Technologie, procesy i systemy produkcyjne
Technologies, processes and systems of manufacturing
Engineer of XXI Century'2024


# Case study: Integration of an industrial robot into the material cutting process

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**Abstract:**. The present paper examines a case study of the integration of an industrial robot for tasks in engineering production that were previously performed manually. The content includes the requirements set, the proposed solutions as well as simulation and real testing of the robotic tasks. Based on the results of the functional verification of the designs of robotic operations, their suitability for integration into real production is analyzed. From the tests carried out, in some cases, further designs have been created to optimize individual operations.

**Keywords:** Industrial robot; combined effector; deburring; palletizing.

# Studium przypadku: Integracja robota przemysłowego z procesem cięcia materiału

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**Streszczenie:** Niniejszy artykuł przedstawia studium przypadku integracji robota przemysłowego do zadań w produkcji inżynieryjnej, które wcześniej były wykonywane ręcznie. Treść obejmuje zestaw wymagań, proponowane rozwiązania, a także symulację i rzeczywiste testowanie zadań zrobotyzowanych. Na podstawie wyników weryfikacji funkcjonalnej projektów operacji zrobotyzowanych analizowana jest ich przydatność do integracji z rzeczywistą produkcją. Na podstawie przeprowadzonych testów, w niektórych przypadkach stworzono dalsze projekty w celu optymalizacji poszczególnych operacji.

**Słowa kluczowe:** Robot przemysłowy; efektor kombinowany; gratowanie; paletyzacja.

DOI: https://doi.org/10.53052/9788367652278.18

## 1. Introduction

Nowadays, high demands are placed on industrial production to achieve the required product quality at the lowest possible cost and in the shortest possible time. In industrial production, it is not easy to choose the right combination of these three main aspects of production. However, their appropriate combination is essential in any industry because it largely determines the competitiveness of the production plants. Automation and robotics represent a suitable solution that provides the opportunity to increase competitiveness. In particular, industrial robots make it possible, in many cases, to achieve higher productivity, stable quality, and a reduction in production cycle times, which is particularly reflected in the final product price. Given the advantages mentioned above and also the global problem of stability and the professional qualification of employees, many manual tasks are gradually being robotized. This makes it possible to harness the potential of the human workforce for a different task that is less stereotyped and less physically strenuous. The implementation of industrial robots is possible in almost every sector. The object of their application can be the execution of simple activities but also sophisticated workflows. [1-4]

The motivation for the present study is the requirement of a company that operates in the engineering sector and is predominantly engaged in machining. The aim is to replace (robotize) the manual task of removing semi-finished products from an automatic machine for material cutting, subsequent deburring of sharp edges, and palletizing. In this case, the input semi-finished product is a drawn aluminium profile with a length of 6000 mm. The first operation is the cutting of this item by sawing technology in an automatic machine into shorter pieces of 165 mm in length. This is followed by the removal of these cut pieces, together with the manual deburring of the selected edges and the successive stacking on a pallet. The requirement for robotization of this work cycle arose due to stability problems of the employees performing this activity, which caused inconsistency in production. This paper is devoted to the implementation of an industrial robot in an established production. Considering the production already in progress, it was necessary to adapt the design of the robotized workstation to the real conditions and space possibilities in the production plant. The essence of the article is a comprehensive design of a solution for the aforementioned object handling, which includes the process of deburring and subsequent palletization.

## 2. Description of the robotization design

At the beginning of this project, the selection of a suitable industrial robot was necessary, especially for the size of the workspace, the reach, the payload capacity, and the robot's placement capabilities. Based on the aforementioned considerations, an industrial robot with serial kinematics of the FANUC M-10iD/10L model was selected. The existing workspace, which was suitable for the manual tasks mentioned above, represents a limited space for the implementation of an industrial robot. For this reason, it was chosen to place the robot on the "wall" which can be seen in figure 1. The reach of the robot when so positioned also extended beyond the dedicated workspace intended for this operation. For this reason, it was necessary to limit its workspace. The FANUC DCS (Dual Check Safety) software solution was used to limit the space in which the robot could perform movements.

