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DESIGN OF A TRAINING WORKPLACE WITH A COLLABORATIVE AND INDUSTRIAL ROBOT

The article deals with the design of a training workplace equipped with two robots, one of which is industrial and the other collaborative. The assembly of a gearbox model equipped with three different shafts is carried out at the training robotic workplace. The entire assembly process requires the mutual cooperation of an industrial, collaborative robot and a human operator. Use the assembly parts to create a large number of combinations, so that a number of individual tasks can be created at the workplace. The safety of workers at the workplace is solved by the use of safety laser scanners, so that there is no danger to people.

Keywords: *Industrial robot; collaborative robot; training workplace; cooperation.*
Fig.:7. Tables.:0. References:11.

Relevance of the research. In the 1990s, the US Occupational Safety and Health Administration began looking at how the manufacturing industry was addressing ergonomic issues in manufacturing plants. These problems occurred to a large extent in the automotive industry, especially in the field of final assembly. This type of work process consisted of actions such as the transfer and installation of car batteries weighing 20 kilograms, which had a negative impact on the health of workers during long-term performance of this work activity. General Motors, as a leading company in the automotive industry, decided to analyze this problem and, together with the University of California, began to work on its solution [1]. In 1999, the first definition of a collaborative robot was registered at the US Patent Office. This was IAD, which is considered to be the forerunner of modern collaborative robots. This device could work outside the protective cage and assist workers in the performance of assembly operations, but it did not contain a source of motion force from the safety robots [2].

Problem statement. In 2004, KUKA, a German robot manufacturer, introduced a self-powered collaborative robot called LBR 3. This robot was the result of a long-term collaboration between KUKA and the German Aerospace Center DLR. In the following years, KUKA further improved this technology, resulting in the collaborative robots LBR 4 introduced in 2008, LBR 4+ introduced in 2010 and LBR iiwa, introduced in 2013 [3]. In 2008, Universal Robots, a Danish robot manufacturer, introduced a collaborative robot that could perform its work alongside human workers without the need for a protective cage called the UR5. This robot helped usher in the era of flexible, user-friendly and affordable collaborative robots [4]. ABB, a Swedish-Swiss robot manufacturer, launched the world's first two-armed collaborative robot called YuMi in 2015. This robot enables safe cooperation between a human worker and a robot, for example in the assembly of small parts [5].

Analysis of recent research and publications. Collaborative robotics can be seen as a progressive stage in the development of industrial robotics. This new stage in the development of industrial robotics assumes that people will cooperate with robots and that this cooperation will be

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safe for them. For this reason, collaborative robots are equipped with a wide range of sensors and vision systems. For example, if a person were to enter the working zone of a collaborative robot, this robot is able to change its behavior algorithm so as not to harm this person [1,2].

Uninvestigated parts of a common problem. The concept of the development of human-robot interaction is reflected in the concept of the fourth industrial revolution. The essence of the Industry 4.0 concept is that an industrial robot can serve as a cooperative and working tool in production. The main element of this concept is artificial intelligence based on the Internet of Things. In a simplified concept, IoT is a network of physical objects that communicate with each other via the Internet. Collaborative robotics and other innovations are modifying business models in modern industry, while the very integration of robots contributes to the computerization and automation of production and the introduction of the concept of intelligent production [6]. Collaborative robots perform a similar range of work activities to conventional industrial robots, but are typically lighter and smaller in size. The collaborative robot has integrated force control and sensors, thanks to which it automatically slows down or stops its activity when a person approaches it. This allows them to work in close proximity to people with minimal or no safety precautions. They have a multi-axis construction of the manipulator, which allows these robots to be deployed to perform various work tasks [7]. ISO/TS 15066:2016, "Safety of collaborative robots", provides information on how to implement a collaborative robot application to ensure worker safety [8].

Research objective. The goal of the design of the training workplace is to create a workplace where there would be cooperation between a person, a collaborative robot and an industrial robot. We decided to demonstrate this collaboration by having a human and a collaborative robot participate in the assembly operation, and the industrial robot then wraps the final gearbox assembly.

