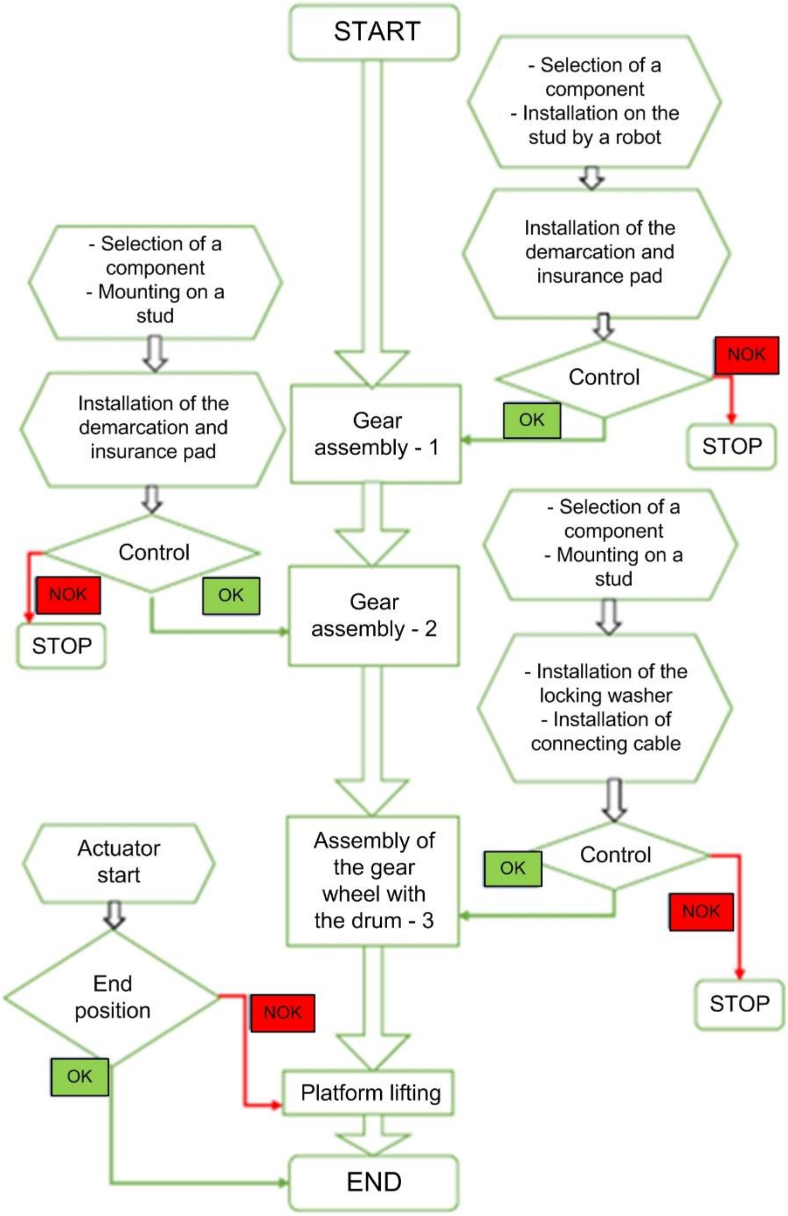

Fig. 5. Work task sequence in the workplace with a collaborative robot

After mounting the first gear, the work cycle is repeated and the robot grabs the second gear in the magazine and places it on the next pin so that it engages with the previous gear. It is important to pay attention to the precise programming of the position for gripping the gear wheel so that the entire surface of the gripping fingers is used. After correctly grasping the manipulated object with the Close instruction, the robot will gradually return to the position above the magazine with a Linear movement and then to the basic position with a Jog movement. From this position, the operation continues to fit the gear on the next pin. Attention during programming must be focused on the orientation of the gripping effector to avoid unwanted contact with other elements of the assembly. After centering the axis of the pin and the axis of the wheel, the second gear wheel is set to its end position by a Linear movement. The robot will gradually return using the Linear instruction to the position in front of the pivot and the Jog instruction to the basic position to allow the operator to perform his part of the task. After mounting the first and second gears on the base plate, there follows the operation of mounting the driven gear, which is fitted with a drum for unwinding the connecting element between the gear and the lifting platform. Assembling the drum gear is the last operation performed by the collaborative robot. The robot is moved from its home position by a jog type movement above the magazine, where the gear wheel with the drum is located. This is followed by a Linear movement in the direction of the z axis, bringing the robot closer to touching the drum. In this position, the gripping effector is closed with the instruction Close, fig. 46 and the attached object rises back above the magazine, then returns to its original position, from where it moves to the last pin for assembly. After the correct position is set, the gear wheel is pushed into the end position, the gripper effector is opened with the "Open" command, and the robot returns to the home position. The operator puts on the safety washer and connects the connecting cable through the pulley to the lifting platform located at the end of the aluminum profile structure. After completing the system of gears and connecting the driven wheel with the drum to the platform, it is possible to start the lift of the platform. Applying the supply voltage to the terminals of the Faulhauber servo drive will cause the gears to move. When the last gear rotates, the connecting cable is wound on the drum and thus the platform is lifted. The lift of the platform is stopped manually by the operator upon reaching the top position.