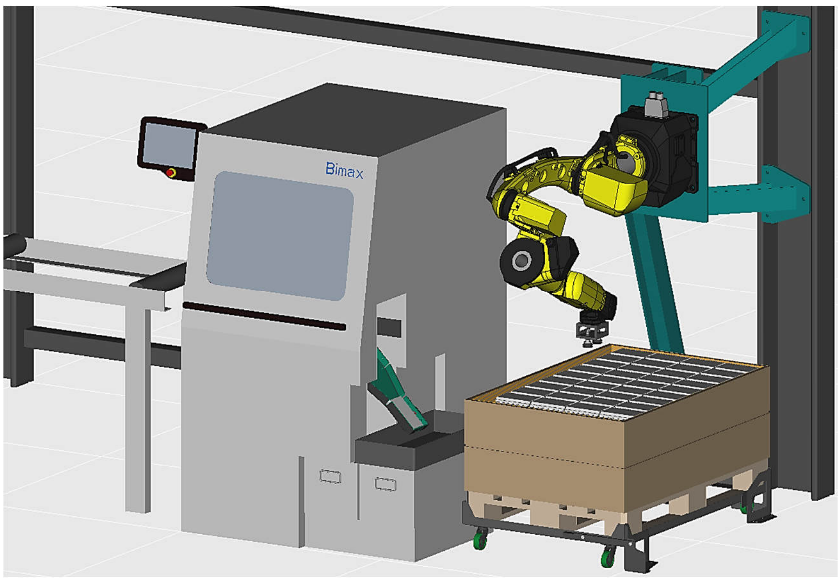


**Figure 1.** Selected location of the robot for the proposed operations

Robotization requires replacing humans in the above-mentioned work activities. This means that after the aluminium profile cutting operation, the robot needs to perform the following operations:

- removal of the semi-finished product,
- deburring the selected edges,
- palletizing the semi-finished product.

### 2.1. Semi-finished product removal

The task of removing a semi-finished product from an automatic material-cutting machine is the first part of the sequence of work operations that an industrial robot is tasked to perform. This task required, at the beginning of the solution, the design of a system that would ensure a reasonable repeatability of the position that the semi-finished product reaches after the cutting process. For this operation, a static positioning system with a stop-slip was designed at the beginning of the project. The slip was designed as part of an automatic material cutting machine into which the cut semi-finished product slides. Its dimensions were adapted to ensure the highest possible repeatability of the position of the cut piece. The repeatability of the position of the semi-finished product in the designed slip will ensure the achievement of constant quality in the deburring and palletizing process. The presence of the cut-off piece in the slip is detected by an optical sensor that communicates with the higher-level control system.

The second essential part of this task was to design how the handling of the cut semi-finished product would occur. In this case, it was necessary to choose a suitable gripping method concerning the material and the necessary execution of other tasks. There are several options for which effector to choose for gripping the semi-finished product. In the initial design of the whole process, the use of a pneumatic effector with suction cups was proposed. This gripping principle (Figure 2) was chosen mainly because it was possible to design the effector so that it did not extend beyond the plan of the semi-finished product. An effector that does not extend beyond the plan of the semi-finished product indicates that its length and width are not greater than the length and width of the semi-finished product being handled. The pneumatic effector has been designed with smaller plan view dimensions than the semi-finished product, mainly for more convenient maneuverability and accessibility. In other words, by having larger plan dimensions than the effector, the object does not limit the working space or increase the risk of collision due to the dimensions of the effector. This presents an advantage in the limited workspace that forms a significant complication of this industrial robot integration.

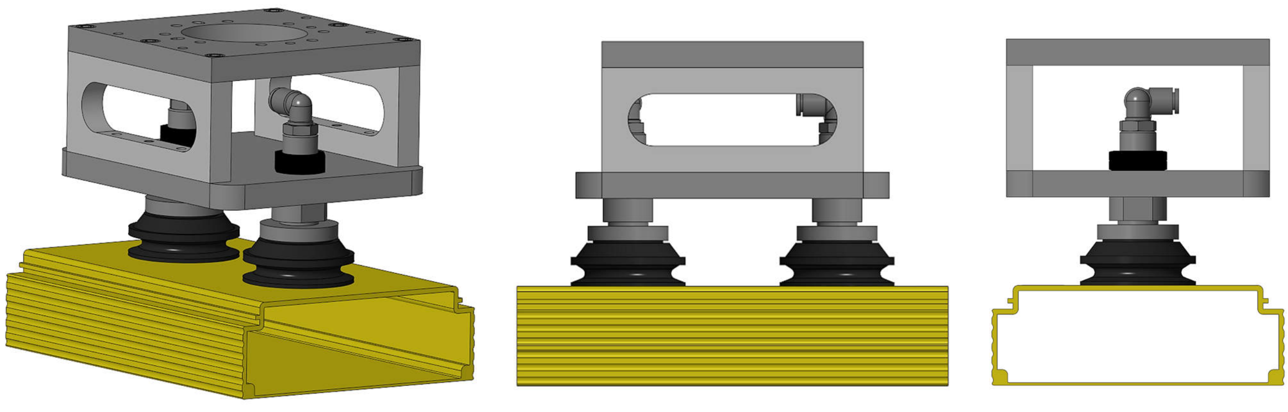

**Figure 2.** Designed pneumatic effector with semi-finished product

### 2.2. Deburring of selected edges of the semi-finished product

The deburring process is used to remove small sharp edges and burrs that are created on the surface of the parts after mechanical cutting. In this case, sharp edges and small protrusions were formed on the surfaces of the aluminium profile in the places where it was cut. These small sharp edges are undesirable for further operations. This results in a reduction in the overall quality of the product. [5]