The statement of basic materials. The assembly operation consists of assembling a simplified model of the gearbox, which consists of shaft 1 (A), shaft 2 (B), shaft 3 (C), the lower part of the gearbox (E) and the upper part of the gearbox (F). The packing operation consists of transferring the finished model to the box (D). In fig. 1 shows shaft 1 (A), the largest diameter of which is 80 mm. Shaft 2 (B) has a largest diameter of 70 mm and shaft 3 (C) has a largest diameter of 60 mm. The other dimensions of the shafts are identical. The individual shafts in the starting position are located on pedestals with an opening for storing the shaft, which are attached to the work table. The components that make up the gearbox model, as well as the pedestals for storing the shafts, are made of PLA plastic, so it would be possible to use 3D printing for their physical realization.

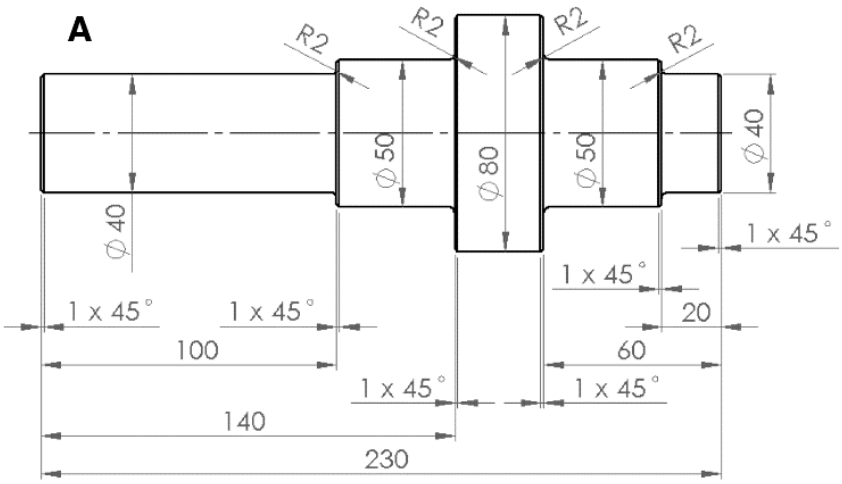

Fig. 2 Shaft dimensions (A)

The dimensions and face of the lower and upper part (body) of the gearbox are shown in fig. 2. The mentioned parts contain a system of three storage places with a diameter of 40 mm, in which it is possible to store any of the mentioned shafts (A, B, C) in any place.