If necessary, the whole assembly can be disassembled using reverse commands, after disconnecting the connecting cable from the platform and winding it on the drum, as well as removing the locking and limiting washers from the pinions of the gear wheels.

Conclusions. In this article, the design of a workplace for the mutual cooperation of a collaborative robot and a human operator is shown. At the workplace, it is possible to change the arrangement of a maximum of four pieces of gears with direct teeth. One of the wheels is also equipped with a drum for winding the cable, enabling the lifting of the platform. The lift of the platform is realized using a drive consisting of a DC motor and a planetary gearbox. Cooperation between a robot and a human can consist in two basic areas. The first and simpler area is the combination of mounting the gears on the fixture. The teacher can tell the student which wheels the robot places and which the student places. The second more difficult area is the need to secure the mounted gears on the pins using seger rings and spacers. This can be done by hand or with the help of seger pliers.

The uploaded educational workplace solution allows the teacher to enter different gear arrangement configurations for individual students. At the same time, the designed workplace allows to test the student's acquired knowledge in the field of design and calculation of gear transmission. This is ensured by providing the student with several pieces of gears, but only some combinations of them can set the designed mechanism in motion. This creates a complex task for the student consisting in the design of the gear, its recalculation, the programming of the robot, the implementation of collaborative assembly and the testing of the functionality of the solution using a lifting platform.

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ПРОЄКТУВАННЯ НАВЧАЛЬНОГО РОБОЧОГО МІСЦЯ ДЛЯ РОБОТИ З КОЛАБОРАТИВНИМ РОБОТОМ

У статті розглянуто питання розробки, проєктування, виробництва та запуску випробувального робочого місця, оснащеного колаборативним роботом і людиною-сервісом. Запропоноване рішення базується на необхідності навчання працівників підприємства під час комплектації зубчастих пар. Оскільки це не великомасштабне виробництво, необхідно було спроєктувати навчальне обладнання таким чином, щоб воно було портативним, його можна було розміщувати на різних робочих місцях і мало достатню варіативність. Варіативність устаткування дозволяє його модифікувати таким чином, щоб складність навчання була адаптована до знань працівника, що навчається. Розроблене устаткування дозволяє підвищити мануальні, логічні та програмні навички працівника. Ручні навички вдосконалюються за рахунок необхідності використання ручних інструментів під час складання, якими працівник повинен вміти керувати за встановлений час. Логічну компетентність працівника можна покращити, додавши додаткові шестерні з різною кількістю зубів, що змушує працівника виконати базовий розрахунок передавального числа для складання вузла. Компетентність працівників у програмуванні покращується завдяки необхідності програмування колаборативного робота, щоб він міг безпечно пересуватися в обмеженому просторі. Розрахункові зазори в опорах та між шестернями вимагають необхідності точного програмування та оптимізації руху. Розроблене навчальне робоче місце підходить для вдосконалення знань працівників, які вже мають досвід подібної діяльності та потребують підвищення продуктивності, оптимізації процесів або скорочення часу простою. Запропонований колаборативний робот характеризується достатньою вантажопідйомністю та радіусом дії. Для програмування робота, а також керування роботом методом відтворення використовується планшет із сенсорним керуванням. Це дозволяє прискорити процес створення відповідних траєкторій і оптимізувати логічні функції робота.

Ключові слова: *колаборативний робот; колаборативний ефектор; система зубчастих передач; співробітництво.*

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