The company for which the robotization is being carried out requires only eight edges of the cut semi-finished product to be deburred (Figure 3). Currently, this operation is carried out manually using a hand-held deburring tool. For robotic deburring, a static positioning of the manual deburring tool in the robot workspace has been proposed. That is, the robot would manipulate the pneumatically clamped semi-finished product against this tool. For robotic deburring, a V-shaped knife was chosen as the deburring tool for manual deburring. Two edges could be deburred in one linear movement against this tool. It follows that four linear movements at the experimentally determined speed would be required to deburr the selected edges of the semi-finished product.

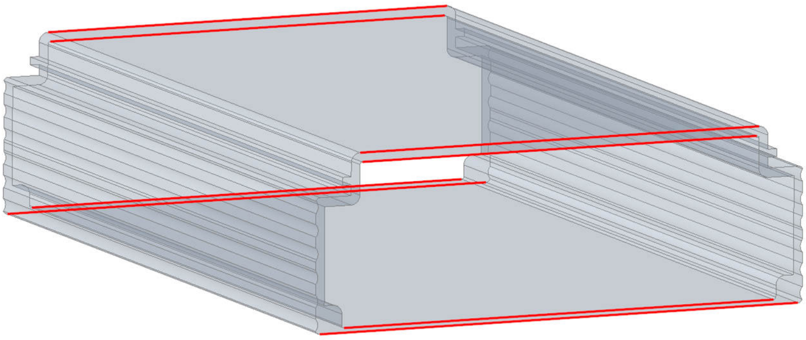

**Figure 3.** Marked edges of the semi-finished product for deburring

**2.3. Palletization of the semi-finished product**

The palletizing process occurs mostly in high-volume and mass production. It is the orderly placing of products on a pallet according to a defined pattern. Palletizing products is particularly important for logistics when it allows for to maximization of the number of arranged goods on a pallet, which simplifies their transport and storage. At present, this process is also carried out manually in the company in question, which is a stereotypical task for humans. Considering the basic purpose of industrial robots - to relieve humans from stereotypical and strenuous work, this task is suitable for the application of an industrial robot. [6]

To create an optimal solution for the storage of semi-finished products, it was necessary to design a palletizing pattern concerning the specified palletizing requirements:

- achieving the largest possible number of semi-finished products on a pallet,
- not exceeding the maximum dimensions of the pallet,
- creating an interleaved pattern.

Achieving the largest possible number of items in a pallet is essential, especially for optimum use of pallet space. Increasing the number of semi-finished products on a pallet will reduce the number of pallet exchanges and pallet transfers required. In high-volume or mass production, palletization can save costs, space, and time depending on transport and storage.

The second requirement of palletization stems from the maximum dimensions of the pallet that is designed to store the semi-finished product being handled. This is a Europallet, whose space for storing parts is supplemented by wooden pallet enclosures. This solution allows for an increase in the volume of space for the stored semi-finished products and also secures them against possible dropping during transport. The resulting space into which the aluminium semi-finished products can be palletized is 760 x 1160 x 398 mm.

The requirement of an interleaved pattern is a condition for the creation of a palletization pattern, each single layer of which will be interleaved with each other. The interleaved layers will allow for increased stability of the palletized material in the pallet during transport. If an uninterleaved stacking pattern is created, shifting and mutually disordered positions of the semi-finished products could occur during transport. The unstable or disordered position of the semi-finished products in the pallet may complicate automated or robotic processes following transport.

Based on the above requirements for creating an optimal palletizing pattern, four different arrangements of semi-finished products on the pallet were created (Figure 4). The palletizing patterns were created in the CAD system Creo Parametric.

The deciding factor in selecting a suitable pattern is the number of pieces placed in the pallet. Table 1 shows the quantity of semi-finished products in a pallet depending on the palletizing pattern.