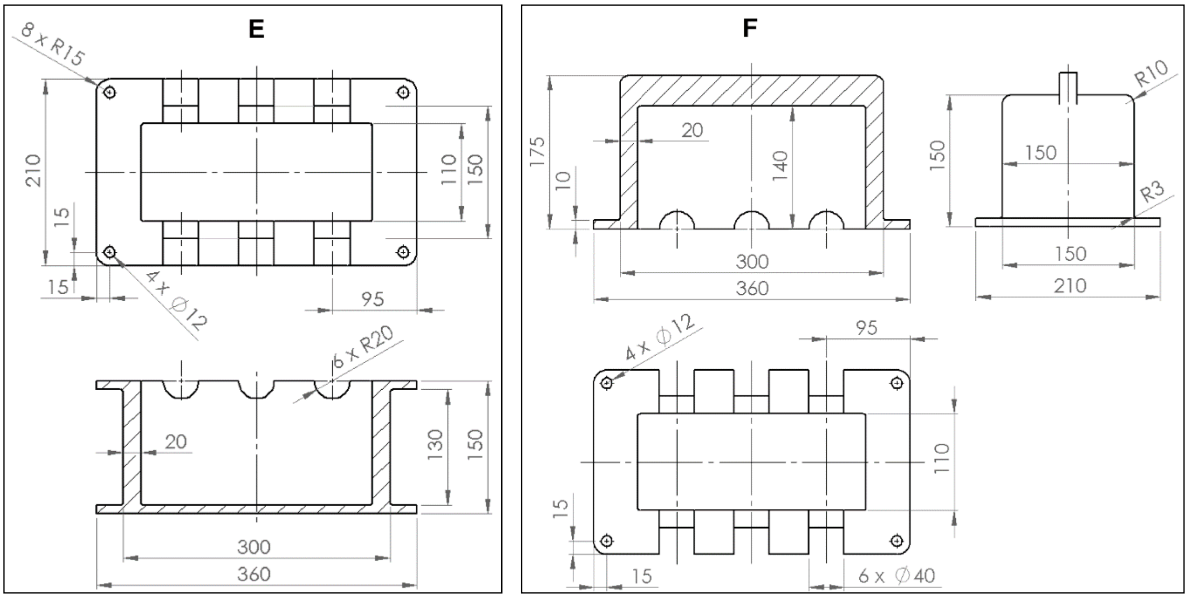

Fig. 2 Dimensions of the lower (E) and upper (F) part of the gearbox

The components that make up the gearbox model, as well as the box, are placed on the tables, while their positions relative to the tables are precisely given. In fig. 3 shows a view of the floor plan of the workplace with the corresponding dimensions of the location of the manipulated objects.

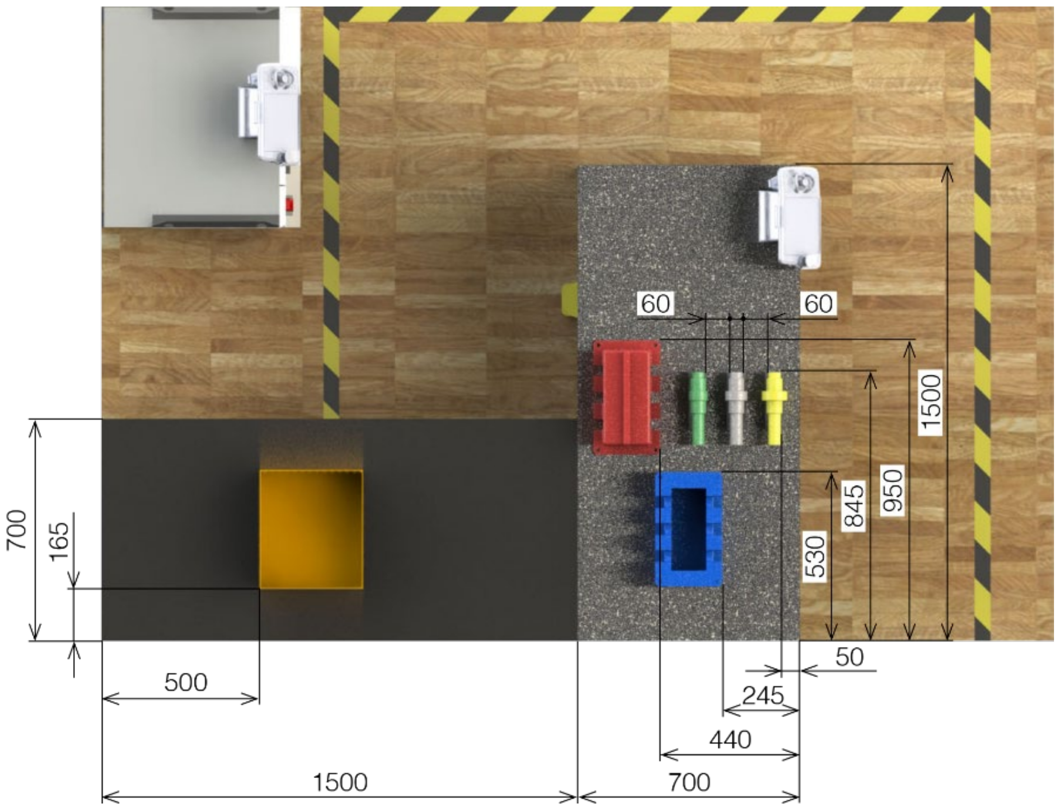

Fig. 3 The dimensions of the tables and the location of the manipulated parts

The industrial robot IRB 1200 and the collaborative robot GoFa CRB 15000 [9, 10] were chosen to perform selected operations. Both robots are manufactured by ABB, thanks to which it would be possible to simulate the workplace in the ABB Robot Studio program. To handle the components, both robots are equipped with an RG6 gripper from OnRobot, which has a finger span of 160 mm and a load capacity of 10 kg. The robots are installed on tables with the dimensions length: 1500 mm, width: 700 mm and height: 780 mm, these tables are also used to perform work operations. The visualization of the proposed educational workplace in a 3D environment is shown in fig. 4.

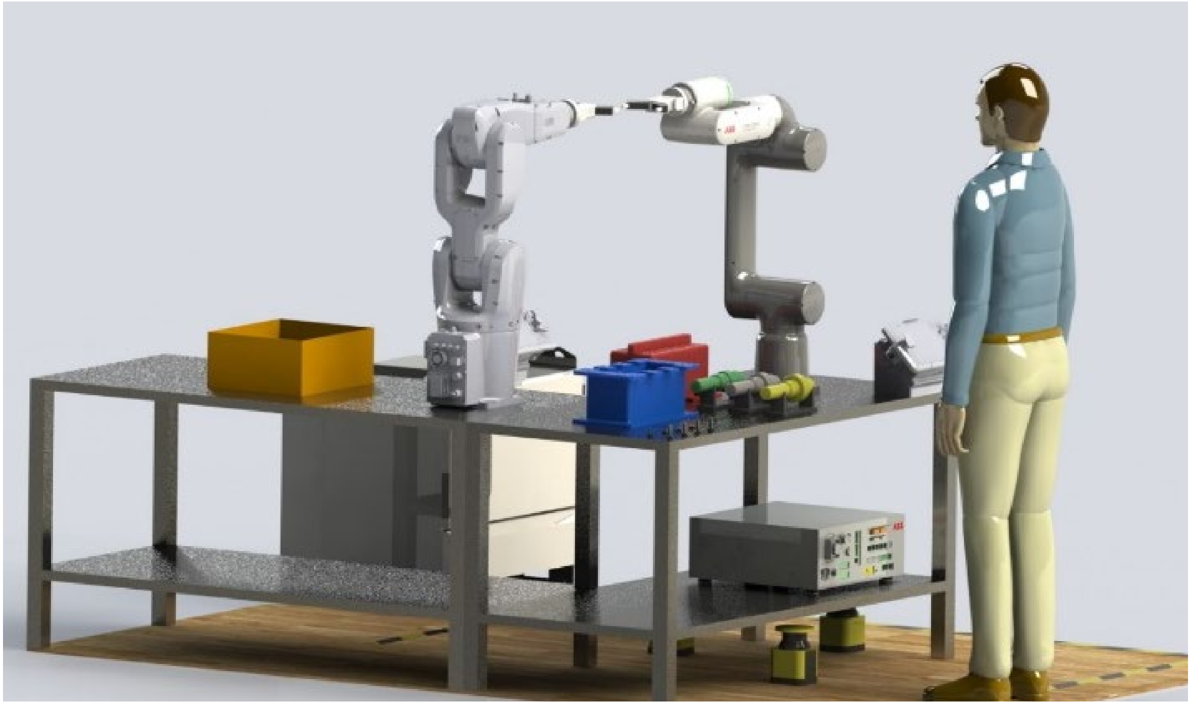

Fig. 4 A 3D view of the proposed educational workplace

The individual steps of the sequence of work operations are as follows, fig. 5:

• In the first step, one places the individual components in their starting positions.

• In the second to fourth steps, individual shafts are grasped, moved and placed in the holes in the lower part of the gearbox by a collaborative robot.

• In the fifth step, the collaborative robot grabs, moves and places the upper part of the gearbox on the lower part of the gearbox.

• In the sixth step, a person creates bolted connections between the upper and lower parts of the gearbox using bolts and nuts.

• In the seventh step, the resulting assembly is grabbed, moved and stored in the box by an industrial robot.