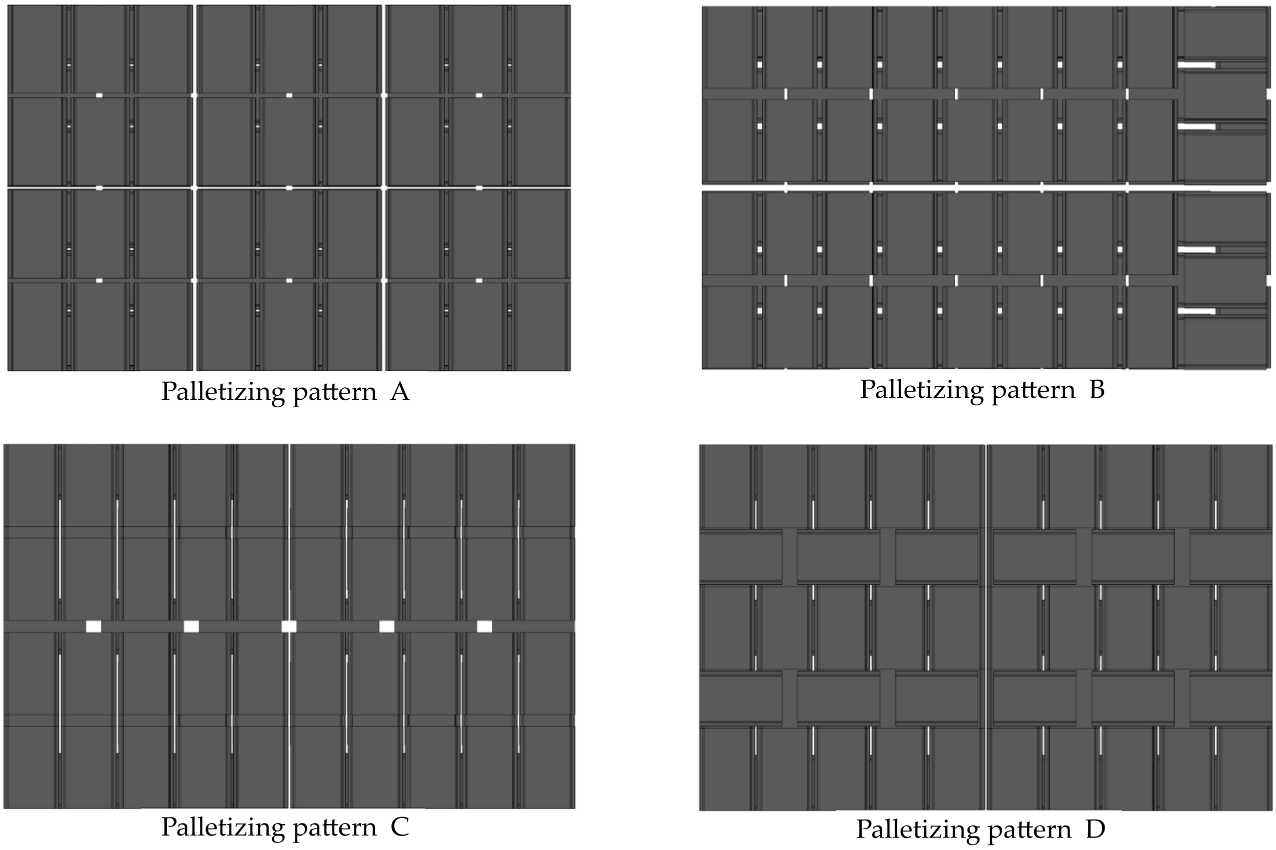


**Figure 4.** Placement of semi-finished products in the pallet according to the designed palletization patterns

**Table 1.** Quantity of pieces on the pallet according to the palletization pattern

| Palletizing pattern | Quantity of stored pieces |
|---|---|
| A | 720 |
| B | 780 |
| C | 780 |
| D | 800 |

From the above, it can be concluded that concerning the stability of the stored semi-finished products in the pallet, palletizing pattern C or D, which is shown in figure 4. is suitable. In these two patterns of stacking the semi-finished products, the layers are interlocked. Taking into account the number of pieces of the semi-finished product that can be placed in the pallet, palletizing pattern D is suitable. In this pattern, 800 pieces of this aluminium profile fit into the pallet space intended for the placement of semi-finished products.