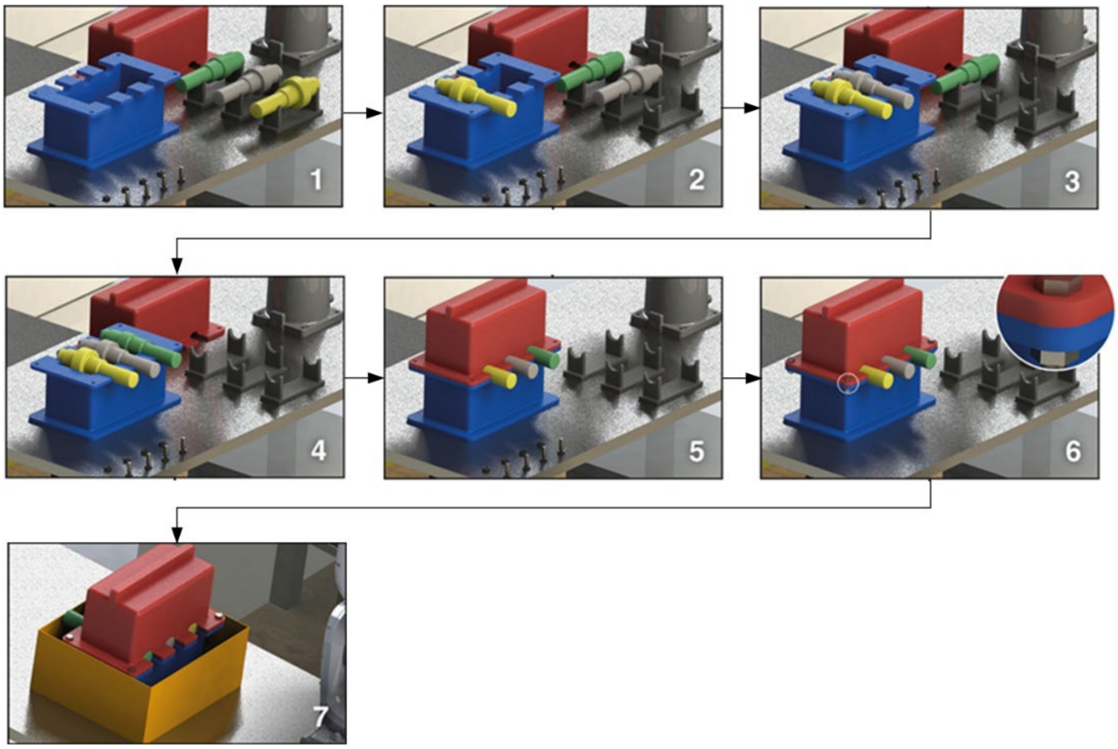

Fig. 5. Sequence of work operations

We ensured the safety of the robotic educational workplace with the help of three laser scanners [11]. These scanners are placed under the table and create protective zones around the workplace, fig. 6. The surroundings of the workplace are also visually delimited by safety tape.

After a person enters protective zone 1, the activity of the collaborative robot slows down and the activity of the industrial robot stops, in this zone there is interaction between the person and the collaborative robot. After a person enters protective zone 2, the activity of the industrial and collaborative robot will stop, in this zone interaction between the person and the robot is not possible.

Fig. 6. Protection zones of the training workplace

The workplace is designed in such a way that each student can be assigned a unique assignment. This is ensured by the fact that the individual shafts can be stored in the holes in the lower part of the gearbox in six different combinations, and at the same time there are two different storage positions for each shaft, creating a total of forty-eight variations in the way the task is performed. Variations of shaft placement based on possible mutual orientations are shown in fig. 7.