### 3. Simulation and real testing of designed processes

This chapter is devoted to the verification of the proposed solutions and is divided into subchapters according to the individual operations. The need for testing stems from the robotization designs created, which needed to be verified for their functionality and usability in a real environment. Some tasks could be verified in programming and simulation software, others required real tests to be performed. If software verification was sufficient, the CARC system FANUC Roboguide was used. In this software, a workstation was created that corresponds to the real workstation layout. In cases that required real testing, the verification was performed in the laboratory of the Department of Automation and Production Systems. In this laboratory, tests with a different model of the FANUC robot are being carried out, the purpose of which is only to verify the functionality of the proposed technologies in real conditions.

DOI: https://doi.org/10.53052/9788367652278.18

### 3.1. Semi-finished product removal operation

To verify the functionality of this operation, a slip was constructed to ensure a repeatable position for each piece of semi-finished product cut. At the same time, the individual parts needed to assemble the pneumatic effector (Figure 2), which was designed at the beginning of the project, were manufactured and purchased. Based on the developed program, which contained simple instructions, the functionality and applicability of the proposed solution were verified in real conditions. The fabricated slip ensured sufficient repeatability of the positions of the semi-finished product for removal and also the execution of the following operations. The created effector represented a suitable solution for object manipulation. The plan dimensions of the effector do not exceed the plan dimensions of the manipulated object and the gripping force is sufficient for its manipulation. The applicability of the proposed solutions for the operation of removing and repositioning the cut-off semi-finished product was verified by the conducted test.

### 3.2. Deburring operation

Edge deburring testing was also carried out in the department's laboratory to obtain realistic results for this manufacturing operation. The verification was done based on the design where the robot manipulates the semi-finished product using the effector created. In this case, the tool intended for deburring (a V-shaped knife) is statically placed in the working environment of the robot, see figure 5a. During the tests performed on the proposed deburring process, the tool was "bitten" into the semi-finished product, causing it to change its position - displaced relative to the effector. The change of position in the effector caused insufficient deburring of the given edge. It was also not possible to continue to deburr the next edge or to continue to another operation because collisions would occur. The collisions would be caused by the displaced position of the semi-finished product relative to the effector.
Based on the aforementioned testing results of the first design, a second variant of the design for the deburring process was created. The second variant considers the use of a different tool to deburr the required edges. The subject would be the use of an abrasive tool that would perform a rotary motion about its axis at high speeds. Commercial automation companies provide tools that could apply to this application. To test this design, a hand-held grinder was used in laboratory conditions and was also statically positioned in the robot's workspace (Figure **5**b). The test consisted of performing appropriate robot movements under the same conditions but using a different tool. There was no change in the position of the semi-finished product relative to the effector during the test. Also, the desired quality of the deburring was achieved. The result of the practical testing of the second variant shows that using a tool based on this principle, it is possible to successfully carry out the deburring operation while clamping the semi-finished product in the effector via suction cups.