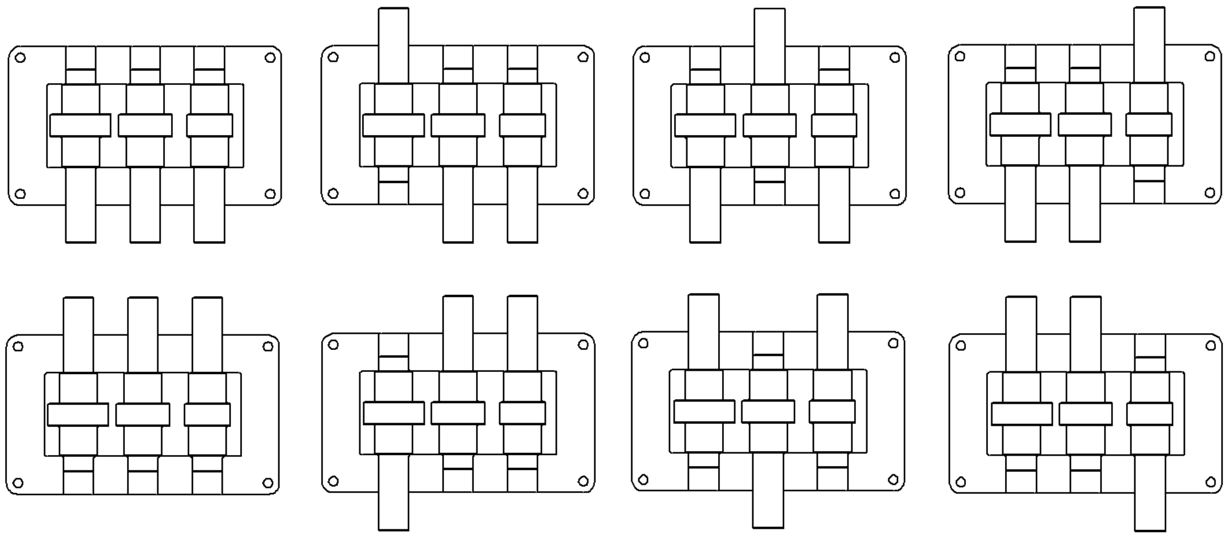

Fig. 7. Variation of shaft placement based on orientation

The program for the collaborative robot can be made to grasp shafts of any diameter, but only grasping the Ø50, Ø60 diameter (shaft 3) and the face of the largest diameter (shaft 1 and 2) guarantees collision-free storage.

Conclusions. This article shows the design of an educational robotic workplace, where a collaborative and industrial robot is used. The workplace is designed so that it is possible to assign individual assignments to individual students. The student who implements the programming of the workplace is also part of the programmed assembly process. In addition to programming two robots, it is necessary for the student to solve the issue of workplace safety. For this reason, three safety laser scanners are part of the workplace. The parts that the students manipulate are made by 3D printing to reduce production costs. This creates the possibility of manufacturing additional components allowing to implement a change in the handling process.

Acknowledgements

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ПРОЕКТУВАННЯ НАВЧАЛЬНОГО РОБОЧОГО МІСЦЯ З КОЛАБОРАТИВНИМ І ПРОМИСЛОВИМ РОБОТОМ

У статті розглядається конструкція монтажного навчального робочого місця, обладнаного двома роботами, один з яких є промисловим, а інший – коллаборативним. Це роботи від компанії ABB, а промисловий робот – IRB 1200, а колаборативний – GoFa CRB 15000. Використання роботів від компанії ABB обумовлено тим, що у нас є автономне середовище Robot Studio. на робочому місці. Це дає змогу створювати симуляції, переміщаючи обох роботів, виявляти стан зіткнення та оптимізувати траєкторії руху. Кінцеві механізми роботів від компанії OnRobot, зокрема це двокулачний захват RG6 вантажопідйомністю 10 кг. Пропоноване робоче місце має розміри 2000 х 2500 мм і оснащене парою робочих столів. Збірка моделі коробки передач призначена лише для навчання, вона не базується на фактично виготовлених деталях. Модель коробки передач оснащена трьома різними валами, де їх довжина однакова, а різниця полягає лише в найбільшому діаметрі валів. Весь процес складання вимагає взаємної співпраці промислового колаборативного робота та людини-оператора. За допомогою складальних деталей можна створювати велику кількість комбінацій, так що на робочому місці може виникати багато окремих завдань. Це пов'язано з тим, що ми можемо зберігати кожен із валів у трьох місцях корпусу коробки передач, а їх можна зберігати у двох положеннях. Комбінуючи зазначені варіанти зберігання валів, можна досягти до 48 варіацій. Безпека працівників на робочому місці вирішується використанням безпечних лазерних сканерів. Вони зберігаються в зонах, де можливий доступ людини до робочого місця. Захисні зони навчального робочого місця дозволяють уповільнити або зупинити рух промислового робота.

Ключові слова: *Промисловий робот; колаборативний робот; навчальне робоче місце; співробітництво.*

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