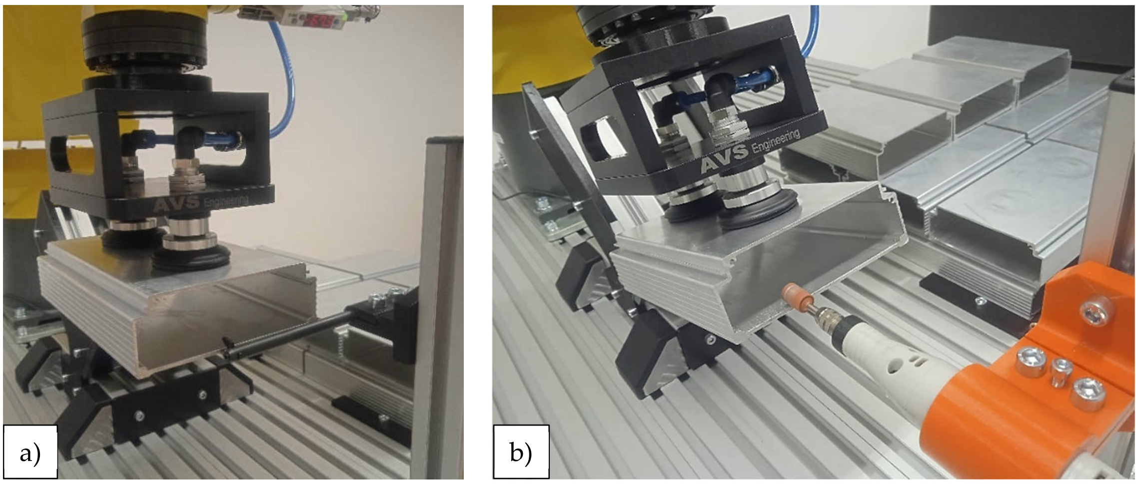


**Figure 5.** Testing the deburring process – a) first variant, b) second variant

### 3.3. Palletizing operation

The palletization task for this project was solved based on the proposed palletization patterns. The program was created in FANUC Roboguide software with a software extension called PalletPRO. This software extension is used to create and program the palletizing tasks. Using the aforementioned software extension, a palletizing program for palletizing pattern D was created. Already during the creation of the program and the subsequent simulation of the palletization process, a collision between the robot arm and the wooden pallet box occurred, which can be seen in figure 6. The red color in this figure indicates the collision condition. This collision occurred at some edge positions of the pallet due to the tight fit of the semi-finished products away from the edge of the pallet box. The collision detected in the CARC system allowed to reveal the unusability of the created palletizing pattern in the current robotic cell arrangement.

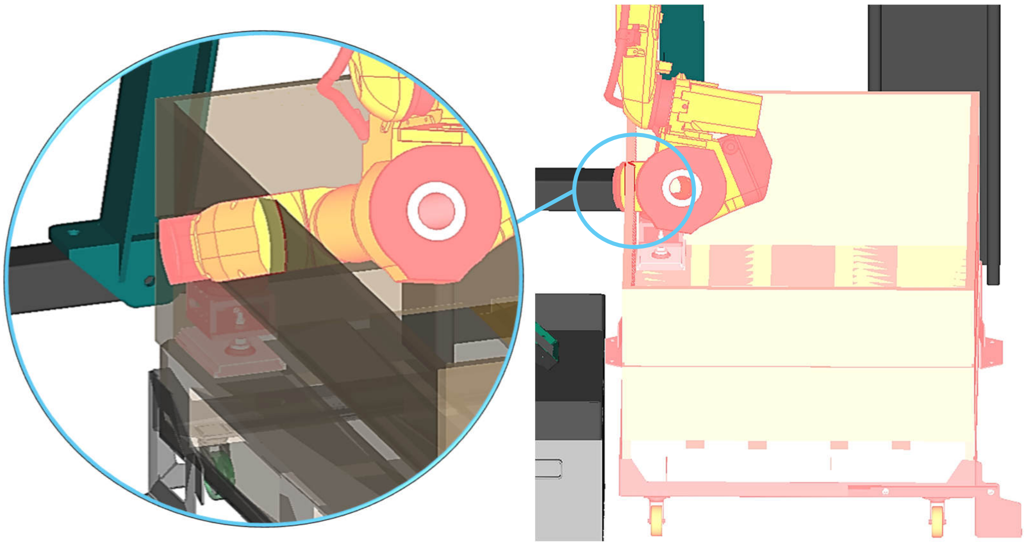

**Figure 6.** Display of robot arm collision with pallet box

Due to the aforementioned collision, a palletization program with other palletization patterns was also created and simulated. Similar collisions also occurred in the case of palletizing patterns B and C. When the palletizing operation was verified by simulation, the location of palletizing pattern A in the pallet space was experimentally determined. Due to the sufficient space due to the influence of fewer semi-finished products, it was possible to eliminate the collision conditions by moving the whole pattern to the location designated for palletizing. A suitable positioning of the palletizing pattern A in the pallet space can be seen in figure 7. From the above, it is clear that such semi-finished products will also be applicable in real conditions. The palletizing pattern A provides the smallest number of semi-finished products to be stacked in the pallet and partially satisfies the condition of interleaving the layers. Of the palletizing pattern designs created, this variant is the least convenient solution but the only usable one in the proposed robot cell layout.

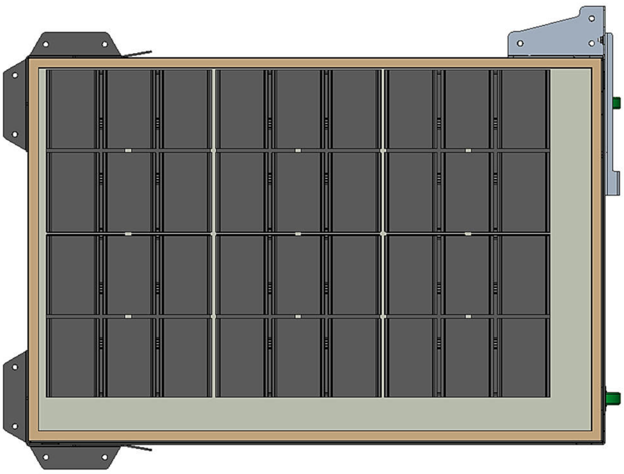

**Figure 7.** Location of palletization pattern A in the pallet space

Part of the palletization task was also tested in the department's laboratory. The aim of the test in real conditions was to verify the palletizing position even after placing the pneumatic suction cup. The motivation for verifying the relative positions of the semi-finished products in a real environment was the risk of collision that could occur if the position of the semi-finished product changed after the suction cup gripping force was deactivated. Testing in the real environment was only performed on a certain part of the palletization pattern. From the test performed in the real environment, it can be seen in figure 8 that the changes in the position of the semi-finished product after the suction cup is deactivated can be neglected. The mutual displacement of the semi-finished products concerning each other is minimal and does not cause collision conditions. The results of the palletization test according to the proposed pattern (A) indicate that this solution is suitable for the chosen industrial robot application.

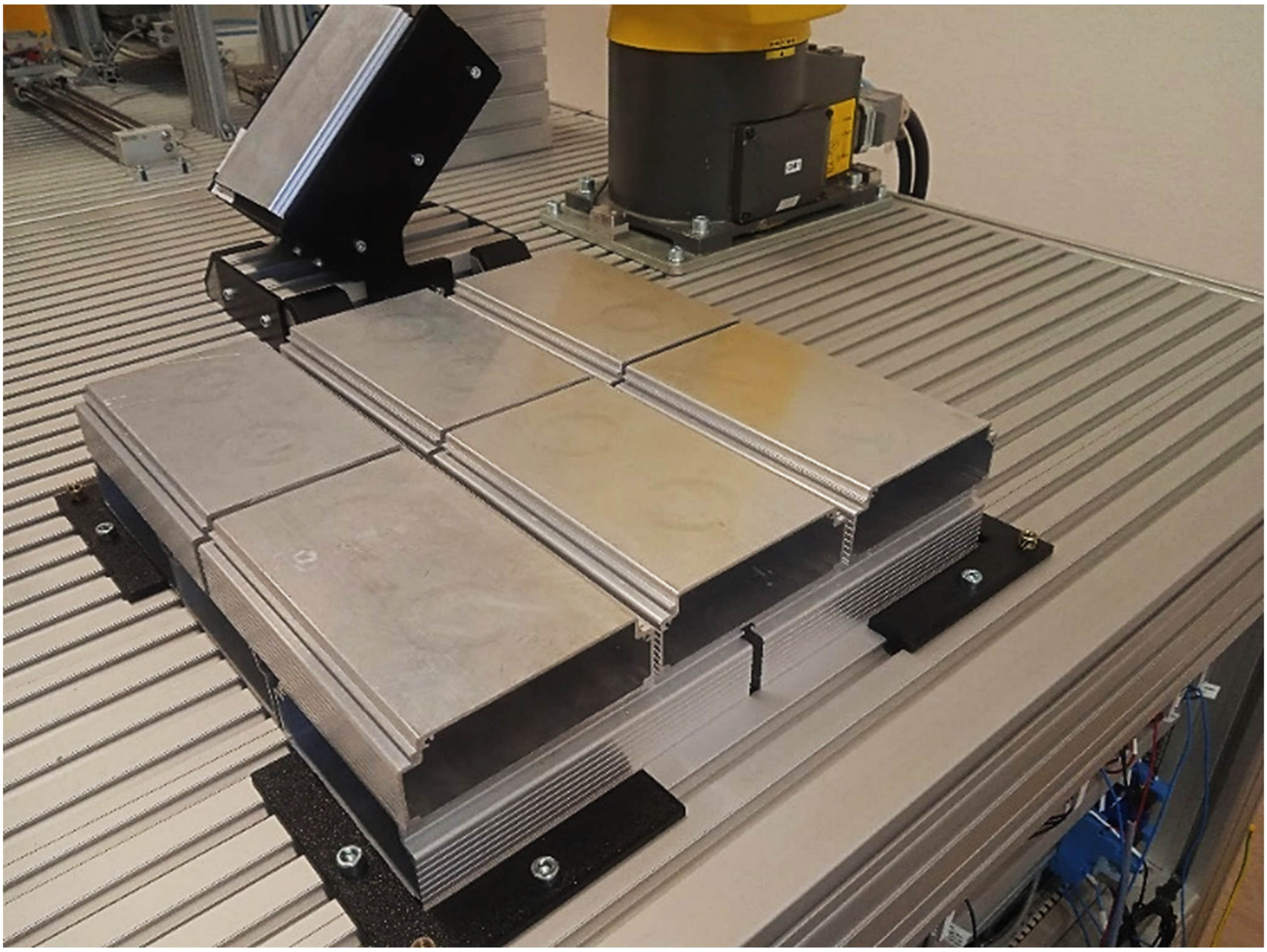

**Figure 8.** Real test of the palletization part

**4. Optimization of the created effector**

Based on the text presented in the previous chapters, it can be concluded that the biggest complication for robot integration in this case is the limited working space. From the tests performed (Chapter 3), it is clear that each operation can be performed with the desired results. During the tests, some complications were encountered, especially during the deburring and palletizing process. The "biting" of the tool into the semi-finished product during the deburring process caused the resulting drag forces to be higher than the suction cup vacuum forces. Changing the position of the semi-finished product relative to the effector required additional design or modification of the deburring tool.

This chapter contains the optimization of the proposed effector. An alternative way to ensure a stable position of the semi-finished product against the effector would be to fix it additionally. This fixation could be performed on the principle of a classical effector with radial movement of the jaws. However, the requirement for the design of the effector remains a condition - the plan view of the effector must not exceed the plan view of the object to be handled. From a review of the effectors available on the current market, it was found that no effector provides an opening angle of 180° per jaw. If the manufacturer specifies a 180° jaw opening angle, this is the opening angle of both jaws. The creation of a combined pneumatic effector which would grip the semi-finished product using a suction cup and additionally be able to stabilize its position by clamping the jaws would provide an effective solution. Such an approach would allow the edges to be deburred to the required quality using a V-shaped knife deburring tool. The flow of the entire robotic operation would be as follows:

- removal of the semi-finished product from the slip by an effector with an activated suction cup and open jaws,
- closing the jaws and performing the deburring,
- opening the jaws and palletizing the semi-finish product.

During the removal process, the jaws would be open (tipped upwards) which means that they would not exceed the dimensions of the plan view of the object to be removed. Once a vacuum is created between the suction cup and the contact surface of the semi-finished product, the object can be manipulated. The robot would move the semi-finished product out of the slip and then close the jaws. This would stabilize the position of the semi-finished product by compressing its lateral surfaces. In this condition, the plan view of the effector would be larger than the plan view of the semi-finished product. In this particular situation, this would not be significant for the reason that this state would only be activated for the duration of the chamfering of the intended edges. After the edge deburring process, the jaws would open and the semi-finished product would then be palletized.
This idea of modifying the effector was supported by a test performed in the laboratory when a pneumatic effector with parallel jaw movement was used. This type of effector was used only for the deburring process because the jaws extended beyond the plan of the semi-finished product and after opening them the plan of the effector only increased. The purpose of this test was to determine if the position of the semi-finished product relative to the effector would change during the deburring process when the semi-finished product was stabilized. From the tests carried out, it appeared that such a method of fixing the manipulated object in conjunction with the suction cup vacuum force could be used for the application under consideration.

## 5. Conclusion

The increase in the application of industrial robots is progressing due to the capabilities they provide for most tasks in various industries. The motivation for this case study was to solve the problem of established production with stability and quality of tasks performed. The unstable quality and production in this case is due to the lack of workforce to perform these work activities. Considering the quality possibilities and advantages of the application of industrial robots, it was appropriate to solve this problem by robotizing the tasks performed. The complication for the integration of the industrial robot was mainly the space that was adapted for the manual execution of the tasks. It was necessary to design and subsequently test how the gripping and removal of the semi-finished product, the subsequent deburring of the selected edges, and the palletizing would take place.
Based on the requirements for robotization, proposals were made for how the individual work operations would be carried out. The designs created included an idea for a slip that ensures a repeatable position of the semi-finished products after the sawing process. A pneumatic effector with suction cups was designed for handling these semi-finished products. The process of deburring the selected edges was designed in two variants and several palletizing patterns were created for the palletizing process. During the tests carried out in the CARC system and also in the real environment, some designs did not prove to be suitable or could not achieve the required quality. Therefore, new variants were selected or proposed that demonstrated the possibility of application to the proposed robotic cell during the tests.
During the optimization of the deburring process using the designed effector and the possibility of using the initially intended tool, an idea for the modification of the current effector was created. The results of the first variant of the deburring operation showed insufficient deburring quality with the proposed approach for this operation. This led to the idea of creating an effector in a combination of suction cups and jaws with angular movement. Given that there is no effector on the current market with a 180° opening angle per jaw this idea presents scope for further investigation. The goal would be to create an effector designed for specific applications that require the highest degree of maneuverability and accessibility in a confined space. The emphasis in such a design would be on additional firm and stable gripping of the manipulated object only when this is required.

**Acknowledgement:** This work was supported by the project VEGA 1/0470/23 - "Research of implementation methods and means of artificial intelligence in systems of automated quality control of products with volatile quality parameters."

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